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ALKALI-AGGREGATE REACTIVITY — IS IT ALWAYS HARMFUL?

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Abstract

In an extensive survey of the present state of aging of concrete in 8 dams built between 1910 and 1960 with a wide range of aggregates, evidence of alkali-aggregate reactions were observed in almost all the core specimens tested. Alkali-aggregate reactions in these dams manifect themselves in a number of ways: reaction rim around aggregates, discoloration of aggregates in the peripheral region, polygonization of grains, loss of cohesion between paste and aggregate, inter and intragranular fissures, and delamination of stratified rocks. Compressive and splitting strength, and permeability measurements show that in most cases these alkali-aggregate reactions did not cause any significant loss in the engineering properties of concrete. It may be stated that unless the aggregate deterioration is well advanced, mere evidence of alkali-aggregate reactivity itself need not cause alarm. It is possible that due to lack of favorable environment and limited amount of reactive materials available, the reactivity tends to stabilize at an innocuous level.

1. INTRODUCTION

Hydro Québec owns several hydroelectric installations comprising over one hundred concrete structures of different ages made with different concrete mixes. A large variety of aggregates have been used for these concretes. Thirty six of these aged concrete structures were examined in an effort to learn more about the aging characteristics of concrete in hydraulic structures built in a very harsh environment, and in different administrative regions. Eight of these concrete structures (listed in Table 1) were investigated in much greater details.

The results discussed in this paper were obtained from representative core samples, extracted from deep within the structure, and from the surface of the structure (less than 3 m deep).

Practical observations and monitoring during the last decade have shown that in most cases the development of alkali aggregate reaction within the concrete of a hydraulic structure may not necessarily require any immediate corrective measures. Repairs as and when required, are generally carried out as a part of punctual action for the purpose of restoration of some specific operating part (deblocking of a gate, friction within a turbine, etc.), rarely to restore the short stability of the structure. Therefore, it is time to question whether alkali aggregate reaction is really always so harmful?

2. DESCRIPTION OF THE STUDIED STRUCTURES

The principal characteristics of these structures are presented in Table 1, where the type of coarse and fine aggregate used are described in terms of mineralogy, petrography and the maximum diameter. This table also indicates the external appearance of the concrete.

From Table 1 it is evident the aggregates used in the concrete of these structures represent a wide variety, which originate from igneous rocks like diorite, granite, monzonite, sedimentary and metamorphic rocks like marble metagreywacke, dolomitic limestone, sandstone, gneiss, etc. On some occasions these were found to be of detritic origin, and composed of wide range of minerals, mainly quartz, feldspar, biotite, muscovite ferromagnesians, (amphibole, pyroxene), while in other cases these were the processed aggregates from a rock quarry, and therefore, were more homogeneous from a petrographical point of view. The maximum size of the coarse aggregate varied between 25 and 100 mm.

The fine aggregates mostly were of detritic origin, except in two cases; in Beauharnois concrete it was a manufactured sand composed of the finer part of the crushed sandstone, and in the case of Grand-Mère a small portion of it was crushed diorite.

All the cores extracted from these hydraulic structures were tested for compressive and splitting strength, as well as for permeability measurement. In some cases in-situ permeability measurements were made in an attempt to correlate the laboratory measurements with some field values. These results are presented in Table 2. It is clear that the concrete compressive strength is spread over a wide range, not only from one dam to the other, the lowest value measured being 22 MPa for Shawinigan dam while the highest is 59 MPa for Mercier dam, but also within the same structure, eg., the compressive strength varied from 23 MPa to 51 MPa in La Gabelle dam. The same spread for the splitting strengths was also noted. It can be stated that the most affected concrete (by an AAR), the Beauharnois concrete, does not show drastic strength loss, but a low elastic modulus was measured in this case (18 GPa).

Water permeability values measured radially in 150 × 300 mm hollow cores (37.5 mm axial hole) shows that the permeability of the concrete also covers a wide range, from 2×10^{-6} m/s to 5×10^{-13} m/s.

The most extraordinary feature detected when examining the microstructure of these concretes under a transmitted light optical microscope was the presence of some form of AAR. in almost all the cases. Table 3 presents a synthesis of these observations that are discussed in more details in the following section.

3. MICROSTRUCTURAL OBSERVATIONS

Optical microscopy still forms one of the principal tools for studying degradation, such as alkali-aggregate reactions, in concrete. Bulk chemical analysis of the affected region no doubt provides an insight into the possible chemical alterations which may have taken place in the course of these reactions, but the morphology, the present state and the chemical composition of resultant products, eg., the reaction rim itself or the deposits within the expansion cracks can only be determined by SEM/EDX analysis. Hence, these two techniques were principally used to characterize the effects of alkali-aggregate reactions in these concretes.

TABLE 1. Summary of construction data of dams studied

	NAME	AGGREGATE TYPE	PRESENT CONDITION OF THE DAM: VISUAL OBSERVATIONS
LAURENTIDE	FARMERS	COARSE: diorite, granite, monzonite gneiss FINE: detritic sand - 65% quartz, 10% feldspar, ferromagnesians 5%	The exposed surface concrete is in bad condition, but in excellent condition inside. AAR is noticeable. Ø max 2 in.
	MERCIER	COARSE: marble 45%, metagreywacke 50%, gravel 5% FINE: quartz 70%, K - feldspar 25%, ferromagnesians 3 to 4%	Excellent. Non air entrained concrete (1.5%). Only localized signs of AAR. Ø max 4 in.
	RAWDON	COARSE: granitic pebbles with some quartzite, anorthosite, clayey dolomitic limestone. FINE: detritic sand - quartz, feldspar	In some areas the concrete is of excellent quality, in others quite poor. Localized signs of AAR. Ø max 1 in.
MAISONNEUVE	BEAUHARNOIS	COARSE: Postdam sandstone. FINE: Postdam sandstone.	The whole structure subjected to severe AAR. The exposed concrete appears to be more damaged. Ø max 2 in.
	LES CÈDRES	COARSE: 80% dolomitic limestone, 16% quartzite FINE: detritic sand - quartz, feldspar.	Concrete in good condition, but signs of AAR are visible around the quartzite aggregates. Ø max 2 in.
MAURICIE	GRAND'MÈRE	COARSE: quartzitic diorite 75%, granite 10%, quartzite 15% FINE: quartzitic diorite and detritic sand	In fairly good condition. No significant exterior signs of AAR. Ø max 4 in.
	LA GABELLE	COARSE: sandstone containing some mafic inclusins. FINE: siliceous sand.	Most of the exposed concrete is in bad condition. The concrete inside the dam is much better. Ø max 1 in.
	SHAWINIGAN	COARSE: gneiss FINE: granitic sand	Parts of the exposed concrete is in good condition, whereas others have deteriorated, depending on the location. Local exudation of silica gel. Ø max 2 in.

TABLE 2. Summary of engineering properties of concrete of each dam

	Compressive strength (MPa)	Splitting strength (MPa)	Permeability	
			Laboratory (m/s)	In-situ L/min/m
FARMERS	Not recovered	Too weak	N.M.	7 to 23
MERCIER	42.4 to 59.2	1.5 to 4.0	4.5×10^{-8}	N.M.
RAWDON	49.3 to 54.2 24.5 to 34.7	3.1 0.4 to 1	1×10^{-8}	0.3 to 0.8
BEAUHARNOIS	40 to 45	1.6 to 3.4	15×10^{-12}	N.M.
LES CÈDRES	36 to 67	N.M.	2×10^{-6} 0.2×10^{-8}	N.M.
GRAND'MÈRE	24 to 43	1.6 to 3.7	1×10^{-9} to 5×10^{-10}	N.M.
LA GABELLE	23 to 28 47 to 51	N.M.	8×10^{-8} 5×10^{-13}	0.2 to 24
SHAWINIGAN	22 to 45	4 to 5	10^{-10}	N.M.

TABLE 3. Summary of the observations of alkali aggregate reaction in each dam

	Manifestation of alkali aggregate reactions
FARMERS	Exudation of some silica gel. Severe internal cracking in the laminated rocks (Fig. 1). The other aggregates are intact.
MERCIER	Localized reaction rims around some coarse granitic aggregates (Fig. 2). Some quartz grains are heavily microcracked (Fig. 3). No detrimental effect on the concrete.
RAWDON	Some reaction rims around some coarse granitic and quartzite aggregates. Some quartz grains show polygonization (Fig. 4).
BEAUHARNOIS	Reaction rims around coarse aggregates and severe microcracking inside. Boundary discoloration visible (Fig. 5).
LES CÈDRES	Severe microcracking around quartzite aggregates (Fig. 6). Secondary cracks are filled with some silica gel. Dolomitic aggregates are unaffected by AAR.
GRAND'MÈRE	Only very localized AAR observable with an optical microscope. No detrimental effect on the concrete.
LA GABELLE	Quartz with undulatory extinction. Reaction rims can be observed at microscopic level. No detrimental effect on the concrete.
SHAWINIGAN	Two types of localized reactions. Alkali silica and alkali silicate reaction rims around some aggregates with no harmful effect on the concrete.

It is well known that a large number of these rocks used in the construction of these dams are reactive [1-4]. Hence it is needless to state the concretes examined do exhibit alkali-aggregate reactions. They manifest themselves in a number of ways, which are illustrated in a series of optical micrographs (Figs. 1-6).

Under the SEM, ettringite crystals in the reaction zones were found to be very common, and at times they appear to have carbonated. Both alkaline and non-alkaline silicate and aluminate gels were also observed. Rosette structure corresponding to calcium alumino-ferrite in composition have formed in places. The reaction rim and decohesion between aggregate and paste is also evident. Similar products in concrete structures in Quebec have been observed by other workers [5,6].

4. CONCLUSIONS

When this investigation started it was already known that two of the eight studied dams were severely affected by AAR, and in one case minor repairs had already been carried out. In the six remaining dams the concrete was still in good condition although through a detailed microscopic examination evidence of localized AAR was detected. The type and extent of reaction dictates whether immediate corrective measures are necessary, or the nature and frequency of follow up that has to be undertaken. Characterization of engineering properties of these concrete show that even if localized AAR is prevelant in hydroelectric concrete structures, it is not necessarily always harmful.

5. REFERENCES

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Fig. 1: Delamination in a stratified rock

Fig. 2: A thick reaction rim around the aggregate

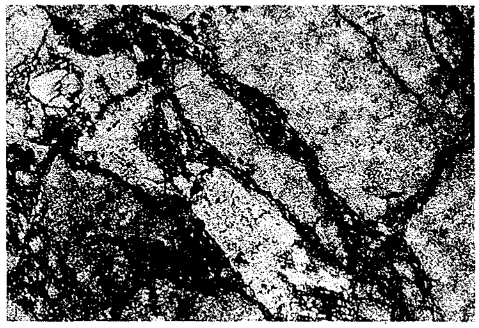

Fig. 3: Inter and intragranular fissures in quartz grains

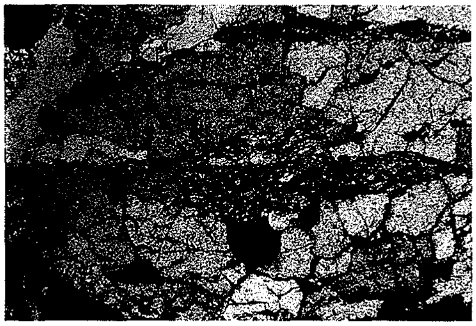

Fig. 4: Polygonization of a quartz aggregate

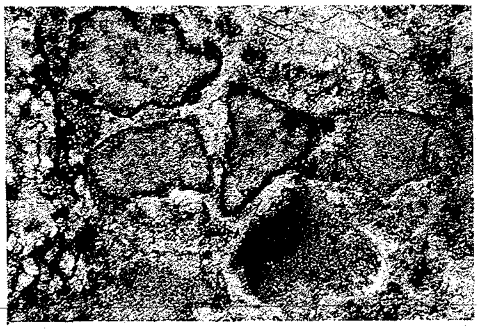

Fig. 5: Discoloration along the periphery of aggregates

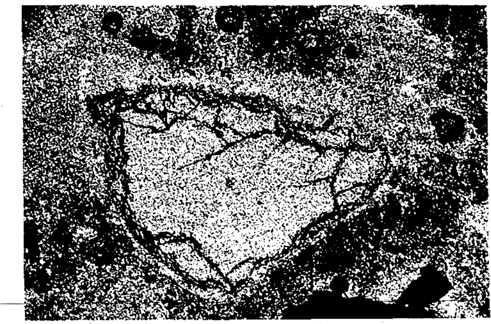

Fig. 6: Boundary cracks in a quartz aggregate