

# The Influence of Silica Fume in Alkali-Aggregate Reactions

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## ABSTRACT

A systematic study of pozzolanic activity of silica fume at different temperatures has permitted us to draw some conclusions concerning the beneficial influence of silica fume in alkali aggregate reaction. The microscopical examination of hydrated silica fume (SF) blended cement reveals the presence, not only of the expansive gel, but also well crystallized plates already observed in alkali-aggregate damaged concretes. The morphological characteristics of this gel seem to be influenced by its potassium content, and the hydration time and temperature.

## INTRODUCTION

The beneficial role played by some industrial by-products in the inhibition or reduction of alkali-aggregate reaction is well known (Nixon 1983), but the mechanism of this action is not fully understood. Alkalis react simultaneously with both reactive aggregates and pozzolanes in amounts directly proportional to their surface area. However, some parameters must be carefully controlled : the level of cement replacement, the reactivity of the industrial pozzolane towards alkalis, its particle size distribution and its alkali soluble content (Vivian 1983). This work presents a systematic study of the hydration of cement blended with silica fume. This industrial by-product has a very high pozzolanic activity which could explain to some extent, its favourable effect in preventing expansion due to alkali-aggregate reaction.

## MATERIALS AND METHODS

The cement used in this work is an ASTM type I low alkali cement with an equivalent alkali 0,56 %. This silica fume is an Elkem product with a SiO<sub>2</sub> content more than 97,3 %. Microscopical investigation (SEM coupled with EDAX) was performed on 7 days to 1 year hydrated silica fume cements (5 % to 20 %) at 20°C and 90°C.

## RESULTS AND DISCUSSION

The study of pozzolanic activity of SF blended cement showed the beneficial influence of the use of silica fume in reducing the porosity, and hence the permeability of the cement paste (Tenoutasse 1986). The permeability is one of the most important parameters responsible for the alkali-aggregate reaction, by governing the diffusion of the alkalis to the reactive aggregate through the concrete matrix.

The systematic SEM analysis of the microstructure of silica fume blended cement has permitted us to get some information on the influence of this industrial by-product in the alkali aggregate reaction.

Fig. 1 presents the microstructure of a 5 % SF cement after 7 days hydration at 20°C. The very high pozzolanic activity of silica fume at room temperature is clearly exhibited; some residual  $\text{Ca(OH)}_2$  crystals can be observed among massive formations of microcrystalline hydrosilicates containing potassium in significant concentration.



Fig. 1  
5 % SF - 7 d. 20°C

When the hydration progresses the morphological aspect of these hydrosilicates evolves, and after only 14 days, some "cracked calcium-alkali-silica gel" becomes observable, in SF blended cement (fig. 2). This morphology is typical of the type of expansive gel often observed in alkali-aggregate deteriorated concretes.



Fig. 2  
20 % SF -  
14 d. -20°C

The transformation of this gel into the expansive form is enhanced after longer hydration periods (fig. 3).

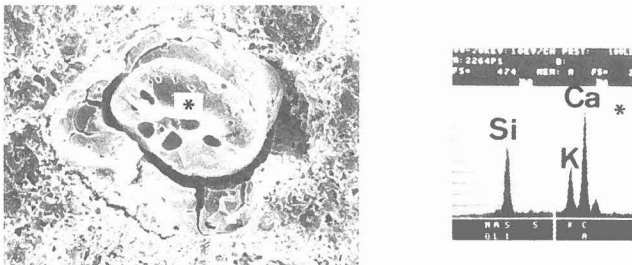


Fig. 3  
10 % SF  
28 d. -20°C

These local gel formations are distributed inhomogeneously in the cement paste. In fact, some macropores, probably air bubbles (fig. 4) persist in the hardened paste, and could have acted as precipitation sites for compounds from the pore fluid. Hence, these "available spaces" could be considered as likely receptacles for the formation of local gel. This hypothesis is illustrated on fig. 5; the rounded shape of the gel formation suggests "in relief" the filling of some macropores.

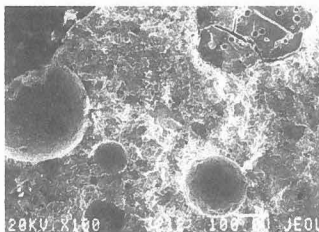


Fig. 4

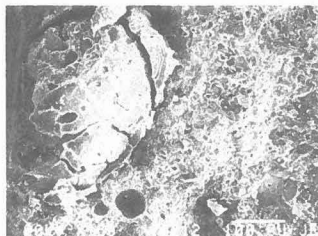


Fig. 5

10 % SF - 14 d. 20°C

The expansive properties of these local gel formations seem to be influenced by their potassium content, and by the hydration temperature.

Fig. 6 presents some hydrosilicate formation (20°C) with relatively low potassium content; these reaction products are apparently non expansive. No cracks are observable. However, the same samples present some important cracking zones with a high potassium content (fig. 7).

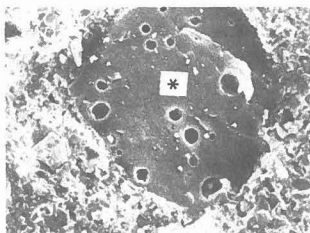


Fig. 6

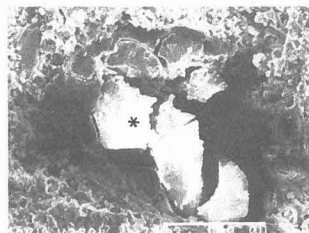
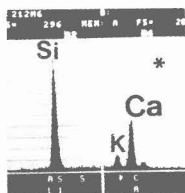
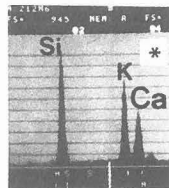


Fig. 7

10 % SF - 14 d. 20°C



The phenomenon is confirmed after longer hydration period : the expansive properties of the local gels are enhanced with increasing potassium content.



The temperature also plays a part in the morphological change of the hydrosilicates in SF blended cement (fig. 8). The reaction between  $\text{Ca}(\text{OH})_2$  and SF at high temperature leads also to the formation of hydrosilicates masses, however, these do not have expansive properties ; no cracks are apparent and the amount of potassium remains relatively low, confirming the previous comment related to the influence of the alkali content.

These results demonstrate the important role of water in alkali-aggregate reaction and in the differentiation of the gel into the harmful expansive forms.

Adequate amounts of alkalis and water must be available to promote the formation of the expansive alkali silica gel. If either alkalis and water become

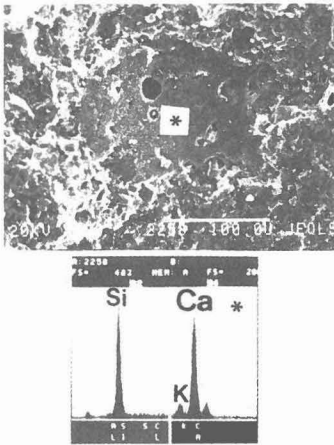


Fig. 8

10 % SF - 24 h. 90°C

is evident that well crystalline compounds need a higher free volume for their formation than the gel does.

This phenomenon is clearly illustrated in the 1 year hydrated SF blended cement (fig. 9). Inside the gel, some well crystallized material, very similar to that reported by Regourd is observed (Regourd 1981).

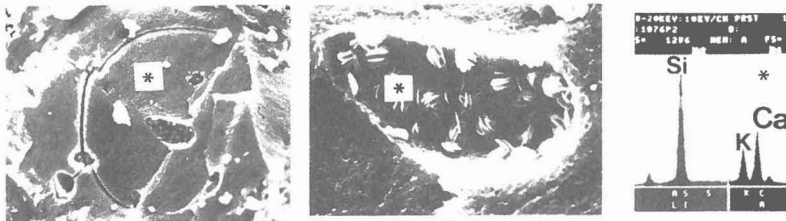


Fig. 9

5 % SF - 1 y. -20°C

The pores where those crystals are developing is probably initially occupied by the pore fluid. Indeed, fig. 10 exhibits circular masses rather similar to those reported by the authors in fly ash cement (Tenoutasse 1986). The chemical composition reveals the only presence of potassium and calcium, these being the major ions in the pore solution (Diamond 1983). When a reaction takes place between those circular masses and silica fume, crystallized plates become observable in those "privileged precipitation sites"(fig. 9).

It is thus the pozzolanic properties of silica fume, associated with its ability to fix alkalis which is responsible for the formation of such calcium-alkali-silica complexes.

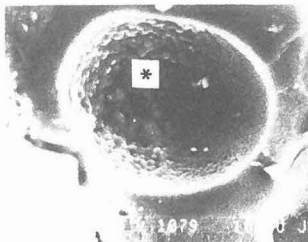
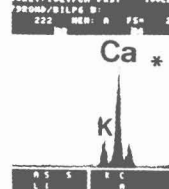


Fig. 10



limited the expanding system reaches an arrested condition which persists until additional alkali or water are supplied to it (Vivian 1983). So, in the samples hydrated at high temperature, the free water content is rapidly limited, due to early high degree of hydration of cement particles. Water being non available, the diffusion of the alkalis through the cement matrix becomes limited, and no expansive gel is formed. There is clearly a variety of alkali-aggregate reactions rather than a single one. The reaction products show various forms, gel material, opaque porous material, semi-crystalline material, or well crystallized compounds. The existence of "such a morphology" rather than another depends mainly on the space available to the alkali-aggregate reaction product when it is forming. It

## CONCLUSIONS

Silica fume is a very active pozzolane which forms microcrystalline hydro-silicates containing alkalis, very similar to the conventional alkali-silica gel. The expansive properties of these hydrosilicate formations are closely related to their potassium content, and the hydration temperature. The existence of such a local calcium-silica gel is probably not harmful because it forms in available space existing in the paste. Furthermore, its development into the expansive form takes place very rapidly, when the cement paste is sufficiently plastic to support such volume change, without disrupting internal strength. The same investigation must be carried out with the high alkali system, to confirm the phenomena observed with low alkali cement and low alkali available pozzolanes.

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