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Practical Evaluation of IPR Index Forecasting ASR on "Granitic" Rocks

Avaliação Prática da Previsão da Reação Álcali-Silicato de Rochas Granitóides

Y. KIHARA [a]

C. S. NETO [b]

M. PECCHIO [c]

Abstract

The "granitic" aggregates, widely used in concrete production, are characterized by its quartz-feldspatic content. These rocks – such as granites, gneiss and migmatites - have been deformed by tectonics efforts of variable intensity in many different geological periods that transformed these rocks into alkali-aggregate reactive ones.
In "granitic rocks" the main reactive phase for alkali-aggregate reaction is deformed fine-grain quartz and on a second level plagioclase and mica, both also deformed by tectonic efforts.
Concrete samples produced with "granitic" aggregates and collected from current works affected by ASR show that:
- The amount of micro-grain quartz (<0.15mm) and medium size rock texture (between 1 and 5 mm) are two aspects clearly correlated with the reactivity of aggregates;
- The increase of extinction angle of quartz occurs together with the increase in amount of micro-grain quartz and a finer texture size and leads to a more intense reactivity;
- A good correlation only between quartz extinction angle and reactivity is not clearly defined in the studied concrete samples.

The forecast of potential reactivity by IPR Index shows a good correlation with concrete samples from structures affected by ASR. This index include not only petrographic data but also type of structure, site conditions and its interaction with environment balanced by individual indexes for each of these factors.

Keywords: alkali silicate reaction, forecast of potential reactivity index, granitic rocks

Resumo

Os agregados "granitóides" amplamente utilizados em obras de concreto, compreendem rochas quartzo-feldspáticas como granitos, gnaisses e migmatitos. Quando deformados por esforços tectônicos de intensidades variadas e atuantes em diferentes períodos geológicos desenvolvem feições texturais e mineralógicas capazes de tornar o agregado potencialmente reativo com os álcalis do cimento. Nos agregados "granitóides" a principal fase reativa, responsável pela reação álcali-silicato é o quartzo deformado e cominuído e, secundariamente, o feldspato plagioclásio e a mica deformados, produtos de esforços tectônico das rochas.
Estudos desenvolvidos em alguns corpos de prova extraídos de estruturas de concreto constituídas de rochas "granitóides" afetados pela reação álcali-agregado indicaram que:
O conteúdo de quartzo microgranular (< 0,15mm) e a granulação média (entre 1 e 5 mm) revelaram-se mais claramente relacionáveis ao potencial álcali reativo dos agregados estudados. Os aumentos nos ângulos de extinção ondulante do quartzo são freqüentemente acompanhados pelo aumento da quantidade de quartzo microgranular e pela redução da granulação da rocha, que atuando simultaneamente podem contribuir para um aumento significativo na reatividade do agregado. Por outro lado, constatou-se que a relação do ângulo de extinção ondulante do quartzo com a reatividade nem sempre é clara, evidenciando que este parâmetro não pode ser avaliado isoladamente em agregados diferentes.
A previsão da reatividade potencial à reação álcali-agregado em rochas "granitóides" pelo índice IPR é avaliada neste trabalho através de exemplos prático de aplicação em casos reais de obra. O índice IPR leva em conta as características petrográficas, o tipo de obra e a sua interação com o meio ambiente balanceando cada um destes fatores com base em pesos atribuídos a cada um deles.

Palavras-chave: reação álcali-silicato, índice de previsão de reação, granitóides

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[a] Associação Brasileira de Cimento Portland – Av. Torres de Oliveira, 76 – São Paulo/SP CEP-05347-902; Professor Doutor do Instituto de Geociências – USP
[b] Professor Doutor Orientador Mestrado Profissional IPT e Vice Presidente do IBRACON
[c] Professor Doutor do Instituto de Geociências – USP

1 Introduction

The solutions of the concrete problems related to the reaction of available alkalis in the concrete and some types of aggregates (AAR) have become a great challenge in concrete technology. In favorable conditions, the reactions produce an alkali-silicon-calcium composition expansible product that induces the concrete’s fissuration and differential movements in the structures, affecting at least its durability. Nowadays, three reaction types are noticeable: alkali-silica, alkali-silicate and alkali-carbonate.

The forecast of the potential reactivity in granitic rocks is a complex problem that has not been properly solved yet. The environmental condition is not well represented by laboratorial test conditions and the expansion in the concrete tested in laboratory is slow and usually only occurs after a long period of time (more than 10 years).

The use of the microscopic method for the forecast of the aggregates reactivity, combined with other parameters, was initially proposed by Rodrigues et al. [1]. The critical evaluation of this methodology, which uses the Index of Potential Reactivity (IPR) as defined by Rodrigues et al [2] to forecast the reactivity, is the objective of this paper.

2 Parameters related to the occurrence of AAR

Many different factors interact in the mechanism of alkali-aggregate reaction in concrete. It is necessary the simultaneous presence of reactive aggregate, enough concentration of alkalis and environmental interaction, supplying the humidity and acting in the reaction kinetics by the increase of the temperature what improves the reaction development [3].

The reactive aggregate rocks are those that include in their mineralogical composition silica mineralogical phases susceptible to the reaction with the concrete soluble alkalis. Among the aggregate rocks, the “granitic aggregates” are quartz-feldspatic rocks as granites, granodiorites, gneiss and migmatites that occur throughout the country and are widely used in Brazilian concrete works.

Tectonic efforts of varied intensities which acted in different geological periods affected not only many of those “granitic rocks” but also are responsible for the development of some textural features like deformations, microcraking, and their mineral recristalization. The quartz and the alkaline feldspar if deformed, tensioned or sheared acquire characteristics that make them potentially reactive with the concrete soluble alkalis. These minerals are responsible for the alkali-silicate reaction. This reaction is slower and much more complex than other reaction types [2].

Although the cement is usually the main source of alkalis, other sources cannot be neglected such as superficial or underground waters and the dissolution of the alkaline components of the aggregates, pozolans and slags. Therefore, the new tendency is to limit the total or soluble alkalis content in a concrete cubic meter. In South Africa [3], the following parameters have been established:

a) Above 3.8 kg/m^3 of equivalent alkaline in sodium – reactions occur

b) Between 1.8 and 3.8 kg/m^3 of equivalent alkaline in sodium – reactions can occur

c) Below 1.8 kg/m^3 of equivalent alkaline in sodium – reactions do not occur

Besides the humidity, the increase of temperature accelerates the cement hydration and the solution’s aggression. The continuous or cyclical exposure to the humidity supports the solubilization and the migration of the alkaline ions, increasing the action of the solution over the aggregates. Japanese researchers [4] studied the influence of the humidity conditions in the alkali-aggregate reaction. They observed strong dependence of the expansion according to the soluble alkalis content and the concrete amount of water. They verified that in concrete that is exposed to environmental humidity of less than 80% and loses water content along the time, a null expansion can occur or even a retraction can happen. When the relative humidity reaches 85% the expansion will happen only in concretes with high alkali content. For low content of alkalis the reaction only happens when the environmental relative humidity reaches 100%, being interrupted in the level of 90% even without loss of concrete water.

3 Index of Potential Reactivity (IPR)

The Index of Potential Reactivity (IPR) proposed by RODRIGUES et al [2] for evaluation of aggregates susceptibility to the alkali-aggregate reaction is based in the following parameters:

- Expansion tests (NBRI) at 14 and 28 days (Note: In this work the ASTM 1260 expansion test was used);
- Microscopic (undulating extinction angle, micro-grain quartz content, microcraking occurrence and medium size rock texture);
- Soluble alkali content;
- Concrete structure type, and;
- Environmental conditions.

3.1 ASTM 1260 expansion tests

Among the methods of reactivity evaluation, the accelerated expansion mortar bar method – method ASTM C 1260 – was considered the most appropriate for the aggregates that have been used. The expansion average in 14 and 28 days of cure in alkaline solution are taken as reference values for the estimation of the potential reactivity. The expansions higher than 0.20% in 14 days of cure indicate that the aggregate is reactive and those between 0.10% and 0.20% are considered potentially reactive, demanding complementary tests to decide about its reactivity. The expansions below 0.10% indicate that the aggregate is innocuous. This factor can increase until the maximum value equals 3.

Table 1 – Index of Potential Reactivity (IPR)

Parameters (A)	Conditions		
ASTM 1260 –14 days	<0.10 (0)	> 0.10 e < 0.20 (2)	> 0.20 (3)
ASTM 1260 – 28 days	–	< 0.20 (0)	> 0.20 (3)
Undulating extinction angle	< 15° (0)	15 a 30° (1)	> 30° (2)
% micro-grain quartz	< 5% (1)	5 a 15% (2)	> 15% (3)
Size rock texture	>1mm (0)	1 - 0.20mm (1)	< 0.20mm(2)
Microcraking	absent or weak (0)	moderate (1)	strong (2)
Cement soluble alkalis content (%)	–	< 0.4% (0)	> 0.4% (3)
Type of structure (B)	Non hydraulic (0)	Partially (1)	Hydraulic (2)
Environmental conditions (C)	hot/dry-cold/dry (0)	moderate/humidity (1)	hot/humidity (2)
INDEX OF POTENTIAL REACTIVITY (IPR) = A . (B+C)			

The results obtained in 28 days show the best correlation coefficients with the microscopic parameters - undulating extinction angle, micro-grain quartz content, microcraking and medium size rock texture [1]. The authors suggest the use of the expansion limit of 0.20% in 28 days for ASTM 1260, as the NBRI method does, as an indicator of the potential of reactivity of granitic aggregates. This factor can increase until the maximum value equals 3.

3.2. Microscopic parameters

The optical-microscopic parameters used in this research are: the content of micro-grain quartz (<0.15mm), the microcraking and the medium size rock texture. These parameters, acting simultaneously in many cases contribute to a significant increase in aggregate reactivity. Otherwise, it was verified that the quartz undulating extinction angle correlation with the reactivity is not always clear, indicating that this parameter can not be evaluated separately in different aggregates. The sum of each parameter can reach the maximum value of 9.

3.3. Cement soluble alkalis content

The alkalis that participate in the reactions are those soluble in water or in the concrete porous solution. They mainly correspond to a portion of the total cement alkalis, although other sources of alkalis should be considered (chemical and mineral/pozzolanic admixtures, superficial or underground waters or even partial dissolution of some aggregates minerals). It is considered the value of 0.4% as the superior limit to classify the cement as high alkali content. This factor can equal 0 or 3.

3.4. Type of concrete structure

The concrete structure can be classified in three categories:

1. Non hydraulic structures - those who are permanently out of contact with humidity such as pillars, beams and slabs of superstructures, without direct contact with the soil or weather conditions. The value attributed to this factor is 0;
2. Partially hydraulic structures – those that are eventually in contact with humidity such as the foundations above the ground water, which can be periodically in contact, with humidity due to the changes of underground water level. The value attributed to this factor equals 1;
3. Hydraulic structure – those permanently exposed to the contact with humidity such as foundations below ground water and the dams structures directly in contact with the water. The value attributed to this factor equals 2.

3.5. Environmental conditions

The environmental conditions are those related to the weather conditions in the concrete structure work site. In polluted atmospheres containing aggressive agents, in situations of high average temperature and under frequent rain conditions, this factor can be increased until the maximum value of 2.

The presence of aggressive agents in the environment can promote the acceleration of the alkali-aggregate reactions. This kind of occurrence can improve expansions, degradation and lixiviation of the concrete, affecting its durability as well as deterioration process that can make it easier moisture penetration.

3.6 IPR determination

The parameters used to calculate the Index of Potential Reactivity (IPR) and the values attributed to each one of them are presented in Table 1, modified from RODRIGUES et al. [1].

The following limits are proposed for IPR classification:

- IPR> 20: reactive aggregate
- IPR 12 - 20: aggregate potentially reactive
- IPR ≤ 12: innocuous aggregate

4 Analysis of Cases

Twelve samples of concrete structures from different origins and variable environmental conditions were selected to verify the applicability of IPR. The concrete samples were evaluated according to the criteria presented in Table 1 and in most cases the reaction alkali-silicate was previous detected by concrete petrographic analysis.

The studied cases in which the IPR was calculated are presented in the Table 2 and they are distributed in the following way:

- Three samples of concrete from tunnel construction
- A sample of concrete pavement
- A sample of pre-casting concrete structure
- Two samples of dam concrete
- Four of concrete building
- A sample of concrete bridge

Most of the samples show IPR values greater than 20, except for the sample of the Building 3, that does not present reaction indications, and which IPR was 16. This fact shows a good correspondence between the values of IPR and the field occurrence of the AAR.

In the cases of the identified concretes of the Bridge and Tunnel 2, in spite of the IPR values are high, 26 and 30 respectively, the analysis classified the intensity of the reactions as incipient. It can be explained by the fact that concretes contain in its compositions blast furnace slag additions, used as pozolans, to minimize the expansible reactions.

In Building 3 concrete the use of non deformed granitic aggregate was a key factor for the non development of the reaction, although the environmental conditions and the type of concrete structure were favorable for it.

The Figures 1 to 6 show the evidences of the reaction in the studied concretes and present the rock features, observed in the microscope in thin section. This kind of observation exemplifies procedures and parameters used to calculate IPR.

5 Conclusions

The evaluation of the aggregate potential reactivity by using the IPR shows a good correlation with extracted concrete samples from AAR affected structures. The occurrence of the alkali silicate reaction was confirmed in the

Table 2 – Index of Potential Reactivity (IPR) – Cases of Study

Parameter (A)	Tunnel 1	Tunnel 2	Tunnel 3	Pavement 1	Pre-casting	Dam 1	Dam 2	Building 1	Bridge	Building 2	Building 3	Building 4
ASTM 1260 14 days	3	3	3	3	3	3	3	3	3	3	0	3
ASTM 1260 28 days	3	3	3	3	3	3	3	3	3	3	0	3
Undulating extinction angle	1	1	1	1	1	1	2	2	1	2	1	1
% micro-grain quartz	3	1	3	3	3	2	2	1	1	2	1	3
Medium size rock texture	2	2	2	2	2	2	2	0	0	2	1	2
Microcraking	2	2	2	2	2	2	2	2	2	2	2	2
Cement soluble alkali content	3	3	3	3	3	3	3	3	3	3	3	3
Type of concrete structure (B)	1	1	1	1	1	2	2	1	1		1	1
Environmental conditions (C)	1	1	1	1	1	1	1	1	1		1	1
Index of Potential Reactivity (IPR)	34	30	34	34	34	48	51	28	26	34	16	34
Type of aggregate	Milonitic Gneiss	Milonitic Gneiss	Milonitic Gneiss	Milonitic Gneiss	Milonitic Granite	Cataclastic Granite	Cataclastic Granite	Cataclastic Granite	Granite	Milonite	Granite	Milonite
Occurrence of AAR in concrete	Evident	Incipient (*)	Evident	Evident	Evident	Evident	Evident	Evident	Incipient (*)	Evident	Non observed	Evident

(*) Greenish colour in concrete indicates the presence of blast furnace slag in its composition

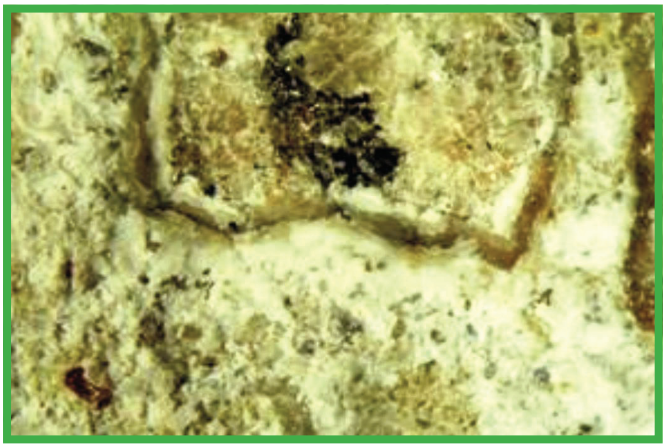

Figure 1 – **Reaction rim surrounding the reactive aggregate associated to a whitish film spread over the mortar**

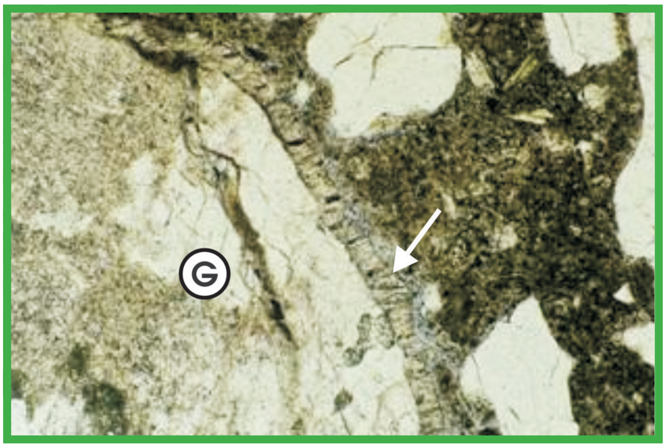

Figure 2 – **Microscopic features of concrete in which the expansible gel is observed (arrow) surrounding the reactive coarse aggregate (G)**

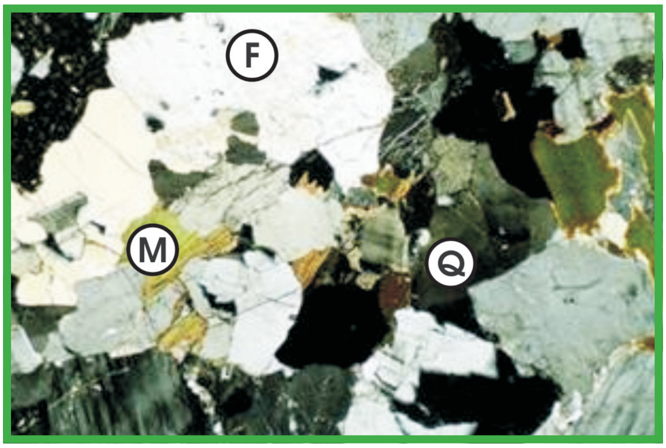

Figure 3 – **Texture of non deformed granite with coarse grains of quartz (Q), feldspars (F) and mica (M). The coarse grain texture is less reactive than a fine grain. Non reactive aggregate**

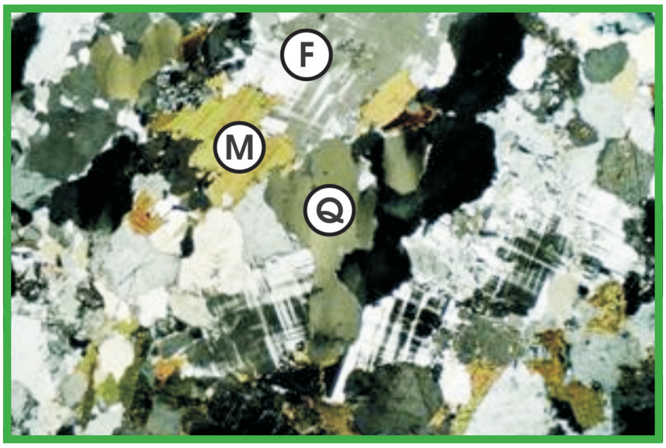

Figure 4 – **Texture of little deformed granite containing quartz crystals with undulating extinction angle (Q), feldspars (F) and mica (M)**

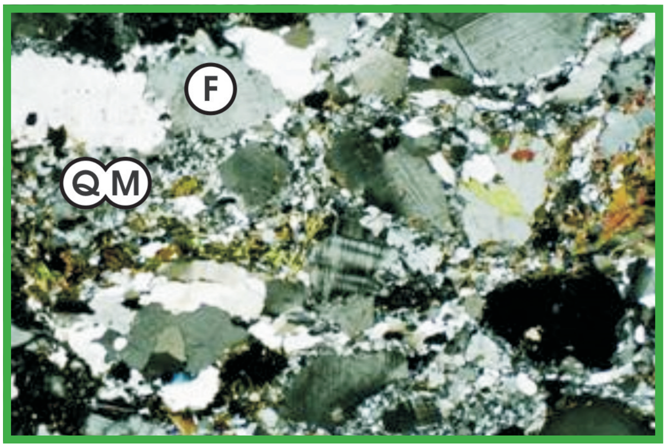

Figure 5 – **Texture of cataclastic gneiss containing feldspars crystals (F) involved by fine quartz grains (QM). Reactive aggregate**

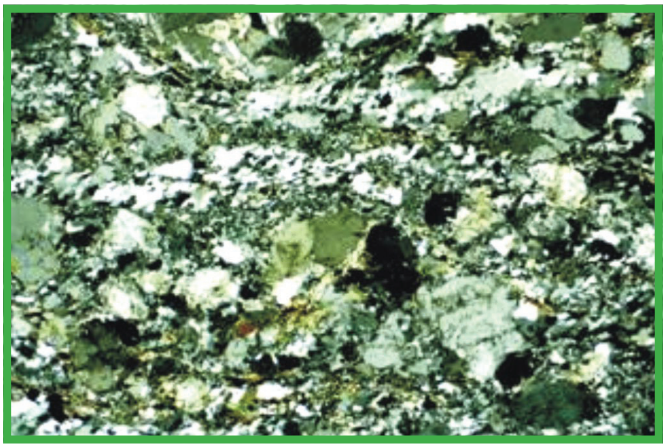

Figure 6 – **Texture of milonitic rock with granitic composition, in which feldspars crystals are involved by fine quartz grains. Reactive aggregate**

concrete samples evaluated by microscope analysis that identified reaction products, as silica-alkaline crystals and expansive gel.

Aggregates with IPR>20 are considered potentially reactive and the innocuous ones have IPR≤12. Intermediate values (between 12 and 20) are considered suspects.

Among the twelve studied cases, the smallest values of calculated IPR came from a concrete without field evidences of the reaction (IPR = 16). Two concretes with greenish coloration show incipient occurrence of reaction (IPR = 26 and 30). Slag grains were identified in these concretes, which indicate that the blast furnace slag content is not sufficient to avoid the development of some reaction.

Generally, the concrete structures with cataclastic/milonitized granitic aggregates show clear evidences of AAR and IPR>20. Other aggregates with similar mineralogical composition like gneisses, migmatites and granulites present the same tendency.

IPR contributes to a faster and easier evaluation of the aggregate’s potential reactivity, and can also be used in the selection and evaluation of the quarries homogeneity.

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