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CASE STUDY OF ALKALI-SILICA REACTION DUE TO SILICA-FUME PELLETS IN A MORTAR REPAIR

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ABSTRACT

In 1997, in the South of France, a building facade was repaired with dry mix shotcrete containing silica fume. Few months later, small pop outs of the coating appeared principally in the wet zone. Macroscopic observations reveal that pellets always are found at the bottoms of the pop-out craters.

Physical and chemical analysis of these black inclusions, about 50 µm to 1 mm in size, show that they consist of an agglomerate of fine grains of silica fume which are surrounded by an alkali-silica reaction gel. Chemical analysis shows that the alkali content of the mortar is moderate (3 kg/m^3) : therefore, although aggregates in mortar are potentially alkali reactive, no supplementary alkali reaction is observed.

This case study confirms previous results published by different authors on the very high alkali reactivity of silica fume agglomerates (Pettersson, 1992; Marusin, 1995; Shayan, 1995; Diamond, 1996). Thus, undispersed pellets of silica fume in shotcrete dry mix can be an effective initiator of localised alkali-silica reactions and seriously reduce the durability of the mortar.

Keywords : Alkali-silica reaction, dry-mix shotcrete, repair mortar, silica fume.

INTRODUCTION

To increase the durability of concrete structures in more or less severe environments, high-performance concretes are used more and more. These concretes are produced with a significant water reduction (water / cement < 0.40) and sometimes with the use of silica fume. To carry out durable repairs of damaged structures, mortars containing silica fume are used often in dry-mix concrete.

Since this type of mortar is intended to be durable, it is surprising to note sometimes that disorders occur, a few months after the end of work. Moreover, the addition of silica fume to limit the risk of alkali reaction (Langley et al, 1995, Shayan, 1995) it is abnormal to see that it is this silica fume which is at the origin of degradation. It is the study of this problem, which has occurred on a repair in the south of France, which is presented in this article.

PRESENTATION OF THE BUILDING SITE AND THE DISORDERS

Between 1996 and 1998, a building was the subject of a general rehabilitation. Among, significant work was coating of frontage on a surface of 6000 m² approximately. The composition of the mortar used is presented in the table 1. This composition was said to give a good durability of repair.

TABLE 1 : Proportion

Components	Unit weight (kg/m^3)
Ordinary Portland Cement (CEM I 52.5)	400
River sand (0/4)	1700
Silica fume with superplasticizer	30
Polypropylene fibre	0.6
Latex	50
Water	150

Sand, cement, silica fume with superplasticizer, and the polypropylene fibres were premixed dry in a concrete mixing plant. Latex and water were added at the building site at the time of projection.

The first disorders appeared towards the end of work. They affect the mortar locally and result in some visible pop outs through painting (photo 1). Most of the pop outs are observed on posts of the southern frontage on which one can note the presence of a strong moisture (related to the presence of flower window box). Other pop outs of mortar are also observed on the other frontages. Systematically, the presence of a black point is noted in bottom of crater. Some cracks are also visible on the work.

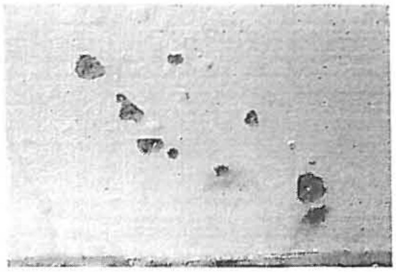

Photo 1 : Disorders on the wall

ANALYSIS OF SAMPLES MORTARS

Visual Observation

Sampling was carried out by coring in damaged zones presenting craters or pop outs and in zones seemingly healthy (photo 2). In all cores, one can observe many black points in all the depth of the mortar (photo 3). These black points can be either in the form of powder (especially in the healthy zones), or be solidified (in the damaged zones).

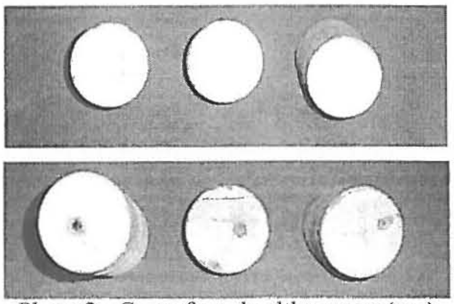

Photo 2 : Cores from healthy zones (top) and damaged zones (down)

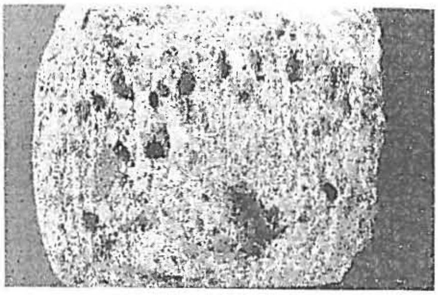

Photo 3 : Black points on the depth of mortar

Mineralogical Analysis by X-Ray Diffraction

The diagrams obtained on the mortars taken in healthy zones and in damaged zones are similar and show (Fig.1) :

- characteristic phases of the aggregates : quartz, feldspar, chlorite, and mica ;
- crystallized phase of the hydrated cement paste : portlandite.

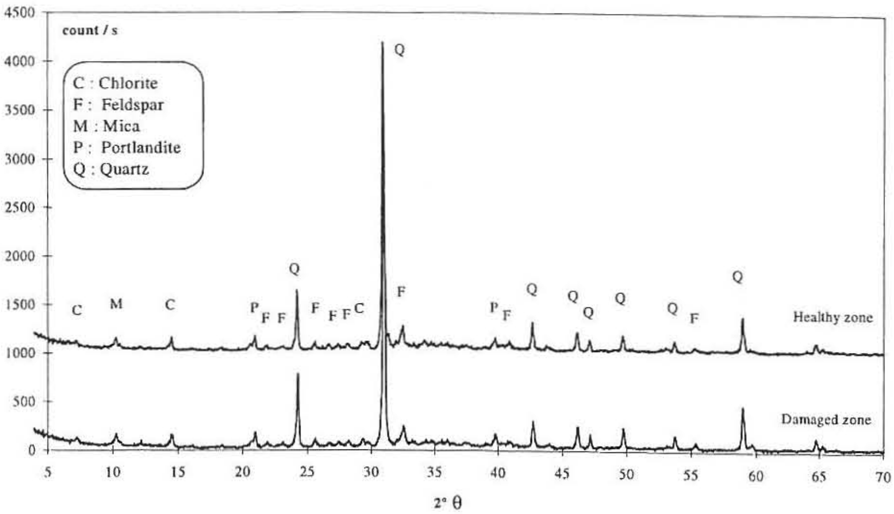

Fig. 1 : X-Ray diffractogram of the mortars

The diagram carried out on the black points show only one important vitreous phase (Fig. 2).

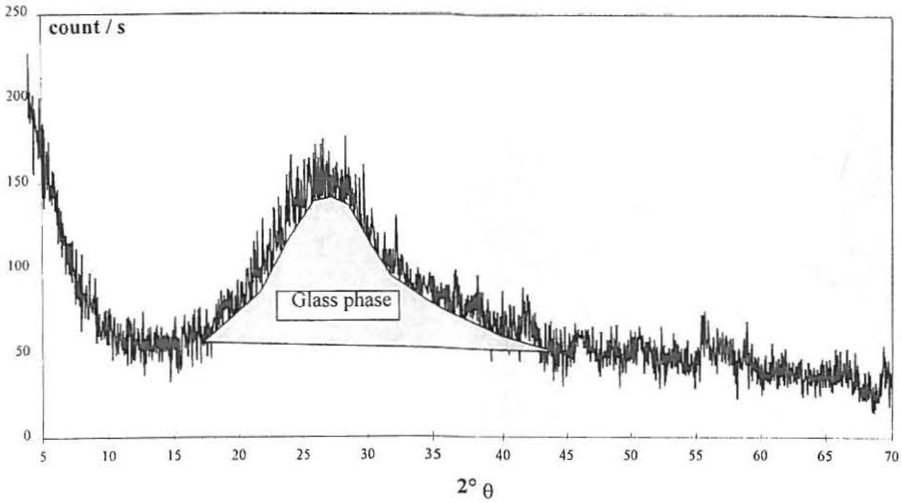

Fig. 2 : X-Ray diffractogram of the black point

Petrographic Analysis

The petrography study was undertaken on thin sections with a polarising optical microscope.

Sand present in the mortar is a clastic rock made up of quartz (86 %), feldspar (6%), mica (4%) and chlorite (4%) :

- quartz is primarily in the shape of microcrystalline quartz or undulatory extinction quartz ;
- feldspars are primarily calco-sodic plagioclases altered ;
- micas are muscovites or biotites in the course of chloritisation ;
- the chlorites come from the deterioration of plagioclases or biotites.

Most of the granular phases observed (about 80 to 90 %), can be classified as sensitive minerals in alkaline solution. However, no alkali reaction of the quartz was observed at the interfaces between sand particles and the cement paste.

Black points appear in the form of amorphous gel distributed in the mortar (5 black points on average per cm² of mortar). The form of the gel observed is generally spherical or ovoidal. Their dimension varies between 50 µm and 1 mm but can reach several millimetres (up to 5 mm). Certain black points can still contain powder in the central part. Some gel disseminated in the cement paste of the mortar is also observed.

Observations of the Microstructure by Scanning Electron Microscope

The observations carried out on polished sections confirm that, in damaged zones, black points appear as amorphous gel of variable size (photo 4). The qualitative chemical analysis carried out by X-spectrometry on the gel of photo 4 (figure 3) reveals the presence of silicon, potassium, sodium, and calcium. The gel observed is thus silico-calco-alkaline gel, comparable to the classical gel of alkali reaction.

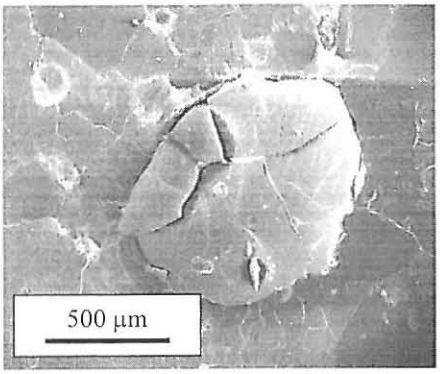

Photo 4 : Pellet of gel observed in the mortar

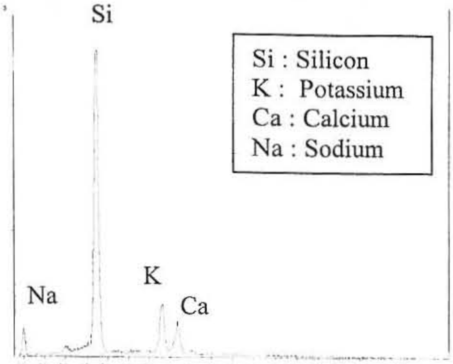

Fig. 3 : X–spectrometry of gel shown on photo 4

The quantitative chemical analyses carried out by spectrometer makes it possible to determine with precision the chemical composition of the silico-calco-alkaline gel. The averages of the results obtained on 10 points of analyses, expressed as a percentage by mass, are presented in Table 2 (with standard deviation). This gel is strongly siliceous.

TABLE 2 : Composition of Gel (with standard deviation)

SiO_2	CaO	K_2O	Na_2O	Al_2O_3	Fe_2O_3	MgO	SO_3
75,8 (± 3.7)	8,6 (± 3.2)	10.3 (± 0.5)	3,0 (± 0.3)	0,4 (± 0.1)	0,6 (± 0.4)	0,6 (± 0.1)	0,7 (± 0.2)

Certain gel was also observed in the zones seemingly healthy (photo 5). One can notice a beginning of formation of gel at the periphery of the black point and a powder aspect in the center. The chemical analyses by X-spectrometry show a more significant potassium content in gel in formation that in the heart of the black point (figure 4). So, the alkali–silica reaction is in progress.

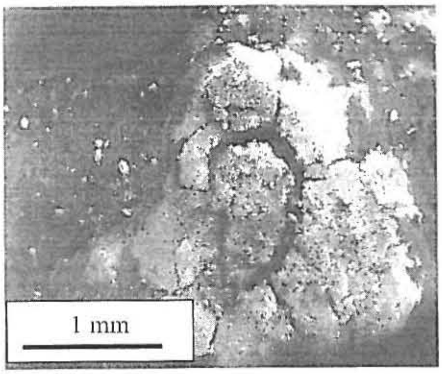

Photo 5 : Pellet of gel in formation observed in the mortar

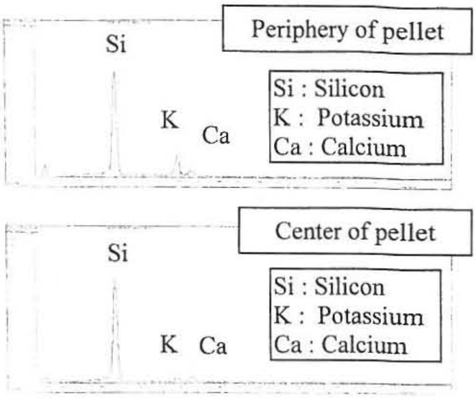

Fig. 4 : X–spectrometry of gel shown on photo 4

Content of Soluble Alkali

The chemical analysis for soluble alkali is carried out by atomic absorption after quartering, crushing and dissolving the mortar (Rogers 1993). The content of sodium, expressed in Na_2O, is equal to 0.051 %. The content potassium, expressed in K_2O, is equal to 0.124 %. The content of Na_2O equivalent is thus equal to 0.132 % (Na_2O equivalent = $Na_2O + 0.658\ K_2O$).

The apparent bulk density of the mortar is about 2300 kg/m3, the content of Na_2O equivalent of the mortar is about 3 kg/m3. This value corresponds to the limit which is recommended in France as the maximum allowable alkali content for use with aggregate susceptible to alkali-silica reaction (LCPC, 1994). Assuming all alkalies were derived from the cement, this suggests that the portland cement used had an alkali content of about 0.75% of Na_2O equivalent.

COMMENTS

Origin of the Alkali Gel - Reaction

The mineralogical and petrographic analyses showed that sand was composed of sensitive minerals in an alkaline medium. However, the observations carried out on thin sections, did not reveal gel at the interfaces between sand particles and cement paste. Alkali gel-reaction observed in the mortar thus does not come from a reaction with sand.

The macroscopic observations revealed the systematic presence of a black point under the pop out of mortar as well as many black points in all the thickness of the mortar. The various observations and analyses carried out in the damaged zones show that these black points are silico-calco-alkaline gel come from pellets of condensed silica fume, very reactive in an alkaline medium to form a sort of swelling aggregate. In this case, condensed silica fume can be regarded as a very reactive aggregate due to its high amorphous silica content and extreme fineness. This reaction was carried out very quickly in the wet areas (flows of water) and occurs slower in the drier zones.

Formation of the Pellets of Silica Fume

The formation of undispersed pellets of silica fume is certainly connected to the manufactoring process of the dry-mix shotcrete which does not provide for the dispersion of these particles.

Indeed, the industrial silica fume used is preliminary condensed and this condensation is generally accompanied by the formation of pellets of some µm in diameter.

Moreover, in the case of a dry-mix shotcrete, the preliminary mixture is carried out in mixing plant only with the water brought by sand. This mixture generally supports the formation of pellets of the size of the sand grains. During the projection, and thus of the final water addition, the process does not allow the dispersion of the clusters previously formed.

Formation of the Alkali - Silica Gels

The silica fume being composed of reactive amorphous silica, it can react quickly in the presence of water in an alkaline solution to form alkali-reaction gel. According to the dimension of the clusters of silica fume, this formation of gels can involve disorders in the mortars appearing either in the form of cracks, or in the form of pop out when gel is formed near to surface. Formation of alkali gels starting from cluster of silica fume already was observed and studied by many researchers (Pettersson 1992, Shayan and Al 1994, Marusin and Al 1995, Diamond 1996) but not by all (Mitchell et al., 1998).

However, in the majority of the studies, alkaline contents having involved alkali reactions were high (> 3 kg Na_2O equ/m^3). But, in this study, the reaction occurred whereas the content of alkaline mortar is in conformity with the French specifications. It is thus possible that, for very reactive products like the silica fume, this higher limit into alkaline in a mortar or concrete is still too high. It is as possible as, with a total content of alkali of 3 kg/m^3, the local contents close to surface are higher following displacements of the interstitial liquid (Nilsson 1981). This last assumption consolidates the current observations of only surface disorders.

Durability of the Repair

Taking into account the disorders observed, it is obvious that the repair is not durable. Moreover, it should be stressed that the pozzolanic reaction not being entirely produced. The lower permeability and consequent lower ion mobility assumed by the introduction of silica fume are not verified. In the same way, the fixing of alkali ions by the pozzolanic CSH did not occur and a significant share of these ions present in the mortar are still free and can react.

Precautions for Use to be Taken in the Future

Although silica fume is recommended to obtain durable mortars and concretes and to reduce the risk of alkali-reaction (Shayan 1995, Langley et al. 1995), the formation of clusters of silica fume particles during the densification of the silica fume can involve the formation of alkali-silica gel and the appearance of disorders. It is thus advisable to make sure that the techniques of manufacture do not lead to the formation of these clusters. These precautions are especially to take into account when the silica fume is used in its densified form (St John 1994) and when the water-cement ratio is very low.

CONCLUSION

This case study shows that the introduction of silica fume into a mortar can be at the origin of an alkali-silica reaction. It is the presence of pellets of condensed silica fume and its reaction in alkaline environment in presence of moisture which is the cause of the disorders. It would be thus essential systematically to check the dispersion of silica fume in the mortars or concretes especially when the silica fume used is beforehand condensed and that the water contents are low. In the case of the dry-mix shotcrete, it would be advisable to modify the introduction of the silica fume either by directly using blended cements containing silica fume, or by incorporating a slurrified silica fume during projection.

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