GEOLOGIC CONDITIONING OF ASR DEVELOPMENT. A BRIEF EVALUATION OF PORTUGUESE MAINLAND

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ABSTRACT

In Portugal, up to now little attention has been given to AAR problems in concrete structures, in particular due to the fact that only few cases of this kind of deterioration have been detected. However, as the structures become older, some of them are beginning to show evident signs of ASR in concrete. The analysis and evaluation of the factors which can conditionate ASR in portuguese concrete structures, aiming at not only to diagnose the declared cases of affected structures but also to prognose the potential deterioration in others, is an important task that is being performed in LNEC. This paper deals with a simplified methodology to evaluate the geological conditioning of the use of aggregates for concrete based on a lithologic zonning of portuguese mainland, wich was applied to the geologic sources of aggregates.
Keywords: ASR, aggregates, lithologic zonning of portuguese mainland

INTRODUCTION

Actually, the development of deleterious chemical reactions, among the components of the concrete themselves or with aggressive agents coming from outside, with formation of expansive products is one of the most important process of concrete structures damage. Typical processes are those based on the alkali-aggregate reactions (alkali-silica, ASR, alkali-silicate, ASSR, and alkali-carbonate reactions) and on the sulfate-alumina reactions. In Portugal, some concrete structures have began in the last years to show evident signs of ASR occurrence and, in LNEC, quite a lot of work is being performed aiming at not only the diagnose of the declared cases of damaged structures but also the evaluation of the factors wich can conditionate ASR in portuguese concrete structures and also to attract attention for these problems (Silva, H. 1992), (Silva, H. & Rodrigues, J.D. 1993), (Reis, M.O.B. 1990).

As well known, the main conditioning factors for ASR in concrete are the existence of reactive silica and alkalis, in adequate proportions, a sufficiently high pH, usually higher than 12, and an environment where the relative humidity (RH) is higher than 80% (Coutinho, A. 1993), (CMCD 1989), (Idorn 1967). The source of reactive silica is usually the aggregate and the source of alkalis may be the cement, the additives and even the aggregates. The mixing water and the percolation water (of importance for example in dams) may also be a source of alkalis, in the first case with global distribution in the concrete mass and in the second case with a localised incidence, in the vicinity of seepage channels.

Potentially reactive silica forms are essentially those having an amorphous, subcrystalline and cryptocristalline nature and those that are strongly tectonised, presenting an undulatory extinction. The former, like opal, chert, silex, chalcedony, are considered as having an assured potential reactivity to alkalis, the ASR process occurring at short term, as long as the other conditioning factors (pH, RH, temperature) are propitious. The latter, like strained quartz, usually cause slow late reactions, whose development reaches highest rates only after ten or twenty years (Glasser & Kataoka 1981), (Hyward et al. 1988).

In the portuguese mainland there are some of the above mentioned potentially reactive silica forms, which form part of the mineralogical composition of rocks that provide aggregates for concrete. Consequently, an adequate selection of aggregates based on an early evaluation of national resources may help in avoiding or at least attenuate future distresses by ASR in concrete structures.

Studies of this nature can be carried out on several scales:

- on a national territory scale, giving access to a global knowledge, through the preparation of macrozonings;
- on a regional scale, introducing regional conditioning factors (sedimentologic, orogenic, tectonic, etc.), the knowledge being substantiated in microzonings;
- on a local scale, based on experimental criteria (mineralogical and petrographic analysis, alterability, expansibility and reactivity tests, etc.), leading to the characterization of the geologic formations to be used for concrete.

In this paper a global lithological framework is given, taking into consideration two important factors for the development of ASR in concrete (Gillot 1975), (Gogte 1981), existence of potentially reactive silica forms and of minerals with high alkali content. The zonings presented make a contribution to the global knowledge, on a national scale, of fundamental aspects related to the nature of aggregates used in the manufacturing of concrete, in the light of the possible occurrence of ASR.

MAIN LITHOLOGIC ASPECTS OF THE PORTUGUESE MAINLAND

General

Almost all types of rocks, namelly igneous, sedimentary and metamorphic ones, outcrops in the portuguese mainland (Teixeira & Gonçalves 1980), (Soares da Silva 1983). The predominant igneous rocks belong to the family of granites and gabbros (basalts mainly), and occupy about 30% of the portuguese mainland. The predominant sedimentary rocks are of a limestone nature (limestones, marlaceous limestones, marls, dolomitic limestones and dolomite), which occur in about 10% of the territory, and of a clastic nature (especially sandstones, conglomerates, sands and clays), which are distributed over about 20% of the portuguese mainland. The metamorphic rocks occur in the other 40% of the territory being of a polimetamorphic and monometamorphic nature, predominantly of hercynian age, and are composed mainly by schists, almost always associated with metagreywackes, quartzites, marbles and rocks of gneissic and amphibolic nature.

The supply of potentially reactive silica forms

The analysis of the Portuguese Geologic Chart, in the scale of 1/500.000, 1/200.000 and 1/50.000 (SGP 1972), (Teixeira 1972), and of specific documents (Neiva et al.

1979), reporting the lithologic and petrographic nature of geologic formations in the portuguese mainland, made it possible to define the potential sources of reactive silica forms and of alkalis grouped in Table 1, and conclude as follows (Silva, H. 1992):

- The silica forms, to which a greater potential reactivity is attributed, are: chert, flint, fhtanite (including jasper quartz), lyddite and palaeozoic formations associated with polimetamorphic, schist-greywacquic and quartzitic complexes; flint especially associated with mesozoic formations and of carbonaceous nature, namely jurassic limestones; several silicifications ("silcretes" included), associated with formations of very different ages; from siliceous palaeozoic schists, predominantly, to jurassic limestones with silicified vegetable fossils and radiolarians and to cenozoic and quaternary arkosic, conglomeratic and sandy deposits.
- Other potentially reactive silica forms can be identified as quartz with a disturbed cristalline network, usually metastable, due to deformation and marked shearing, or finely granulated. Quartz with those characteristics is more often found in the metamorphic palaeozoic series (quartzites, leptynites, gneisses and ordovician and silurian granulites) and particularly in palingenetic granites and of a early hercynian emplacement. Its potential reactivity has been identified with the value of the undulatory extinction angle (Gillot 1975), (Dolar-Mantuani 1981), (Buck 1986). In the descriptive documents of geologic cartography, however, the values of the measured angles are not included, so that consideration of all the rocks in which the undulatory character of the extinction was recognised may therefore be too condemnatory.

Table 1 Potential sources of reactive silica forms and alkalis in Portuguese aggregates.

POTENTIAL SOURCES OF REACTIVE SILICA FORMS	
Minerals:	Opal, Opal CT (Cristobalite, Tridimite), Obsidian, Flint, Chert, Chalcedony, Tectonized Quartz (TQ)
Rocks:	Jasper, Lyddite, Phtanyte, Diatomite, Siliceous Schist, Phyllite, (with TQ, chert or silex), Quartzite (with TQ, chert or silex), Granitoid (with TQ), Volcanite (Rhyolite, Dacite, Andesite, Basalt), Limestone (with silex or chert), Dolomite (with silex or chert)
POTENTIAL SOURCES OF ALKALIS	
Minerals:	Potassium: Sanidine, Orthoclase, Microcline, Leucite, Biotite & Muscovite Sodium: Perthite, Albite, Oligoclase, Nepheline, Sodalite
Rocks:	Granitic, Syenitic & Dioritic families, Feldspathic Hornfels, Leptynite, Arkose, Ectinite (Phyllite & Greywacke)

The supply of alkalis

In the majority of concrete works damaged by ASR, the principal source of alkalis is, in general, the aggregates themselves. The minerals that can be source of alkalis are essentially feldspars, plagioclases, (albite and oligoclase), feldspathoids and micas, that are the major components of igneous and metamorphic rocks, like granites, syenites and ectinites (SGP 1972), largely disseminated in the portuguese mainland and therefore commonly used as aggregates. Some immature alluvial sands, resulting from the alteration of granite, can also contain a high content of feldspars, plagioclases and micas and also be an important source of alkalis. This is a common situation observed in works affected by ASR.

LITHOLOGIC MACROZONING OF ASR SUSCEPTIBILITY

Methodology of evaluation

The zoning of the territory was made by taking into account the availability of outcrop materials for concrete aggregates which may be a source of the above mentioned potentially reactive silica forms and alkalis. The origins of the silica forms were divided into two groups: rocks with amorphous, subcrystalline and cryptocrystalline silica (chert, silex, fhtanite, chalcedony and silicifications); and rocks with crystalline silica (deformed quartz and with cataclasis, recognised by the undulatory character of the extinction). The analysis was made on the squares mesh corresponding to the Portuguese Geological Chart in the scale of 1/50.000. The percentage of area occupied in each square by the lithologic outcrop units was quantified on the basis of the mean area method (Silva, H. 1992). On the basis of this method, three zonings were established, two of them concerning the occurrence of silica forms potentially reactive to alkalis and one related with the occurrence of formations with alkalis. Three groups of percentage of area of squares occupied by rocks with those species were considered: an outcrop area less than 5%, practically meaningless from a global point of view, which can be ignored on a national scale; an outcrop area between 5 and 50%, and an outcrop area higher than 50%.

Potentially reactive silica forms

The map of Fig. 1 represents the network of squares with the distribution of the outcrops of rocks with silica forms of the following types: chert, silex, fhtanite, lyddite, chalcedony and several silicifications. The histogram includes also the number of squares with outcrops that occupy areas less than 5%. Its analysis makes it possible to verify that lyddites were mapped in 59 squares, while chert, fhtanite and other silicifications were mapped in more than 30 squares and silex in about 20. The zones where outcrops occupy more extensive areas are basically located in the Districts of Trás-os-Montes and Baixo Alentejo, Northeast and South of the country respectivelly.

In a similar way, the distribution of the outcrop areas of rocks with well crystallised silica forms (quartz) but with a potential reactivity conferred by the metastable crystalline structure, due to deformation, and by cataclasis, which originates a high specific surface of minerals was also made. In this zoning the same three divisions of outcrop area referred to above were also considered. As can be assumed from the analysis of the distribution, there are 67 squares where a mapping was made of the outcrop areas of igneous and metamorphic rocks higher than 5%, in which quartz presented an undulatory extinction. Only in 21, among the 67 squares, the outcrop area of those rocks was higher than 50%.

Potential sources of alkalis

Considering the rocks which usually contain minerals with a high alkali content (granites, syenites and ectinites), the respective zoning was prepared. The percentage of area occupied in the square by those types of rocks, and, as in the case of zoning of silica forms, three groups were considered: less than 5%, which was disregarded; between 5 and 50%; and higher than 50%. In about 75% of the squares there are areas higher than 5% occupied by formations which contain minerals capable of being an alkali source sufficient to feed ASR. In about 40% of the total squares, the areas occupied are higher than 50%.

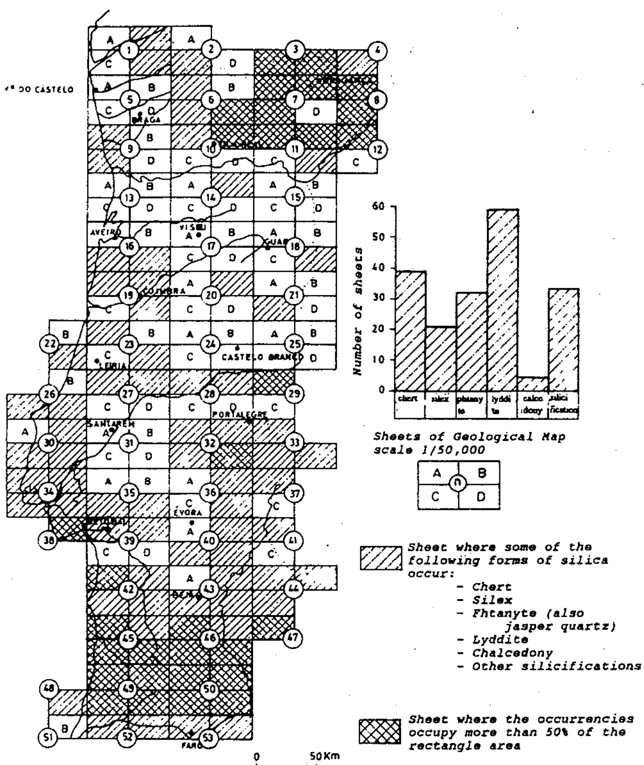

Fig. 1 Distribution of rocks with potential reactive silica forms others than quartz with undulatory extinction.

Regional distribution

Table 2 presents an estimate of the areas of the mainland districts where rocks with potentially reactive silica forms and with alkalis outcrop. Districts are indicated by their capital towns.

Table 2 Percentages of District mainland areas where rocks with potential reactive silica forms outcrop.

DISTRICT	% of outcroping area(*)		
	A	B	C
Aveiro	7.1	18.4	41.4
Beja	48.8	1.6	47.9
Braga	11.4	33.3	64.5
Bragança	52.6	4.4	31.3
Castelo Branco	1.1	13.8	31.9
Coimbra	8.8	11.6	23.6
Évora	12.2	13	35.5
Faro	58.8	0	33.2
Guarda	1.9	45.9	65.7
Leiria	11.6	0.4	1.1
Lisboa	12.7	0	13.5
Portalegre	17.5	19.2	35.3
Porto	5	38.6	62.1
Santarém	7.6	2.1	9.9
Setúbal	28.2	0	32
Viana do Castelo	3.8	54.7	77
Vila Real	21.6	15	72.4
Viseu	17.5	34.3	79.7

(*) Rocks with:
A = chert, silex, phtanite, lyddite, chalcedony, other silicifications;
B = quartz with undulatory extinction; C = minerals with alkalis.

The comparison of the distributions of rocks with potential reactive silica forms and of whose minerals can be source of alkali elements and of the areas by region presented in Table 2, makes it possible to conclude as follows:

- In the zones where silica forms with an ensured potential reactivity (chert, silex, etc.) are more frequent, there are also rocks which constitute a potential alkali source, occurring less frequently in Trás-os-Montes (region of Bragança) and more frequently in Baixo Alentejo (region of Beja) and in Algarve (region of Faro). In the Western and Algarve (South) borders however, the rocks with a high alkali content occur in very reduced areas (syenites and dolerites or basalts).
- The zones where rocks with quartz presenting an undulatory extinction and cataclasis occur more frequently are located in Minho (regions of Braga and Viana do Castelo), Douro Litoral (region of Oporto) and Beira Alta (regions of Guarda and Viseu); in these zones, rocks with high alkali content can also be more frequently found. In most cases, these are rocks presenting the two conditions referred to above, namely rocks of granitic nature.

CONCLUDING REMARKS

The analysis of the lithologic characteristics of geologic formations in the Portuguese mainland shows the existence of materials which, when used as aggregates in an extremely basic environment, may cause alkali-silica reactions. The assumption that has served as a basis for the identification of the potential reactivity of tectonic quartz was the undulatory character of the extinction when observed in a polarising microscope. Normally, the potential reactivity increases with the value of this angle, which was not quantified. There can therefore result from this zoning an aggravated conditioning for certain rocks, namely granitic, which constitute a source of the largest volume of aggregates used in Portugal. The usefulness of this study is due precisely to the global nature of the analysis prepared, but it obviously neither replaces nor invalidates studies and regional or local zonings based on criteria of petrographic and mineralogic analysis and on other appropriate tests. The development of adequate studies for the evaluation of the potential reactivity of this type of rocks in a certain site, can be the most effective way to confirm the situation resulting from the global zoning or, on the contrary, to desaggravate it.

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