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NEW ADDITIVES FOR MICROFINE GROUTS WITH LOW WATER : CEMENT RATIOS

NOUVEAUX ADJUVANTS POUR COULIS MICROFINS A FAIBLES RAPPORTS EAU/CIMENT

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SYNOPSIS

The main advantage of the use of grouts with low water-cement ratio is the improved sealing effect against aggressive fluids. In this paper, it is shown how the disadvantages of such suspensions (difficulties in the injection process, groutability) can be avoided using suitable additives.

BACKGROUND

Penetration grouting is commonly used in geotechnical engineering to reduce the permeability of soils and/or to improve their mechanical properties. Since the use of chemical solutions, especially for the hardening of soils, is often combined with the compliance with strict statutory conditions because of problems related to toxicity, the injection of mineral materials like cement becomes more and more important. However, grouting was restricted to coarse soils. Due to the development of microfine cements which have much smaller particles than ordinary cement, it is now possible to penetrate fine grained soils up to fine sand (e.g. ARENZANA et al., 1989, ZEBOVITZ et al., 1989) which till now could only be penetrated with chemical solutions.

One of the main applications for grouting measures was up to now - besides foundation grouting - the horizontal sealing of pervious soil layers in the course of the construction of (from the technical point of view) watertight excavations. In principle, grouted layers - in combination with vertical sealing elements - can also serve as waste containment. This is a problem which gets more and more importance. These new applications, however, imply substantially harder requirements for the grouting materials in question concerning the long-term stability, especially under chemical attack.

Recent investigations (SCHULZE, 1991) have shown that suspension grouts with conventional composition (e.g. W/C or - as common in Germany - W/B (B = binding agent) ≥ 5) can resist the attack of aggressive fluids only for a limited time (see example in Fig. 1).

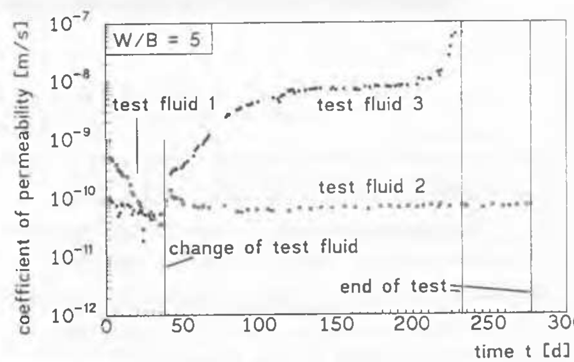
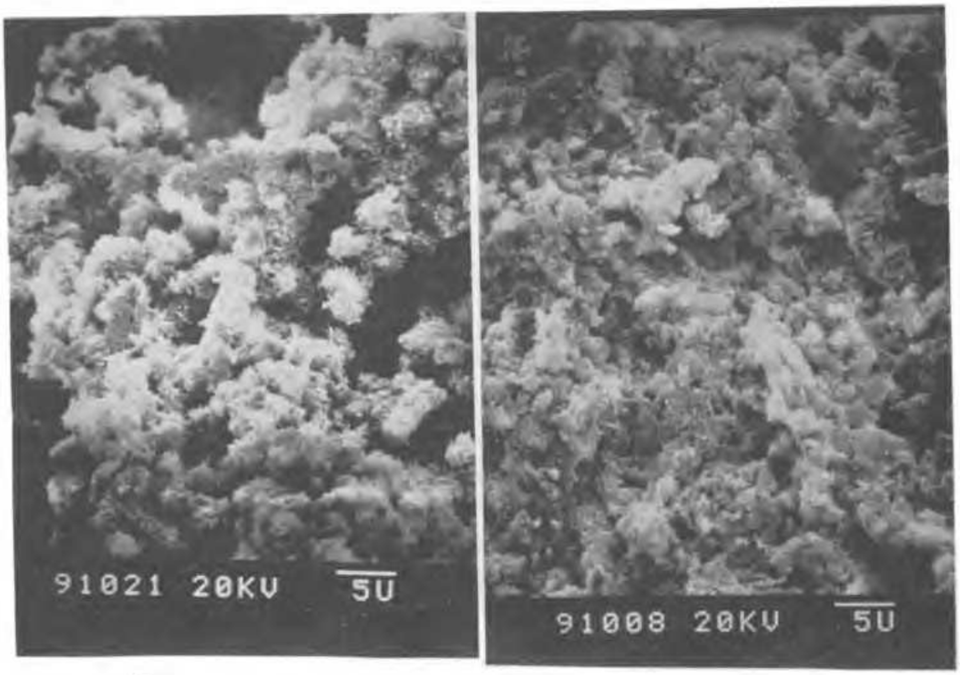


Fig.1: Influence of the test fluid on the development of the coefficient of permeability (SCHULZE, 1991)

The test fluid 1 was ordinary tap water. After a period of about 40 days, the test fluid was changed. One of two specimens with identical composition was charged with demineralised, deaired water (test fluid 2), the other with a 5% $MgCl_2$-solution (test fluid 3). Seeping water which corrodes cement in a manner similar to test fluid 3 can be found in practice (e.g. under waste deposits), so that a reliable and long lasting sealing effect can not be expected if low concentrated cement grouts are used under such conditions.

USE OF SUSPENSIONS WITH LOW WATER: CEMENT RATIOS

The sealing effect, however, is considerable improved, if suspensions with a high concentration of solids (W/B small) are used. Due to a reduction of the porosity (see Fig. 2), an improvement of resistance against chemical attack can also be expected.



W/B = 0.6 W/B = 1.6

Fig.2: Influence of the W/B-ratio on the porosity of hardened cement-suspension (optical micrograph; 5U = 5 µm)

Unfortunately, a reduction of the W/B value implies a remarkable increase of the yield stress and a quick hardening of the suspensions which lead to difficulties in the injection process. The efficient use of grout suspensions with low water: cement ratios in practice, however, is limited by the fact that the grain size distribution of the solids in the suspension - which controls the penetrability of the grout into porous media - is also influenced by the water: cement ratio (TAUSCH/TEICHERT, 1990).

The grain size distribution of the dry solids is much finer than the grain size distribution of the particles in the suspension. A decrease in the water: cement ratio implies a shifting of the grain size distribution curve towards the coarser region(see Fig. 3). This fact has been hardly considered till now.

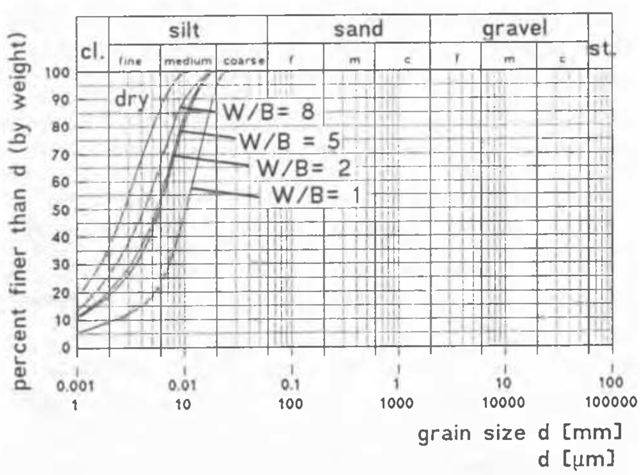


Fig. 3: Influence of the W/B-ratio on the grain-size distribution of microfine cement in suspensions (laser granulometer)

The same effect can be observed if the grain size distribution curves of suspensions are determined at once and at a certain time after the mixing. The reason for this behaviour is on one hand the fact that the addition of water, as a strong polar fluid and as a reaction partner for cement obviously leads to an immediate agglomeration of the cement particles. If microfine cements are used, this phenomenon is intensified by the large specific surface of these materials. On the other hand, Ettringit is formed on the surface of the cement particles due to the hydration processes (see Fig. 2). All this leads to the shifting of the grain size distribution curve towards the coarser region. Therefore, only coarse grained soils can be penetrated with suspensions with low water: cement ratios (W/B $\leq$ 2) so that in such cases the advantages gained by using microfine cements are lost.

USE OF ADDITIVES AS "INJECTION HELPERS (IH[1])"

The tendency towards agglomeration which leads to an "enlargement" of the particles, however, can be considerably reduced by the use of suitable additives. The additive which is used here is absorbed onto the surface of the cement particles and onto the products resulting from the reaction of cement and water with the result that the particles are charged with the same sign and therefore repel each other. The repulsive forces are preserved even if the particles are submerged into with water, reducing the inner friction of the cement gel.

When using dispersant additives, the consequences for the properties of the suspension are:

a) The yield stress τ_0 of the liquid suspension which is important for the handling of the grout during the injection process, can be remarkably reduced.

b) The grain size distribution of the cement in suspension is considerably finer (for the duration of the injection process) compared with suspensions without additives (see Fig. 4).

[1]: Products of the Heidelberger material technology GmbH, group ADDIMENT

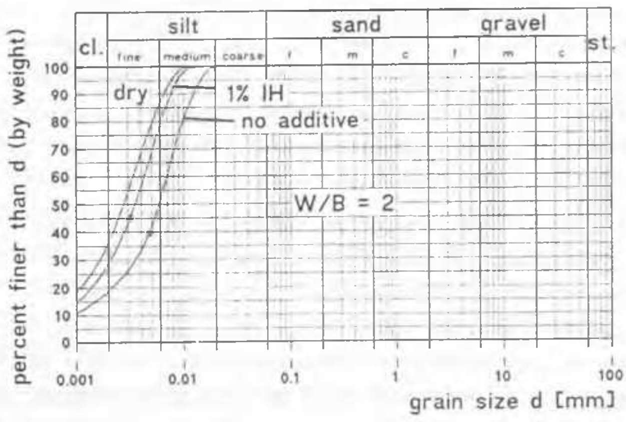


Fig. 4: Influence of the addition of IH on the initial grain size distribution of the microfine cement in suspension

The hardening process of the cement gel is not influenced by the additive.

EXPERIMENTAL INVESTIGATIONS ON THE INFLUENCE OF ADDITIVES

Influence on the properties of the liquid suspension:

The most clear influence of the IH may be expected and can be seen in the rheological properties of the liquid suspension. The most important results are presented in Table 1. The unit weight, the pH-value, the electrical conductivity and the sedimentation process are not influenced by the additive.

Table 1: Important properties of the suspensions (W/B=1)

parameter	no additive	+ 1 % IH (1)	+ 2 % IH
yield stress (2)	45 Pa	36 Pa	14 Pa
Marsh-time	n.m.	900 s/l	61 s/l

(1): additions of ADDIMENT injection helper 1, with reference to the weight of the cement

(2): measured with a rotation-viscosimeter (Haake/Germany)

(3): n.m.: not measurable.

Using W/B-values $\geq$ 2, the influence of the additive on the flow properties is not worth mentioning. Therefore, the use of additives for suspensions with W/B $\geq$ 2 is not required to achieve good flow properties.

Influence on the grain size distribution of the solids in the suspension:

In the present cases (see also Fig. 3) the measurements of the grain size distribution curves were carried out with a laser granulometer CILAS, Type HR 850). It was observed that when using such an apparatus, the procedure used for the preparation of the specimen to be tested (e.g. mixing of the dispersion fluid) greatly influences the results. Hence, the procedure used should be absolutely consistent within a series of tests. It must be pointed out that these measurements were carried out immediately after the mixing process.

In Fig. 4 it can be seen that microfine cement suspension with W/B = 2 and no additive has an average grain size of 4.79 µm and a maximum grain size of 20 µm. A suspension with the same W/B and 1 % IH shows due to the reduced agglomeration an average grain size of 3.13 µm and a maximum grain size of 13 µm. That means that the addition of "injection helpers" can be advantageous even for suspensions with a higher water: cement ration (W/B $\geq$ 2). The influence on the flow properties is very small (look above), but the grain size distribution of the cement in suspension becomes remarkably finer.

The effect of the additive can also be seen in Fig. 5. The photograph on the left shows a cement which was mixed only with water (the agglomerates can be recognized as black spots). In the photograph on the right the same cement was mixed in the same way with water and additive; the agglomerates are clearly smaller.

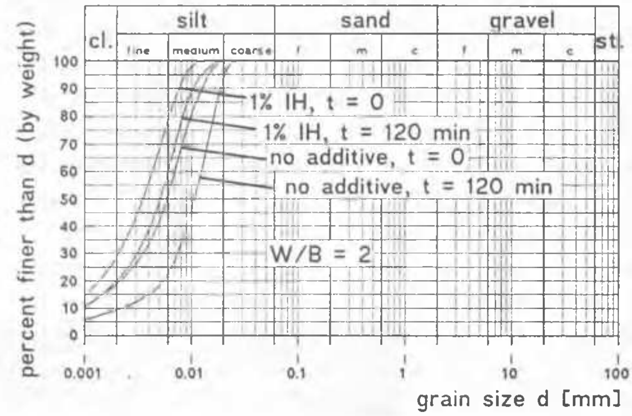


Fig. 6: Influence of the addition of the IH on the grain size distribution of cement in suspension in dependence of time

The importance of these results for the groutability of suspensions in fine grained soils becomes clear when the method for predicting a successful injection (in view of penetration) is taken into consideration. Using a criterion which is well known in the american literature (e.g. ZEBOVITZ et al., 1989) and which has been developed to estimate the filter stability of soils, characteristic grain diameter both of the soil and the grout are com-

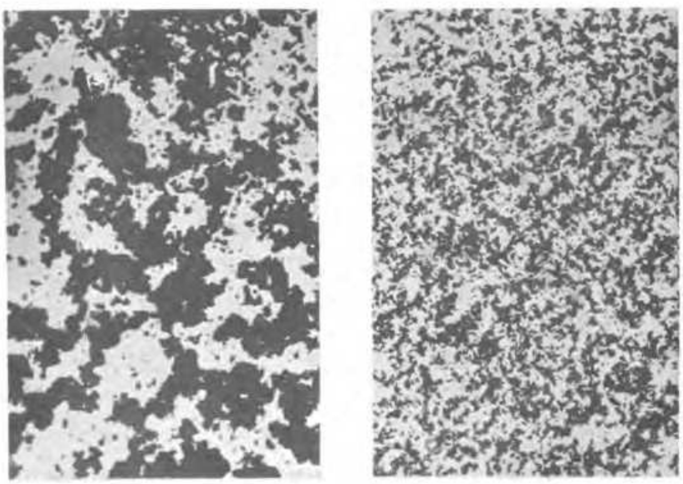


Fig. 5: Influence of additives on the agglomeration (from: RIXOM/MAILVAGANAM, 1986)

It can be seen, however, that the grain size distribution curves of the solids in suspension are shifted towards the coarser region in the course of time even if additives are used. But the grain size distribution curve of a suspension (W/B = 2) with IH even after a time of 120 min is still in a finer region than that of the same suspension without additive immediately after the mixing process, as Fig. 6 shows.

pared with each other, so that the following ratio is obtained:

$$N = \frac{d15_{Soil}}{d85_{Grout}}$$

With $N > 25$, injection (penetration) possible,
with $N \approx 19 - 25$, injection perhaps possible,
with $N < 11$, injection not possible.

It has to be pointed out that this criterion gives reliable results only if **d85 of the suspension** and not d85 of the dry solids is considered. Table 2 shows, how d85 of the suspension changes with time, with and without the addition of the IH.

Table 2: Influence of the addition of IH on the "characteristic" particle diameter d85

W/B = 2	d85 µm
t = 0, no additive	11,0
t = 0, with 1 % IH	6,8
t = 120 min, no additive	17,5
t = 120 min, with 1 % IH	9,0
cement, dry	5,8

RESULTS OF LABORATORY TESTS

From the above results, it follows that the success of the grouting may depend on the addition of suitable "helpers" to suspensions (with identical composition). Table 2 makes it clear that a suspension with suitable additives may penetrate into soils where an injection of the same suspension without additives is impossible.

To verify these statements, numerous laboratory tests (one-dimensional permeation) were carried out. A vertical cylinder was filled with the sand to be injected maintaining the same filling procedure (density index). Then, suspension with different W/B ratios with and without an IH were injected from bottom to top. The tests showed without exception that the injection process is influenced positively by the addition of an IH to the grout. Injections with the same flow velocity lead to considerably smaller pressures, when IH were added to the grout. In some case the penetration was possible only due to the addition of IH; without an additive, the grout could not penetrate into the sand (see Fig. 7).

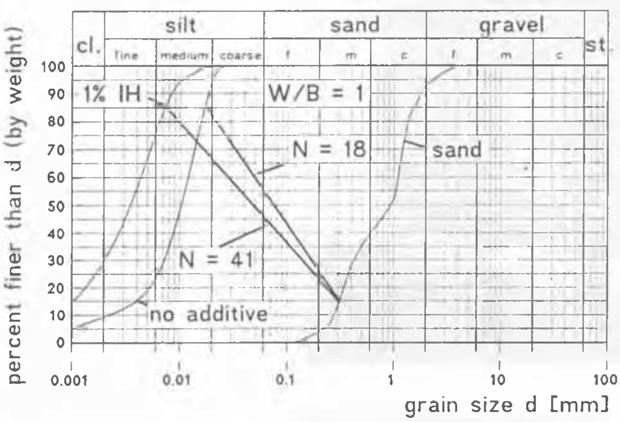


Fig. 7: Influence of the addition of the IH used here on the groutability of suspensions

It is to be noted here that N = 18, using a suspension grout (W/B = 1) without additive and the soil considered. Using the criterion above, a successful injection could be doubted. (This could be confirmed with the permeation tests, the grout didn't penetrate the soil). The grain size distribution of the same suspension **with** additive lead to an N = 41 for the same soil, a penetration could therefore be expected and could be observed in the permeation test.

Results of field tests

The influence of the additives considered on the groutability of high concentration suspensions was also to be checked in the course of an extensive field test. Working under practical site conditions, 20 boreholes were drilled in a testfield with the dimension 6 m x 8 m.From these boreholes the injections were carried out using collar pipes. Because of the subsoil conditions which were met (see Fig. 8) microfine cement suspensions with W/B ratios from 2.0 to 8.0 using different additives were injected.

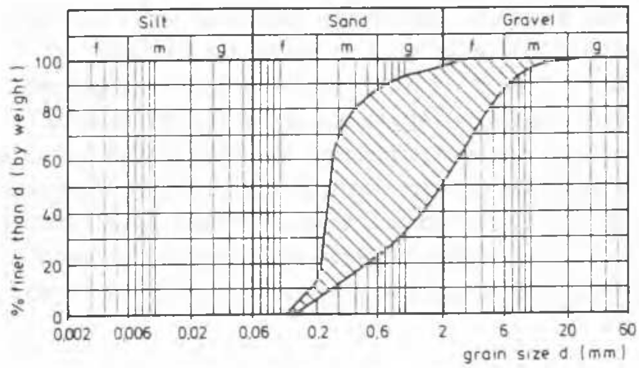


Fig. 8: Range of grain size distribution of the soils in the test field

Although the influence of the inhomogenity of the subsoil conditions at the different injection points has to be considered, the field test showed clearly that the addition of "injection helpers" effects to the grouting process in a positive manner. For example, soils were penetrated using suspensions with W/B = 2 and addition of suitable additives, whereas the injection of comparable soils didn't succeed using suspensions with W/B = 4 and no additives.

INVESTIGATIONS ABOUT THE RESISTANCE OF HIGH CONCENTRATION SUSPENSIONS AGAINST CHEMICAL ATTACK

The background for the demand of high concentrated suspension grouts was the failure of suspensions with conventional composition ($W/B \geq 5$) under the attack of cement corroding fluids. The presumption that the reduced porosity (see Fig. 2) and the resulting reduced permeability lead to an increase in the resistance against chemical attack, however, has yet to be confirmed experimentally.

The question of the resistance of suspension grout contains different aspects:

* Low permeability because of the amount of water seeping through
* Permanent strength because of the danger of erosion
* quality of permeating water because of contamination

An extensive program for a series of tests was started to investigate the long-term behaviour of high concentration suspensions (W/B = 1 and W/B 2) with the considered additive under chemical attack. For this purpose, the different specimens were placed in a special permeation apparatus (glass cylinder, Fig. 9) and charged with different kinds of test fluids (demineralized, deaired water, 5 % $MgCl_2$-solution and two acid mixtures which should represent seeping water from a waste deposit). The permeation tests were carried out with falling hydraulic gradient ($i_{max} = 30$). The cylinders were re-filled with the respective test fluid regularly. The water which permeates the specimen (h = 2.5 cm, d = 4 cm) is stored in bottles and is analyzed chemically. At the end of the test (a duration of at least one year is planned) investigations of both the strength and the mineralogical composition of the specimen will be carried out. Especially these investigations give clear information about the attack of the test fluids and the chemical processes caused by the fluids.

At the moment the tests are not yet finished. The preliminary results show that the specimens resist the chemical attack even after a time of eight months. (Under the same kind of chemical attack, the low concentration suspensions failed already after a few days, see Fig. 1). The coefficients of permeability lie in the range of 10^{-11} m/s for the suspensions with W/B = 1 (see Fig. 10), independent of the test fluid. A reliable statement about the resistance of suspensions with low water: cement ratios, however, can be made after the tests are completed.

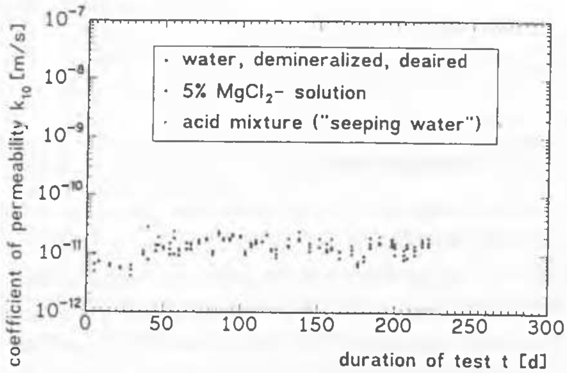


Fig. 10: Permeability tests with aggressive fluids (preliminary results)

SUMMARY

The grouting of cement suspensions in a corrosive environment requires the use of suspensions with low water: cement ratios. Preliminary results show that these suspensions seem to resist the chemical attack. The considerable disadvantages of the high concentration of such suspensions which make the efficient use of such suspensions in practice impossible, however, can be avoided

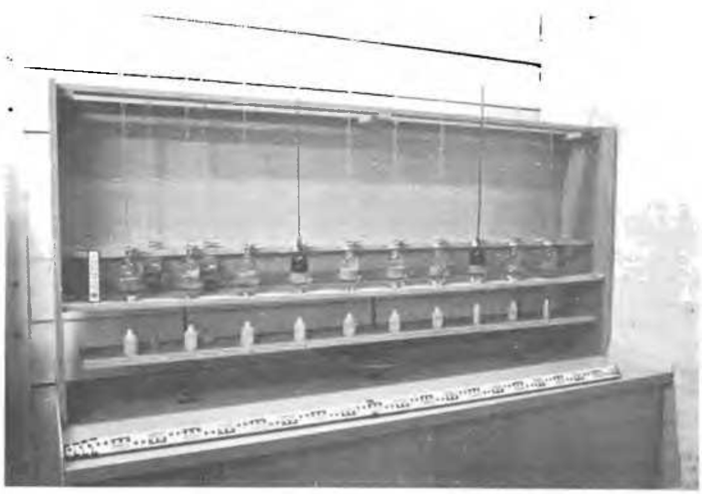


Fig. 9: Experimental setup for the long-term permeability test

using suitable additives. Using the additives which are introduced in this contribution a remarkable reduction of the inner friction of the cement gel thus reducing the yield stress and of the agglomeration if water is added (causing only a little shifting of the grain size distribution of the solids towards the coarser region) can be achieved.

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