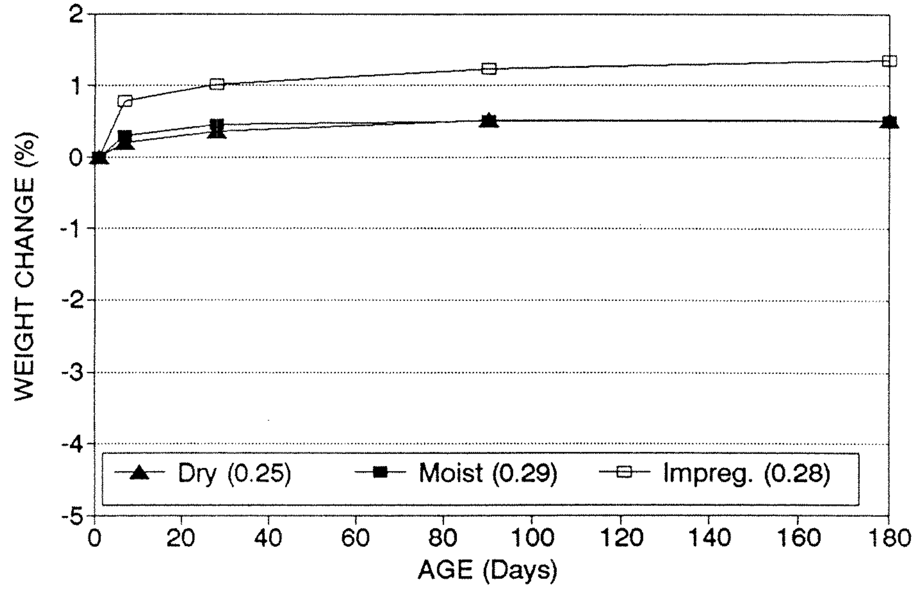

Fig. 15 - Weight changes of beams exposed in water. The LWA was oven dry, moist and impregnated, respectively before mixing. The nominal w/(c+s) ratio was 0.30. Calculated effective w/(c+s) ratios are shown in parentheses.

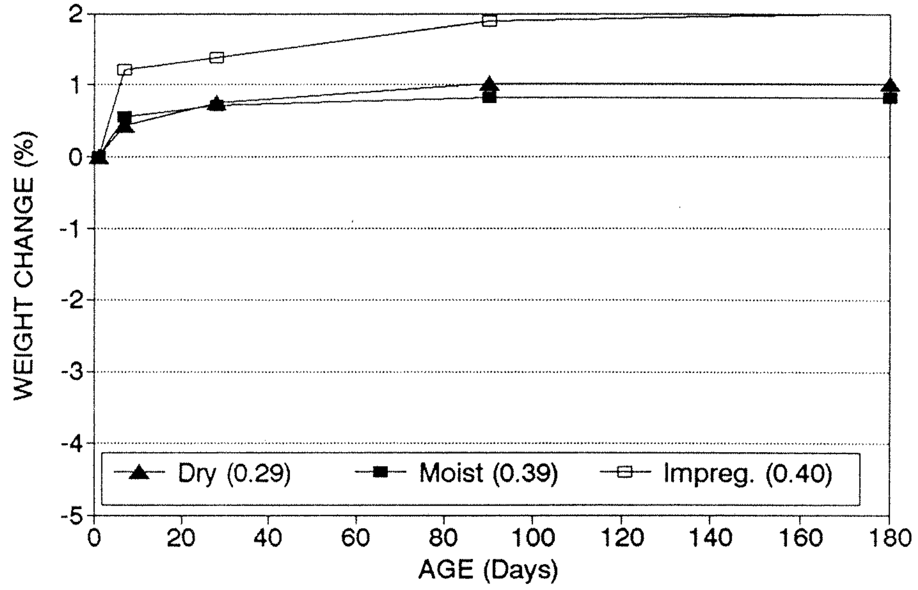

Fig. 16 - Weight changes of beams exposed in water. The LWA was oven dry, moist and impregnated, respectively, before mixing. The nominal w/(c+s) ratio was 0.45. Calculated effective w/(c+s) ratios are shown in parentheses.

Repair Mortars for Concrete exposed To Freeze-Thaw and deicer salts

by F. Alou and Y.F. Houst

Synopsis : In Switzerland, the degradation of concrete bridge superstructures and retaining walls has grown to a large extent this last decade, mainly due to freeze-thaw cycles often associated with deicer salts. The concrete repair has consequently become an activity of great importance. But frequently the repairs have not been durable, essentially because of the misappreciation of the requirements which these mortars had to meet.

A large number of repair materials are used like cementitious or polymer mortars. We tried to develop, for large or patch repairs, a type of mortar with performance higher than that of traditional or ready mix mortars. This mortar has to meet requirements in the fresh state (consistency, workability) as well as after hardening (adhesion, strength, water permeability, diffusion of gas and chloride).

Essentially for a cost reason, we decided to limit our development to cementitious mortars by using water-reducing admixture associated with condensed silica fume.

The results given here concern essentially tests made on one type of mortar with three W/C. Porosity, pore-size distribution and water absorption have been measured as well as mechanical properties like fluxural and compressive strength, elastic modulus, creep and shrinkage and adhesive tensile strength. In addition, frost and deicing salt scaling resistance have been evaluated. The variable curing conditions and the surface roughness have also been taken into consideration.

Keys words : repair mortars, condensed silica fume, superplasticizer, frost resistance, scaling resistance, capillary suction, creep, shrinkage, adhesive tensile strength.

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INTRODUCTION

At the present time, the network of Swiss highways has about 3000 bridges of a value of 4 billions US $. These bridges, essentially made of concrete, are submitted to severe conditions, both climatic and mechanical. For the bridges built after 1975, the cost of inspection and maintenance represent about 1.5 % of the construction cost. For older bridges with a quality wich is not always of the same level, these costs are between 1.5 and 3 %. The situation seems to be relatively the same in Australia [1].

Up to now, the method and the repair materials for concrete bridges have not been intensively studied. Often, repairs have failed within a relatively short time. This situation has lead the authorities, who are in charge of the inspection and maintenance of the highways network, to encourage a systematic research on the maintenance [2].

In this context, we have proposed and entered upon a study on repair mortars.

The repair mortars have to meet requirements in the fresh state as well as in the hardened state. They have to be applied on horizontal and vertical surfaces, by hand or by a machine. They are used both for larges and patch repairs. The workability should last long enough to allow fulfil the site conditions.

Adhesion is always an important point for rendering and thin layers. It is therefore necessary to define and to check the surface roughness before applying the material. The mortars should be little sensitive to climatic conditions (temperature, wind, relative humidity of the air) and should have a low drying shrinkage. From the mechanical point of view, the strength and the elastic modulus should be of the same order of magnitude than that of the substrate concrete in order to avoid decohesion and cracking. On the other hand, creep should be as high as possible to support the strains of the substrate without cracking. For the same reasons, the thermal expansion coefficient should be as close as possible to that of the substrate.

From the point of view of the aggressive environment, repair mortars should be as little permeable as possible to solutions, particularly to chloride solutions of deicing salt. Generally, they should be resistant to frost and to carbon dioxide and other acidic gases diffusion. On the other hand, it is desirable for them to be of a basic nature in order to contribute to reinforcing steel passivation, even to realkalinize a part of the carbonated concrete substrate.

In order to meet at least part of the above requirements, it is possible to use synthetic or hydraulic mortars. Essentially for reasons of cost and of thermal expansion coefficient, we have limited our development to hydraulic mortars. To improve these mortars, we used condensed silica fume associated with a superplasticizer. This solution has already proved to present numerous advantages, especially for the durability. Frost and deicing salt scaling resistances can be largely increased, permeability and chloride solutions diffusion are lowered, without speaking of mechanical resistance.

The composition of the mortar has been choosen on the basis of preliminary tests and we have retained three water/cement ratios. Thus, it is possible to have different workabilities at one's disposal depending on the type of use and application (by hand or by a machine). It is the results of the tests obtained with these mortars and partly on a similar mortar, but without silica fume, which are presented here.

The preliminary tests have shown that these mortars had a high resistance to carbon dioxide diffusion measured by a accelerated test and had generally higher performance than that of five commercially available mortars.

EXPERIMENTAL

Materials

The cement of type PC from the plant at Eclépens (Switzerland), was approximately of ASTM type I, with fineness defined by specific surface area 290 m^2/kg (Blaine). The particle size distribution of the cement, measured by laser diffraction, is given in figure 1. The condensed silica fume (CSF) was imported from Germany (trademark : V.A.W. RW Füller) in a grey powder form slightly densified. The silica content was 96.5 % of amorphous silica, the BET specific surface area was 20'000 to 22'000 m^2/kg, and the specific gravity 2'200 kg/m^3. The particle size distribution measured by laser diffraction is also given in figure 2. A powerful ultrasonic cell has been used to desintegrate the particle agglomerates before measurement.

The sand (0-4 mm) was from a glacial moraine of rounded shape. Mineralogically, the sand was composed of 40 to 46 % calcite, 29 to 32 % quartz, 8 to 13 % residue of crystalline rocks of multimineral composition, predominantly quartzitic, and 12 to 18 % of composite grains, essentially quartzitic. The grading curve of the sand is given in figure 2.

For all the tests only one superplasticizer, consisting of sulfonated melamine formaldehyde condensate, has been used. The dosage of this admixture was 2 % by mass of cement. It has always been added after the water.

For this study, four mortars have been used. Their composition is given in table 1. The first three had the same cement/sand ratio, i.e. 1/3, 10 % of CSF and 2 % of superplasticizer relative to the mass of cement. This composition has been chosen on the basis of results of the preliminary tests. The mortars differ only from one another in their water/cement ratio. In the fourth, the CSF had been replaced by the same absolute volume of cement.

Testing Methods

The total porosity has been calculated on the basis of water absorption under vacuum of pieces of mortar after 28 days of curing. The capillary absorption has been measured on cylinders (ø 50 mm, height 50 mm) immersed in 3 mm of water during 48 hours. During the tests, the relative humidity of the surrounding atmosphere was kept above 95 % and the temperature was 20±1°C.

For the mercury intrusion porosimetry, a standard porosimeter (Micromeritics Autopore 9200) which allows the application of pressure up to 415 MPa has been used. This corresponds to a minimum radius of 1.7 nm. After having introduced a number of simplifying assumptions, the radius r of pores penetrated by mercury at pressure P, can be expressed by the following equation :

$$r = -\frac{2\sigma\cos\theta}{P}$$

where σ stands for the surface tension of mercury and θ for the mortar-mercury contact angle. A value of 135° for θ was used in this study. The pore-size distribution measurements have been carried out on small pieces of mortar (3 to 5 mm) pre-dried at 70° C.

Flexural and compressive tests had been carried out on conventional prisms 40/40/160 mm used for normal tests on cement. After the flexural test, the two parts of the specimen had been used for the compressive test. The prisms had been kept up to the day of the test at a R.H. > 95 % and at 20 ± 1°C.

The elastic modulus had been measured on prisms 60/60/250 mm; at 14 days on the basis of the instantaneous strain of the creep measurements and at 28 days in accordance with DIN 1045 standard.

The specimens were cured as above, i.e. at a R.H. > 95 % and at 20±1°C.

The scaling resistance of the mortars surfaces exposed to deicing salt was performed according to Swiss Standard SIA 162/1 (test No 9) on 90 days old mortars. Before the beginning of the tests, the specimens were saturated of water by capillary suction. A sodium chloride solution (3 %) was used. The freezing temperature was -12°C and room temperature 20°C. The evaluation of results differs from that of the ASTM C 672 test method. The loss of material is measured after 30 cycles. If the loss is lower than 600 g/m^2, the resistance is defined as "high" and if the loss is higher than 3800 g/m^2, the resistance is "low".

The resistance to freezing-thawing was also evaluated according to Swiss Standard SIA 162/1 (Test No 8) on 90 days old mortars. One 8-hour cycle can be decomposed as follows : 2.5 h at 14°C, 0.5 h to decrease the temperature from 14°C to -25°C, 4 h at -25°C and 1 h from -25°C to 14°C. The resistance to freezing-thawing was evaluated on the number of cycles (N_{50}) which leads to a decrease of the elastic modulus of 50 %. If $N_{50} \geq 100$, the resistance is high, if $N_{50} \leq 20$, the resistance is low.

For shrinkage measurements, the specimens (prisms 60/60/320 mm) were cured at a R.H. > 95% and at 20±1°C, until their exposure to the drying environment. This type of curing is preferable to curing in water bath, which has been found to cause nonuniform water intake, significant swelling stresses, and microcracking. The environmental humidity was 60±5%, and the room temperature was 20±1°C throughout the shrinkage.

The shrinkage deformations were measured by taking length readings between the ends of the specimens along the cylinder axis. The deformations of all specimens were measured with one dial gauge which had contacts made of steel balls that fit into ringshaped steel targets glued to the specimens. To be able to record the very initial shrinkage, the targets for deformation measurements had been attached before the molds were stripped. All specimens were exposed to drying at the age of 14 days and shrinkage measurements started immediately. The initial reading, representing the zero strain, was taken within 1 min after the placing of the specimen in their set-up; in previous tests the first reading was apparently taken much later causing a significant initial shrinkage to go unrecorded. The experimental set-up is represented in figure 3.

The creep measurements had been carried out on specimens of the same section than those used for shrinkage measurements, but with a height of 250 mm. The specimens were cured under the same conditions and with the same caution. Then, they were placed at the age of 14 days into their set-up. The stress was maintained at ±5% by a gas pressure accumulator. The mean applied stress was 7 MPa.

The adhesive tensile strength was measured by the pull-off test on cores (ø 75 mm) drilled through the repair mortar and within the concrete substrate. Two metal discs were glued on the end surfaces of the cores by means of an epoxy adhesive. The force necessary to pull off the glued core was measured with a tension test machine. Two types of specimens can be distinguished :

- For type I half-cubes of concrete (200/200/200 mm), obtained by the "Brazilian test" were used. The mortars were applied horizontally by means of a trowel. The specimens have been kept at the climatic laboratory conditions.

- For type II, the repair mortar was applied vertically on a concrete wall with aggregates partially exposed by two masons by means of a trowel. The mortar was No 3 (W/C = 0.45), but the masons could add water to it, which was measured, until it obtained the desired consistency. To obtain thickness of 50 mm, it was necessary to apply 3 layers. The first was 10 mm thick, the second 25 mm and the last one 15 mm. 24 hours had elapsed between the application of the next layer. The mortar was applied outdoors on the two faces of the wall facing North-east (without solar radiation) and South-west (with solar radiation since noon). The climatic conditions during the application of the mortar were 20 to 23°C and 63 to 71 % R.H. The water/cement ratios of the different layers of mortar depending on the mason are given in table 2.

RESULTS AND DISCUSSION

The total porosity and the bulk density of the mortars are given in table 3. The mortars with CSF (No 1 to 3) are less porous than the one without CSF (No 4). The porosity slightly encreases with W/C and the results reflect the fact that the specimens were cast in their molds without further vibration.

The capillary absorption of the mortars is given in figure 4. We can see that the results of the three mortars with CSF are approximately identical, while the mortar without CSF has a significantly higher capillary absorption coefficient. This is due to the well known pore-refining capability of CSF [3,4]. The mortars 1 to 3 have capillary absorption coefficients of the same order of magnitude than those of good concrete used for tunnels in Switzerland. The favorable effect of CSF on permeability [5,6] is therefore also good to reduce capillary absorption.

The relation between total porosity and capillary absorption coefficient is shown in figure 5. We can see a linear relationship only for the mortars with CSF. The first point in this figure was measured during preliminary tests on the same material. The results can be explained by the very similar pore-size distribution of mortars with CSF (figure 6). The one without CSF shows a higher amount of large pores (> 5 µm). This is perhaps due to the relative coarseness of the cement particles replacing the CSF in this mortar. The reduction of the capillary porosity (pores between 0.01 and 5 µm) by addition of CSF is about 1.2%.

Flexural and compressive strength results are given in table 4. The three mortars with CSF and the superplasticizer have practically the same strengths, especially the compressive strength. On the other hand, mortar 4 (without CSF) has much lower strengths. It is essentially due to the pozzolanic effect of CSF, even at early age. These strengths are very high and generally higher than that of the concrete to repair. In practise these strengths will be lower because of the W/C that can be higher and the curing may be less favorable.

It is interesting to note that mortars 1 and 2, with the same compressive strength (80.9 and 80.3 respectively) have also the same total porosity (17.6% and 17.8%). The compressive strength of mortar No 3 is only 95 % of that of mortars 1 or 2, has also a higher porosity (+ 8 %). The compressive strength therefore depends on the ratio (water + air)/ (cement + CSF).

The elastic modulus has been measured only on the mortars 1 to 3 and the results are given in table 5. The data for 14 and 28 days are very similar and the variation is lower than 7.5 %. The mean value of the elastic modulus at the age of 28 days (33.2 GPa) is largely lower than that which can be obtained by means of the formula given in the Swiss Standard SIA 162 ($E = 10400 \sqrt[3]{f_c}$), on the basis of the compressive strength, i.e. 44.7 GPa and lower than that of an old concrete. It is favorable from the point of view of cracking and adhesion.

The deicer salt scaling resistance of the mortars 1 to 3 is given in table 6. There is no significant difference between the three mortars. According to the Swiss Standard, these mortars have a "high" resistance to scaling. It would have been interesting to continue the tests above 30 cycles, because it is known that some high strength concretes show a good behaviour in such a test until a time when the degradation quickly increases. That is why it is recommended to subject the specimens to a number of cycles higher than that currently prescribed [7]. This good resistance could be expected according to previous results [8].

The freezing and thawing resistance of the mortars 1 to 3 is given in table 7. After 115 cycles, no significant decrease of the elastic modulus can be established. By the Swiss Standards, the resistance to freezing-thawing is high. But, the above remark on the number of cycles is also good for this test. Therefore, we continue the tests up to at least 200 cycles. The favorable influence of CSF on freezing and thawing resistance was already known (see for example [9]).

The results of the shrinkage tests are given in figure 7. The values obtained for the mortars 1 to 3 hardly differ (maximum deviation < 10 %), but the shrinkage does vary with the water/(cement + CSF) ratio. Using the mean values of the three mortars, and the following equation :

$$\varepsilon = a\sqrt{\frac{t}{b+t}}$$

which describes the shrinkage ε as a function of time [10], we can determine the parameters a and b by the least square method. We obtain :

$$a = 0.71 \text{ mm/m} \quad ; \quad b = 22 \text{ days}$$

The value of the final shrinkage (a) is low if one takes into consideration the relative humidity and the specimens size. For concrete, a value of 0.76 mm/m can be expected [11].

The measurements of strains as a function of time on specimens under a stress of 7 MPa are given in figure 8. Creep strains are given in table 9. It can be seen that the strains are practically independent of the W/C ratio. The creep value after 112 days is about two times the elastic strain.

The function $\varepsilon = 0.061\ t^{0.41}$ describes well the creep as a function of time. The creep strains for our mortars are higher than that of good concrete. This naturally limits cracking.

The results of the adhesive tensile strength are given in tables 8 and 9. It can be seen that, in the two cases, adhesive strength increases with time, even for the specimens exposed outdoors. The results after 56 days represent between 75 % (type I) and 80 % (type II) of the tensile strength of the concrete. No crack could be observed on a wall of 2 x 1 m^2. The fracture surface showed always at least 25 % of concrete.

CONCLUSIONS

The studied mortars have a plastic consistency and can be easily manipulated. Without special compaction they have a low porosity in the same order of that of a pumped concrete.

Capillary absorption which allows penetration of solutions such as chloride solution is lower than that of a normal concrete substrate. This is due to the use of CSF associated with a superplasticizer.

Flexural and compressive strengths we have measured are very high. But in situ, they will generally be essentially lower because of the curing conditions. Thus, the strengths will be nearer that of the concrete substrate.

The elastic modulus is lower than that of the concrete substrate which is generally an old concrete. This tends to lower the riscs of cracking and decohesion.

Frost and deicing salt scaling resistances are high, though we did not used air entraining admixtures. It could be advantageous to use such an admixture which decreases mechanical strength as well as the elastic modulus. The use of an air entraining admixture will be studied in a further step.

The drying shrinkage of the mortars is lower than that generally found with concrete. Therefore the risk of decohesion is low.

The creep of the mortars is higher than that of standard concrete. This and the low shrinkage should allow to obtain a high durability of repairs with this type of mortar.

The results of adhesive tensile strength measured on specimens kept outdoors are satisfactory. This confirms the above remarks on drying shrinkage and creep.

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Table 1 - Composition of the Mortars

Mortar No	1		2		3		4	
	kg/m^3	L/m^3	kg/m^3	L/m^3	kg/m^3	L/m^3	kg/m^3	L/m^3
Cement	507	163	500	161	495	160	546	176
Silica fume	50	20	50	19	49	19	--	--
Superplasticizer	10	8	10	8	10	8	11	9
Water	203	203	210	210	223	223	219	219
Sand	1520	569	1500	562	1485	556	1464	548
Air	--	38	--	40	--	35	--	48
Sum	2290	1000	2270	1000	2260	1000	2240	1000
Water/Cement	0.40		0.42		0.45		0.45	

Table 2 - Water/Cement of Mortars used for Bonding Strength Tests

Layer No	Mason A	Mason B
1	0.57	0.62
2	0.56	0.55
3	0.56	0.54

Table 3 - Total Porosity and Bulk Density

Mortar No	Bulk density [kg/m^3]	Total porosity [vol. %]
1	2152	17.6
2	2160	17.8
3	2133	19.2
4	2099	20.4

Table 4 - Compressive and Flexural Strength

Mortar No	W/C	Flexural strength [MPa]		Compressive strength [MPa]	
		7 days	28 days	7 days	28 days
1	0.40	17.8	23.6	60.3	80.9
2	0.42	14.8	25.6	60.8	80.3
3	0.45	14.7	20.7	56.7	76.8
4	0.45	6.4	7.7	36.9	48.0

Table 5 - Elastic Modulus

Mortar No	W/C	Elastic modulus [GPa]	
		14 days	28 days
1	0.40	29.7	33.8
2	0.42	29.7	34.1
3	0.45	29.7	31.7

Table 6 - Scaling Resistance of Mortars Exposed to Deicing Salt (according to Swiss Standard SIA 162/1, 1989)

Mortar No	W/C	Loss of dried material [g/m^2] after :		
		10 cycles	20 cycles	30 cycles
1	0.40	244	463	478
2	0.42	215	420	533
3	0.45	247	423	492

Table 7 - Freezing and Thawing Resistance (according to Swiss Standard SIA 162/1, 1989)

Mortar No	W/C	Elastic modulus [GPa] after :				
		0 cycle	10 cycles	30 cycles	50 cycles	115 cycles
1	0.40 *	40.56 40.11*	40.21 --	40.43 40.52*	40.44 --	40.59 40.78*
2	0.42*	40.61 38.86*	40.33 --	40.44 39.20*	40.43 --	40.65 39.51*
3	0.45 *	40.09 39.96*	39.72 --	39.65 40.29*	39.88 --	40.01 40.69*

* reference specimen

Table 8 - Adhesive Tensile Strength Mortar/Concrete Type I

Mortar No	W/C	Tensile strength [MPa] after	
		28 days	56 days
1	0.40	0.8	1.2
2	0.42	1.2	1.3
3	0.45	0.7	1.5

Table 9 - Adhesive Tensile Strength Mortar/Concrete Type II

Mason	Tensile strength [MPa]			
	facing South-west		facing North-east	
	28 days	56 days	28 days	56 days
A	1.3	1.4	1.0	1.2
B	1.3	1.3	1.3	1.5

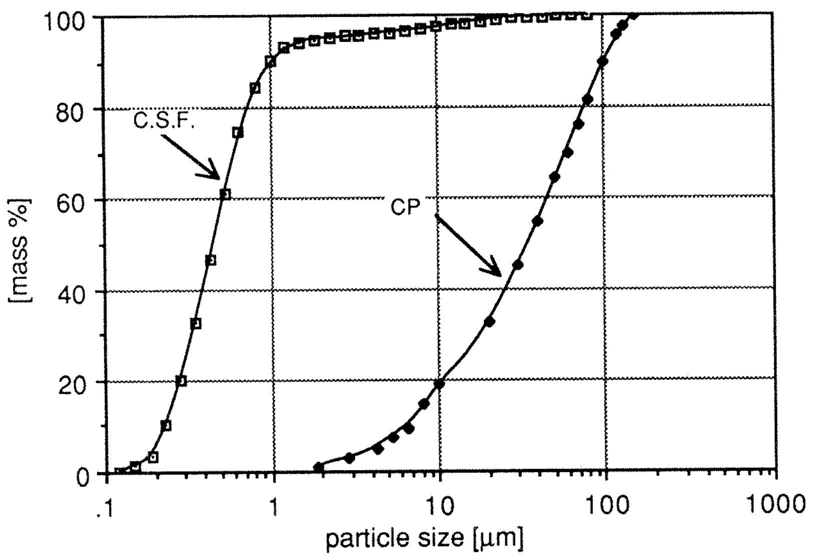

Fig. 1--Particle size distribution for Portland cement and condensed silica fume

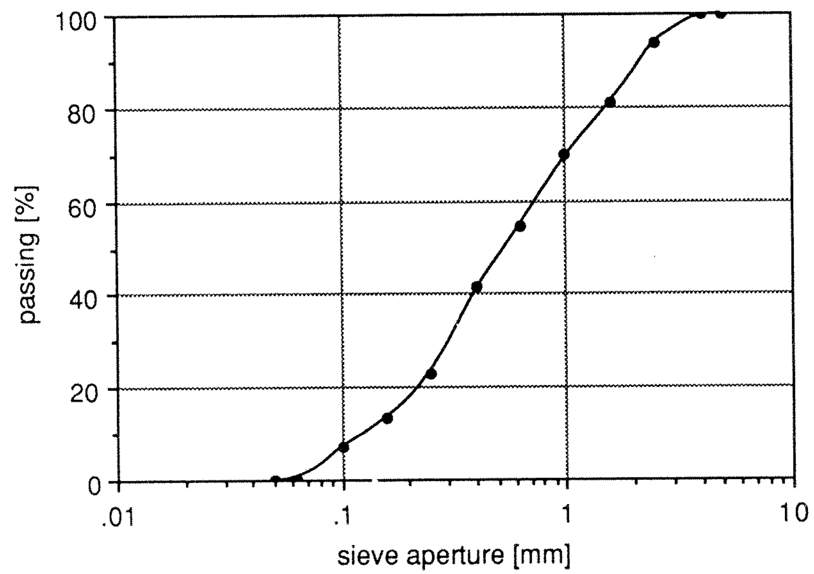

Fig. 2--Grading curve for the sand 0-4 mm

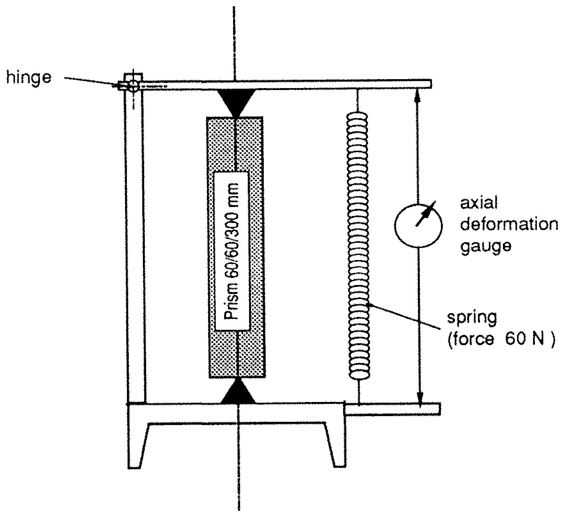

Fig. 3--Experimental set-up used for shrinkage measurements

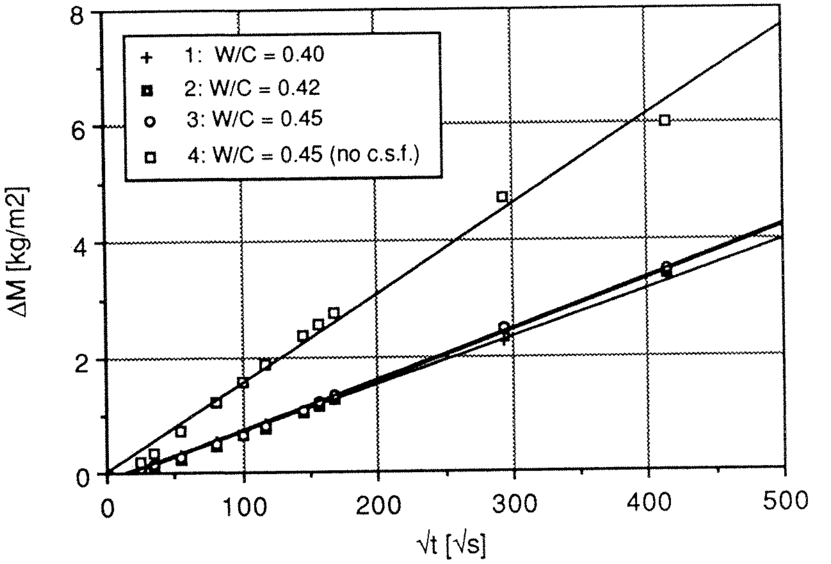

Fig. 4-- Capillary absorption after 28 days of curing of the 3 mortars with condensed silica fume and one without

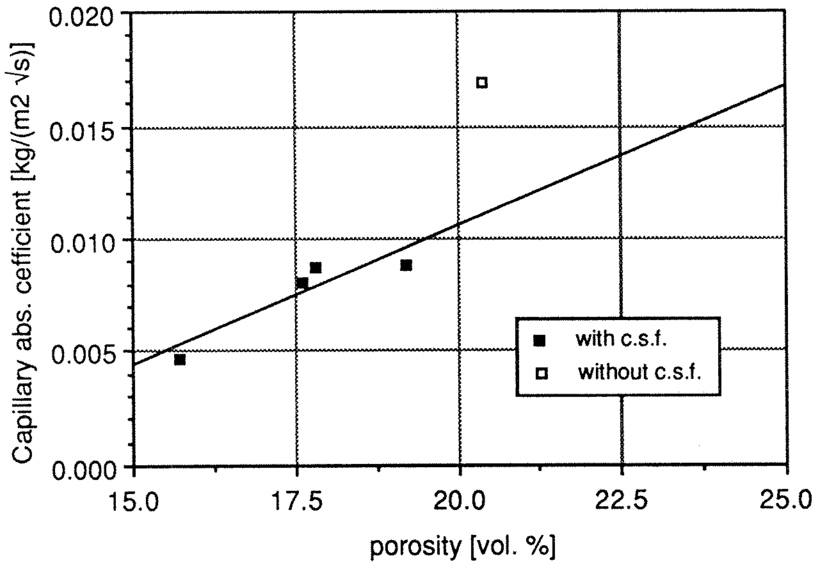

Fig. 5--Relation between total porosity and coefficient of capillary absorption

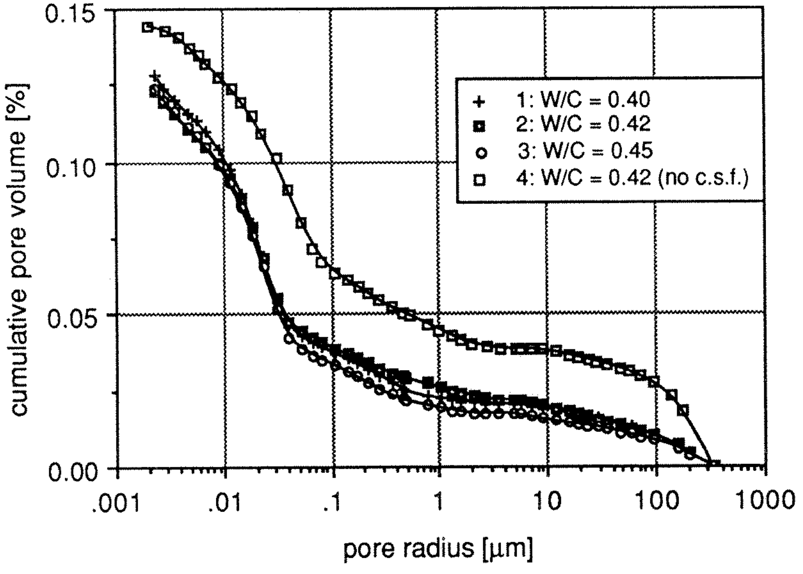

Fig. 6-- Pore size distribution of the different mortars measured by mercury intrusion porosimetry

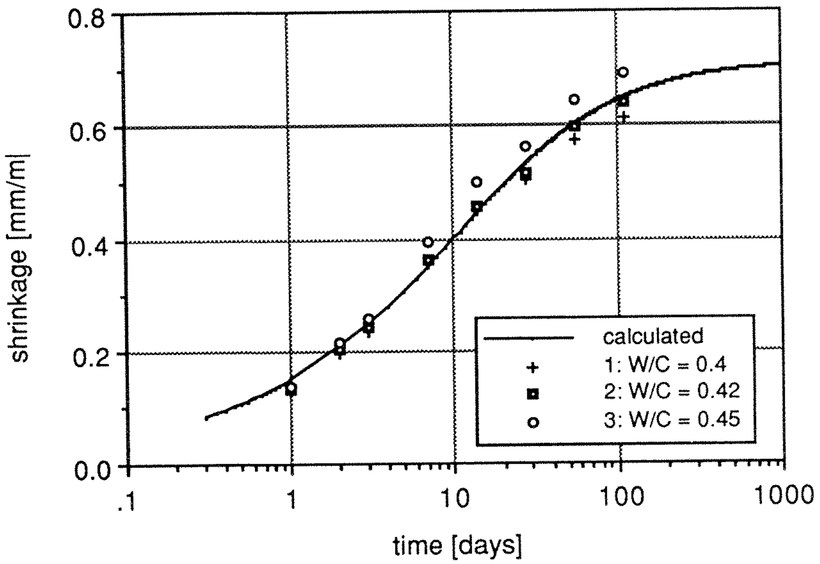

Fig. 7-- Drying shrinkage of the mortars

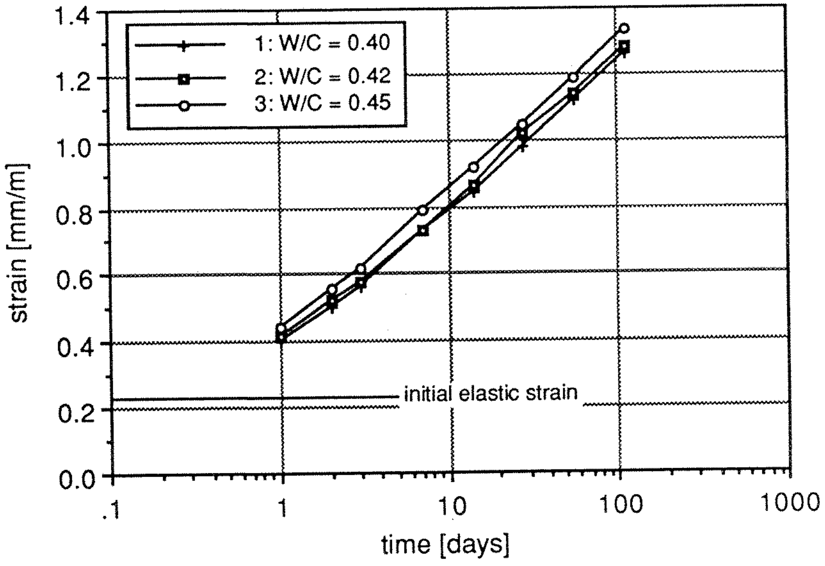

Fig. 8--Total deformations under load

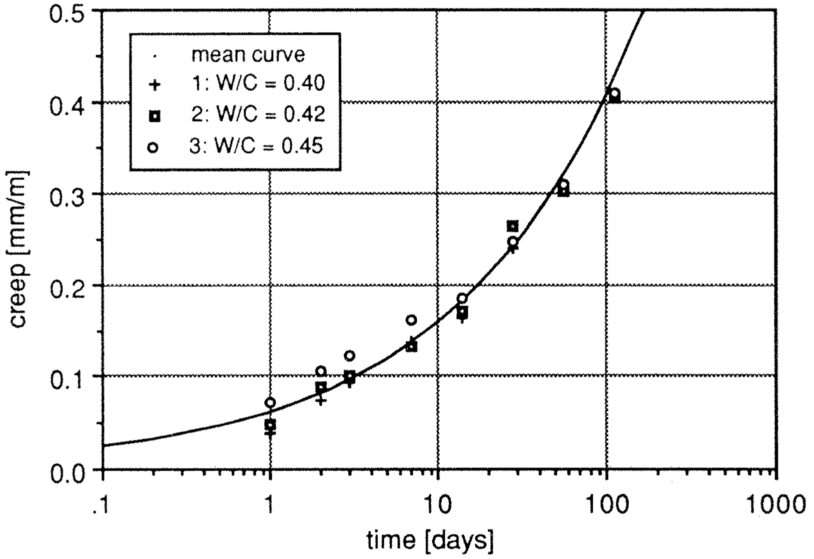

Fig. 9-- Creep of the mortars.
Creep = total strain - initial elastic strain - shrinkage

Study on Liquid Silica based Admixture Suppressing Surface Cracking during Flat Concrete Construction

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Synopsis: In this study, proper amount of liquid silica based admixture, Bentory, is added in mortar and concrete to determine its suppression of plastic cracking on flat surface. The result shows that after adding Bentory, the increase of viscosity of the fresh mortar and concrete can improve flowability, water retention, retardation and low drying shrinkage, and also can prevent the occurrance of plastic cracking on flat concrete surface. Besides, it raises the compressive, split and bonding strength of hardened concrete, and associates with micro-technologies, such as SEM and X-Ray Diffraction Analysis to progess the surfacing analysis, and to proof that high silica based admixture can effectively supress the construction cracking on flat concrete surface.

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Fourth CANMET/ACI International Conference
on
Fly Ash, Silica Fume, Slag
and Natural Pozzolans in Concrete

SUPPLEMENTARY PAPERS

Istanbul, Turkey, 1992

Cover: A view of the gate structure of the
Atatürk Dam on Euphrates river, Turkey.