Filtration stability of cement grouts for injection of concrete structures

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Filtration Stability of Cement Grouts for Injection of Concrete Structures

Stabilité au filtrage du mortier de ciment en vue de son injection dans les constructions en béton

Filtrierstabilität von Zementmörtel für die Injektion von Betonkonstruktionen

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SUMMARY

The most important property of a cement grout for injection, in terms of penetrability, is the filtration stability. A newly developed test method for measuring the filtration stability of cement grouts is presented. Results from the method, and related methods, are compared to different grouting situations simulated in the laboratory. The results show that it is possible to predict the penetrability of a grout by using this test method.

RÉSUMÉ

La propriété la plus importante d'un mortier de ciment pour injection, en termes de pénétrabilité, est la stabilité au filtrage. Une méthode d'essai développée récemment pour mesurer la stabilité au filtrage est présentée. Les résultats de cette méthode et de méthodes similaires sont comparés à différentes conditions d'injection simulées en laboratoire. Les résultats démontrent qu'il est possible de prévoir la faculté de pénétration d'un mortier pour injection à partir de cette méthode.

ZUSAMMENFASSUNG

Die wichtigste Eigenschaft eines Einpressmörtels ist, hinsichtlich der Erzielung einer guten Eindringfähigkeit, die Filtrierstabilität. Ein neuentwickeltes Prüfverfahren für das Messen der Filtrierstabilität von Zementmörtel wird präsentiert. Die Resultate dieses und ähnlicher Verfahren werden mit verschiedenen im Labor simulierten einpressähnlichen Situationen verglichen. Die Ergebnisse zeigen, dass die Eindringfähigkeit eines Einpress-mörtels mit Hilfe des präsentierten Prüfverfahrens vorausgesagt werden kann.

1. INTRODUCTION

To obtain a durable and high strength grouting of concrete subjected to cracking and leaching, it is necessary for the grout to be stable in terms of bleeding and sedimentation. Furthermore the w/c-ratio should be kept as low as possible to avoid a porous cement paste. Extensive laboratory tests on stable, low w/c-ratio, injection grouts shows that the most significant limitation to their penetrability is the tendency of cement grains to agglomerate into an impermeable filter cake. Grout refusal can also occur due to inappropriate rheology of the grout. Restrictions in penetrability due to the latter can in most cases be eliminated using superplasticizer. The ability of a grout to pass constrictions of the flow path without clogging can be designated filtration stability.

Development of a filter cake can occur at a ratio of channel width to maximum particle diameter (D_c/d_p) of as much as ten. If the grout is insufficiently dispersed, agglomerates or flocs of cement grains can certainly clog the channel due to excessive diameter of the agglomerate. However, even if the cement grains initially are dispersed, they can agglomerate if the grout is exposed to filtration situations such as entrances to cracks, fine cracks or porous material.

The filtration stability of a grout is generally improved by the following actions: increasing w/c-ratio, adding superplasticizer (SP), ensuring adequate dispersion and using a finer ground cement. Corresponding impairment is caused e.g. by: adding accelerating agent or by adding stabilizing agent. Exceptions to these rules of thumb occur.

The models available for assessing the risk of filtration are the D_{15}/d_{85} - ratio for soil injection and the groutability ratio (D_c/d_p) for crack injection. These models may be valid using thin grouts without additives but when dealing with stable grouts with additives they have proven to be inadequate. There is some relation between maximum grain size and penetrability but the exceptions are too common to rely on maximum particle size as a classification parameter for injection grouts. Since it is uncertain how much parameters such as chemistry and particle size distribution influence the filtration stability, it is convenient to determine it by measuring on the ready mixed grout.

2. MEASURING FILTRATION STABILITY

A new test method for evaluation of filtration stability has been developed with the aim that it would be suited both for laboratory work and site measurements. An outline of the equipment is shown in fig. 1. The grout is drawn into the device after which it is pressed out into a measuring vessel. The amount that has passed the filter is measured and registered as a qualitative measure of filtration stability. The filter consists of a woven metal wire cloth with a mesh width of 32, 45, 75, 100 or 125 μm depending on the expected performance of the grout to be tested.

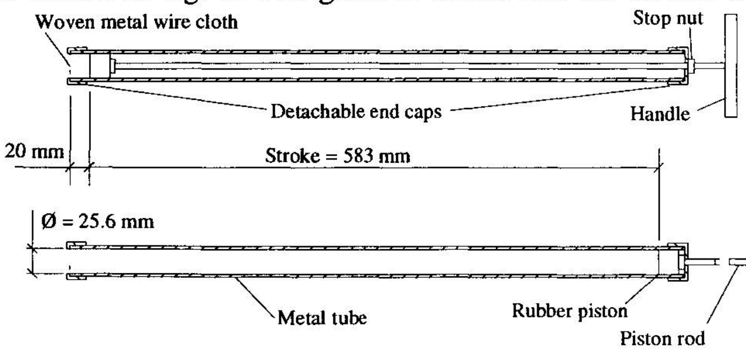

Fig. 1 Filtration device.

The filtration device works according to the cake filtration principle that is the filtration mechanism in effect e.g. at entrances to cracks. Other filtration mechanisms such as deep bed filtration and physiochemical surface attraction applies to some of the laboratory situations presented in this paper.

Since cake filtration is the most basic principle it would be convenient if it was possible to correlate the different filtration mechanisms. Consequently it would be possible to reliably predict the penetrability of a grout by means of the simple filtration device test. The filtration device is considerably easier to handle and keep clean than for instance a sand column equipment.

3. LABORATORY TESTS

The scope of the laboratory tests presented in this paper is to find out whether the penetrability of a grout can be predicted with the filtration device. The tests are preliminary in the manner that the test methods may be improved during the continuance of the project.

All the filtration tests are carried out as single tests. On basis of repeated tests on different grouts, the repeatability of the filtration device test is estimated to be better than ± 10 % by a satisfactory margin.

Since the results from a filtration test is a qualitative measure for filtration stability, the two terms are used interchangeably.

3.1. Concrete crack grouting.

In order to evaluate the influence of filtration stability on the result of grouting crack in concrete studies a number of pilot tests have been carried out. A concrete crack was prepared by splitting a concrete specimen of the size 70 × 70 × 50 cm and drilling a centric grout hole. An outline of the specimen is shown in fig. 2. Before grouting the two halves was wetted and placed in a frame and forced together with a force three times the lifting force induced by the grouting pressure of 50 kPa. Immediately before grouting, the hydraulic crack width was assessed by water loss measurement and calculation assuming laminar flow.

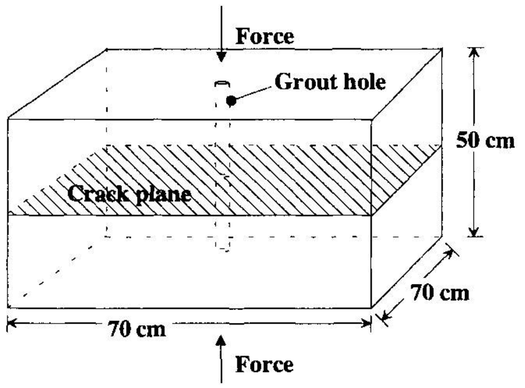

Fig.2 Concrete crack grouting specimen.

All the grouts were based on ultrafine Portland cement with d_{95} = 16 µm. The specific area of this cement determined by the BET-method is 1450 m²/kg. The SP was of an ordinary melamine type. All the grout mixes were designed to have as close to Newtonian rheological properties as possible in order to study the filtration effect separately.

Filtration device measurements (V_f) were compared to the time elapsed between start of grouting and grout refusal (grouting time, t_g) normalized to the hydraulic crack width (d_h). The normalization is made to compensate for the random variation in crack width that occurred due to the test equipment. The exponent on d_h is obtained by best fit calculations maximizing the correlation coefficient (r). Furthermore, V_f was compared to results from a modified filtration device with a sharp crack entrance as filtration site instead of a wire mesh. The amount of grout that passed the sharp entrance is denoted V_e. The test results are shown in table 1. The relation between filtration stability and normalized grouting time is shown in fig. 3.

ID no	1	2	3	4	5
w/c-ratio	0.6	0.7	0.8	0.9	1
SP [%C]	4	4	4	4	4
t_g [s]	990	990	1500	2220	6000
d_h [mm]	0.32	0.25	0.28	0.29	0.35
V_f [ml]	2	50	95	150	170
$t_g / d_h^{3.65} \times 10^{-5}$	0.64	1.57	1.57	2.05	2.78
V_e [ml]	17.3	25.3	29.9	35.0	78.0

Table 1 Results from concrete crack grouting.

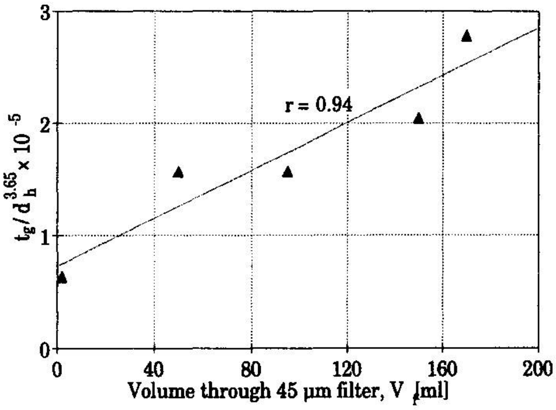

Fig. 3 Normalized grouting time vs. filtration stability.

Bearing in mind that the analysis is based on few tests, a clear tendency of correlation between filtration device measurements and grout take can be seen. It also seems likely that the crack width affects the result more than to the power of one since the best fit calculation resulted in an exponent of 3.65.

Fig. 4 shows the two different filtration devices compared to each other. The relationship in fig. 4 should be linear and some uncertainties in determining the V_e value of test no 5 brings that a linear relationship is possible. The filtration stability measured with the filtration device has proven to be strongly dependant on the w/c-ratio, fig. 5 shows this relationship.

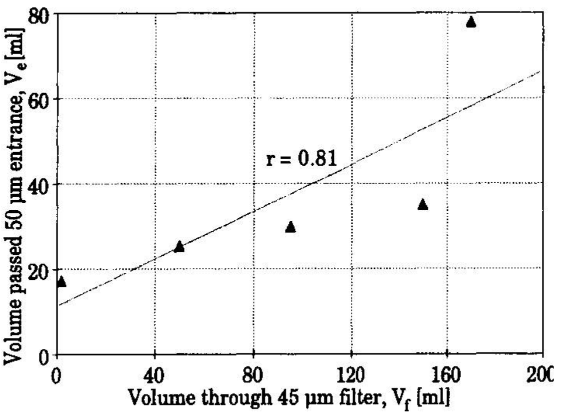

Fig. 4 Comparison between filtration devices.

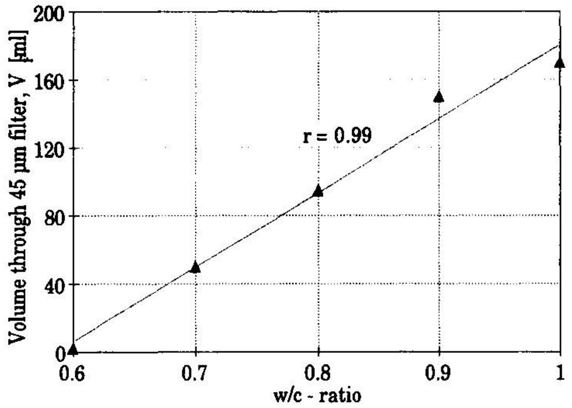

Fig. 5 Relationship between V_e and w/c-ratio

3.2. Sand column test

During the prequalification for a large tunnel project all the grout mixes were tested in laboratory [1]. Fig 6 shows the relationship between filtration stability and penetration of a sand column. The filtration stability is measured by a filtration device with a wire mesh sieve with a diameter of 90 mm and a sieve width of 125 µm. The filter is fed by a pressure tank with an air pressure of 50 kPa. The sand column test was carried out according to a pending CEN standard. The sand had an even particle size distribution between 0.63 and 1.25 mm. The feed pressure was 75 kPa.

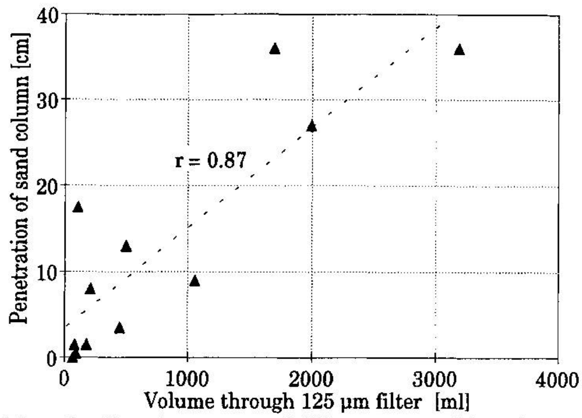

Fig. 6 Sand penetrability vs. filtration stability

Considering that the tests were made on grouts based on nine different types of cement, different additives and dosages and with different rheological properties, there is a tolerable correlation. Accordingly there is a tendency that sand injection results can be predicted by a filtration test.

3.3. Grouting of a smooth crack

An artificial smooth crack was made out of a ground steel plate with a glass plate tightly fastened on top. A constant aperture of 0.2 mm was accomplished by shims between the plates. The width of the channel was 50 mm and the length 1 m. The entrance to the aperture was rounded at a radius of 10 mm. The filtration device was the same as in previous section with the exception of the sieve that was a Fujiplate sintered filter with a sieve width of 150 µm. Both equipments were fed by a pressure tank with an air pressure of 50 kPa. The grouts were based on a Portland cement with d_{95} = 40 µm and a Blaine value of 600 m²/kg. The compositions of the grouts and the test results are shown in table 2 where volume through crack and volume through filter are designated V_{ac} and V_{f150} respectively.

w/c-ratio	SP [%C]	V_{f150} [ml]	V_{ac} [ml]
0.5	5	690	350
0.6	3	640	0
0.6	5	1180	650
0.7	1	430	1
0.7	3	570	120
0.7	5	1950	1400

Table 2 Test matrix and results from grouting of smooth crack.

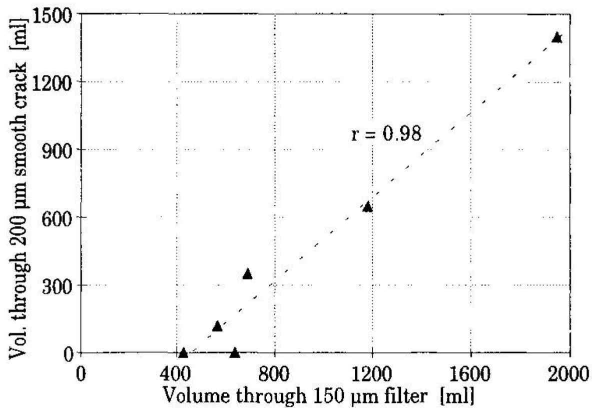

Fig. 7 Volume passed smooth crack vs. filtration stability

All the grout mixes were designed to have nearly Newtonian rheological properties. Fig 7 shows a comparison between volume of grout that passed the entire artificial crack and volume of grout through the filter.

3.4. Example of use - Dispersion time optimum

In order to establish an optimal dispersion effort using an Ultra-Turrax T25 dispersion tool, a series of laboratory tests was carried out. During the tests the dispersion time was varied in 15 seconds increments except an extreme value and the reference tests with superplasticizer (SP). The test sequence is described in [2].

The relation between dispersion time and amount passed the sieve of a 45 μm filtration device, that is a qualitative measure of filtration stability, is shown in fig. 8.

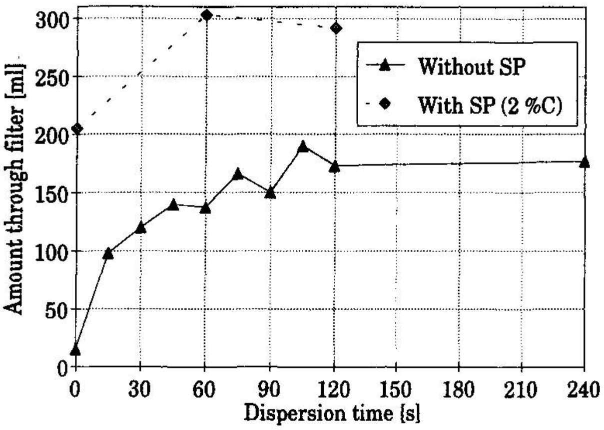

Fig. 8 Dispersion time versus filtration stability.

The effect of dispersion is clearly seen in fig. 8, as is the effect of the SP. However, the filtration stability does not increase much further after 90 s of dispersion why there is little reason to extend the dispersion time beyond that point.

This particular test is carried out in a small scale. However, the test procedure can very well be applied on production scale mixers.

4. CONCLUSIONS

The test results show that a relation between filtration test results and penetrability of cement grouts exists provided that the rheological properties of the grout is closely Newtonian. This regardless of the filtration mechanism that applies to the specific grouting situation. Furthermore there is a strong relationship between w/c-ratio and filtration stability.

Filtration tests can be used to evaluate the effectiveness of mixing as well as for assessing the performance of grout designs.

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