SP 83-1

The Use of Condensed Silica Fume in Grouts

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Synopsis: Condensed silica fume is a by-product of the fabrication of silicon or ferrosilicon alloys. It is composed of very fine glassy spheres of quite pure silica having an average diameter of 0.1 μm. It is a very reactive pozzolan that has been found to increase drastically the compressive strength of concrete and to reduce significantly its permeability.

The unique properties of condensed silica fume can also be used advantageously in grouts if condensed silica fume is used in combination with a superplasticizer. The very fine silica particles give stability to the grout, there is no sedimentation of the cement particles and no bleeding. By adjusting the respective proportions of portland cement, of condensed silica fume, and of the superplasticizer a thixotropic grout can be made.

The hardened grout is stronger and less porous when it contains condensed silica fume because the lime liberated during the hydration of portland cement reacts with the very fine silica particles to form a compact secondary CSH. By this way the possibility of leaching out of the lime is practically suppressed and the resistance of the grout to chemical attack should be improved.

Keywords: bleeding (concrete); compressive strength; grout; plasticizers; porosity; pozzolans; shrinkage; silica; thixotropy viscosity; water-cement ratio.

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INTRODUCTION

Condensed silica fume is a new pozzolanic material that starts to be used currently in the cement and concrete industry (1, 2, 3, 4, 5). It is a by-product of the silicon and ferrosilicon industry. During the reduction of quartz by coal in the submerged electric arc furnace, SiO vapors are formed. Some of these vapors escape through the burden of the furnace, are oxidized when in contact with the oxygen of the air,and condensate in the form of very fine particles of amorphous silica. These particles have a mean diameter of about 0.10 to 0.15 μm (Fig. 1) that is fifty to hundred times finer than cement particles (6) (Fig. 2). The specific surface area of condensed silica fume measured by nitrogen adsorption is about 15 to 20 000 m^2/g.

Condensed silica fumes are currently used in addition to cement or in substitution of certain amount of cement in percentage in between 5 to 15 percent of the cement weight in concrete. This results in mixes where there is practically no bleeding or segregation due to the changes in the rheology of the mortar paste. When it is used in addition the compressive strength of such concrete is greatly increased. When it is used in substitution to produce a given 28-day compressive strength,condensed silica fume can replace 3 to 4 times its cement weight (7).

Condensed silica fume reacts quite rapidly for a pozzolanic material with the lime liberated during the hydration of portland cement to form an amorphous-like CSH (8). (Fig. 3). This pozzolanic reaction results in a decrease of the total porosity of concrete containing condensed silica fume as well as in a refinement of this porosity (9, 10) and a decrease of the permeability of the concrete (11).

In the present research work,we have tried to find if the unique properties of condensed silica fume could be used advantageously to overcome some problems that are normally encountered when dealing with grouts, i.e:

- stability of the grout (sedimentation of cement particles in the water)
- existence of an open porosity favouring the penetration of aggressive chemicals
- possibility of the leaching of the lime present in the hydrated grout.

We have also tried to find if a thixotropic grout could be made using cement, condensed silica fume and a superplasticizer, that is a grout which is fluid when agitated but sticky when at rest, in order to solve the problem of the grouting of roof anchor bolt holes.

EXPERIMENTAL PROCEDURE

All the grouts that contain condensed silica fume will be compared to a reference grout made with a Type 1 cement, having a water/cement ratio of 0.4 and that does not contain any additive.

The condensed silica fume used was a mixture of two condensed silica fumes coming from furnaces producing silicon and a ferrosilicon alloy containing 75 percent silicon. It had the following chemical composition.

SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	K_2O	C	L.O.I.
92.1	0.25	0.8	0.20	0.20	0.16	0.96	2.5	2.8

When dealing with grouts containing condensed silica fume, the water/cement ratio has to be changed for the water/cementitious ratio, that is the water to (cement + silica) ratio expressed in terms of mass. In all the cases the condensed silica fume dosage will be given as the percentage of the total mass of the cementitious particles (cement + silica).

Although the commercial superplasticizer that has been used was in a liquid form, all the superplasticizer dosages will be given as a percentage of their solid particles to the mass of cementitious particles. The superplasticizer used was a condensate of naphthalene formaldehyde.

INFLUENCE OF CONDENSED SILICA FUME ON THE INITIAL PROPERTIES OF THE FRESH GROUT

The influence of condensed silica fume in the initial properties of the fresh grout has been studied in terms of viscosity, thixotropy and bleeding.

Viscosity - - The viscosity of the grouts has been measured with a Synchro-Lectric type viscosimeter. (Fig. 4), and will be expressed as a percentage of the initial viscosity of the reference grout that was equal to 0.8 Pa.s (800 centipoises.) This method has been already used to study the rheological properties of cement mixes (12).

Initial viscosity - - It can been seen in (Fig. 5) that the introduction of condensed silica fume in a grout increases drastically its initial viscosity. The higher the condensed silica fume dosage the higher the increase. In the same Figure it can be seen that the use of a superplasticizer can decrease drastically the viscosity of a grout whether or not it contains condensed silica fume. However, the action of the superplasticizer is more effective on the reference grout than in the grouts containing condensed silica fume. There exists for each condensed silica fume dosage a superplasticizer dosage after which any addition of superplasticizer does not decrease anymore the viscosity of the grout.

For example, the initial viscosity of grout containing 10 percent condensed silica fume can be decreased to 30 percent of the viscosity of the reference grout by using 1 percent of superplasticizer. To reach the same initial viscosity in the reference grout a superplasticizer dosage of 0.47 percent would have been sufficient and a dosage of 0.8 percent for a 5 percent condensed silica fume dosage. However, if a condensed silica fume dosage of 20 percent is used ,the viscosity of the grout cannot be less than 60 percent of the initial viscosity.

Variation of the viscosity with time - - The variation of the viscosity of 5 different grouts has been observed for the first two hours. The results of this experiment have been plotted in (Fig. 6). In this Figure,it can be seen that during the first 10 minutes the viscosity of the reference grout increases rapidly (it practically doubles), then the viscosity stays unchanged for 1 hour after which it increases progressively for 2 hours.

In the two grouts containing 10 and 20 percent of condensed silica fume that have an initial viscosity about the same as the reference grout,it can be seen that there is no longer a plateau. The viscosity increases quite rapidly in spite of the presence of the superplasticizer. After a period of 1 hour the grouts are quite stiff.

However, if the initial viscosity of the grout containing condensed silica fume is adjusted to 30 percent of the initial viscosity of the reference grout,it can be seen in the same Figure that after 2 hours its viscosity is equal to that of the reference grout and no more higher than the one of the superplasticized reference grout of the same initial viscosity.

Thixotropy - - Grouts made by mixing cement and water are slightly thixotropic, but grouts containing condensed silica fume can be highly thixotropic. After a period of 20 minutes,such grouts seem to be stiff, but when agitated they exhibit the same viscosity as a reference grout at the same time. This thixotropicity is illustrated in (Fig. 7). At time 0, the two grouts with and without condensed silica fume have the same viscosity. After 10 minutes the grout without condensed silica fume is still self leveling while the inclination of the becher containing condensed silica fume has to be increased slightly to reach the self leveling state. After 20 minutes,the grout containing condensed silica fume is stiff enough to stand in the beaker practically upside down. However,if agitated this grout become fluid again.

Sedimentation and bleeding - - The cement particles have a tendency to settle in normal grout and a film of pure water has a tendency to appear at the grout surface, that is the reason why grouts have to be agitated until they are injected. However, when condensed silica fume is present in the grout there is no more settling of the cement particles and no water separation. We have tried to visualize this effect in (Fig. 8).

INFLUENCE OF CONDENSED SILICA FUME ON THE PROPERTIES OF HARDENED GROUTS

Compressive strength - - The compressive strength of the grouts has been measured according to ASTM Standard C-109 "Test for Compressive Strength of Hydraulic Cement Mortar". The use of condensed silica fume does not increase significantly the grout compressive strength at 7 days. However at 28 days, the strength gain is more pronounced, and it increases with the amount of condensed silica fume. (Fig. 9).

Porosity measurement - - As the permeability of the grouts was too low (less than 10^{-12} m/s) it has not been possible to measure it. However we have proceeded to pore size measurement using a mercury porosimeter (12). The size of the cylindrical samples was quite big 20 x 100 mm (3/4 x 4"). They had a dry mass of about 50 g.

We have shown in Fig. 10 a and b the reproducibility of the test by running experiments on 3 different samples taken from the same reference grout. Figure 10 a gives the volume of intruded mercury whereas Figure 10 b gives the pore size distribution of the grout as a function of the pore radius.

We have shown in (Fig. 11 a) the average intrusion curve for the reference grout and a grout containing 10 percent of condensed silica fume at 7 and 28 days. It can be seen that the highest volume of intruded mercury is measured on the reference grout at 7 days and the lowest at 28 days in the grout containing silica fume. In this last case,the grout is practically non porous intrusion of (8 mm^3/g of mercury instead of 120 mm^3/g in the first case).

We have plotted in (Fig. 11 b) the pore size distribution at 7 and 28 days for the reference grout and 7 days for the grout containing condensed silica fume. It can be seen that the grout containing condensed silica fume has a finer pore size distribution than that of the reference grout at 28 days.

Shrinkage - - All the grouts that have been tested did not contain any additive at all. The shrinkage measurements have been made according to ASTM Standards C157-75 "Test for Length Change of Drilled or Save Specimens of Cement Mortar and Concrete" with an apparatus complying with the ASTM Standard C490-77 "Apparatus for Use in Measurement of Length Change of Hardened Cement Paste, Mortar and Concrete".

The shrinkage of the reference grout at 60 days was equal to 0.21 percent while the shrinkage of the grouts containing respectively 10 and 20 percent of condensed silica fume was equal to 0.22 and 0.23 percent.

The presence of condensed silica fume in the grout does not change its shrinkage. This result has also been found true in concrete.

DISCUSSION OF THE RESULTS

The increase of the initial viscosity accompanying the replacement of a certain mass of cement by the same mass of condensed silica fume in grout can be overcome by using a superplasticizer. The superplasticizer dosage can be adjusted so that after 2 hours,the viscosity of the condensed silica fume grout be equal to that of a normal grout at the same time. The amount of superplasticizer necessary to decrease the viscosity depends of the condensed silica fume dosage. As there are more very fine particles in the grout, a higher amount of superplasticizer molecules are necessary to lubricate the particles present in the grout. However, when all the particles present in the grout have been lubricated, any addition of superplasticizer does not affect the viscosity of the grout.

It seems that the presence of condensed silica fume changes the kinetics of cement hydration because the viscosity of the grout increases constantly instead of being about the same from 10 minutes to 1 hour after the mixing of the grout.

Moreover, the thixotropic effect of condensed silica fume illustrates also the fact that there is an interaction between the very fine silica particles and the water molecules. This interaction can also explain why no bleeding is observed in grouts and concretes containing condensed silica fume.

Condensed silica fume increases slightly the compressive strength of a grout at early ages most probably due to its filler effect as it has been explained by H. Bache (13). However, the compressive strength increase observed at 28 days is a consequence of the reaction of the very fine silica particles with the lime liberated by the hydration of portland cement (2). This pozzolanic action can also explain the drastic decrease in the porosity of grouts containing condensed silica fume.

CONCLUSION

Condensed silica fume can be used in grouts if combined with superplasticizer in order to control the variation of viscosity with time. Such grouts are very stable, avoiding any water separation problems. The hardened grout exhibits a higher compressive strength and a lower porosity than a normal grout due to the filler and pozzolanic effects of condensed silica fume. Moreover the fixation of the lime liberated during the hydration of portland cement associated to the drastic reduction of the total porosity of the grout should make this type of grout less sensitive to chemical attack from an aggressive environment or to leaching by infiltrated water.

The authors are conscious that this research project is only a beginning in the development of the use of condensed silica fume in grouts, however they are confident that the unique properties of this new mineral additive could be used advantageously in the field of grouts. For example thixotropic compositions can be adjusted very easily without the need of bentonites only by selecting carefully the condensed silica fume and superplasticizer dosages.

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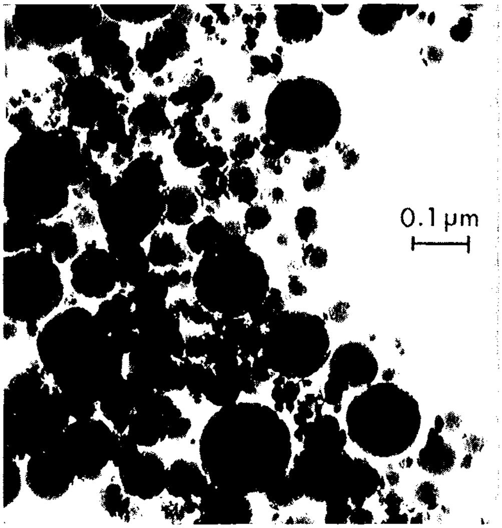

Fig. 1--Condensed silica fume grains

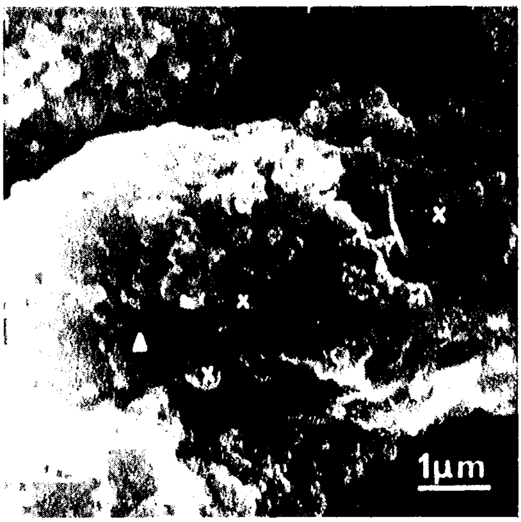

Fig. 2--Comparison of the size of condensed silica fume particles and portland cement clinker grain