BACKFILLING GROUT INCLUDING A MAJOR PART OF FINE SEDIMENTS

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ABSTRACT

This study aims to design backfilling grout, including fine sediments from a harbor in the North of France. Backfilling grout requires high water proportion for manufacture, physical stability along the setting and low mechanical performances at hardened state. These criteria are in line with the use of marine sediments, which keep high water contents after dredging.

The fine sediments of the study, classified as low plastic silt, include a major part of silt with low percentages of fine sand and clay. The behavior at fresh and hardened states has been studied on mixes including various percentages of fine sediments (50%, 70% and 85%) and seawater-setting cement. A superplasticizer is also tested to reduce the bleeding and to promote the gain of resistance.

The fresh study includes the measurements of plastic viscosity, yield stress, thixotropic index, and spreading level. The setting time is followed by the Vicat test. The mechanical behaviors of the mixes are evaluated by flexural and compressive tests at several maturities (3, 7, 28 and 90 days) on specimens cured in wet conditions. Additional tests were done on samples stored in the ambient air. Shrinkage measurements complement the study.

The results show that the presence of the superplasticizer in the mix design improves the behavior of grouts. On the rheological part, the mixes follow the Herschel-Buckley model. At 28 days, the mix, including 70% of fine sediments, 30% of sea-water setting cement (CEM III/C 32.5 N) and superplasticizer, has a flexural strength of 1.5 MPa and a compressive strength of 4 MPa. This level of resistance is acceptable for backfilling grout.

Keywords: Sediment Grout, Cement, Flow, Rheology, Mechanical Tests

INTRODUCTION

Cement grout is well-known in several applications of civil engineering such as soil reinforcement, filling of underground cavities, soil strengthening or concrete repair. Requested mechanical strengths of this type of materials are variable according to the application. Compressive strength can be low (1-2 MPa) for filling grout in opposition to those of concrete repair (around 100 MPa) [1]. The rheological behavior of grout has to be controlled to allow a satisfying filling or injection. The consistency in fresh state can be evaluated by flow measurements (Marsh cone, slump test) and rheological tests with viscometer. Rheological tests give fundamental parameters (plastic viscosity, yield stress, thixotropic index). Cement grouts are considered as non-Newtonian fluids. Several models are used to represent the behaviors of grouts: Bingham, modified Bingham, Hershel-Bulkley, De Kee or Casson models per example [2]. The model is chosen according to the appearance of the curve $\tau = f(\dot{\gamma})$, fitting from rheological tests results.

Traditionally compounded of a hydraulic binder or a mix of hydraulic binders (cement, lime, fly ash) and water, others materials can generally complete the composition of a grout such as sand, fillers or admixtures.

Mineral wastes or industrial by-products can be also considered to complete the composition of grouts [1], [3], [4]. This approach preserves the non-renewable resources in reducing their consumption. At the same time, the development of re-use ways for materials, which induce problems of storage or/and environmental impact, represents a sustainable initiative. In this framework, marine sediments, classified in the European Waste Catalogue (EWC 2000/532/EC), is a granular source studied for several years in various applications such as road materials [5]-[7], paving blocks [8], cemented mortars [9], cement production [10] or grouts for the filling-up of sewerages and the backfilling of trenches [11]. In this last study, with a cement proportion of 10%, the authors have obtained an optimal mix having satisfying fluidity and stability with a low static bleeding, as well as low mechanical strengths (fc_{28} = 0.28 MPa). These results are sufficient for a low-strength filling grout.

In this paper, the authors aim to study the fresh and hardened behaviors of cement-sediment grouts with higher cement proportion, with and without superplasticizer for filling application.

MATERIALS AND PROCEDURES

Description of materials

The studied marine sediments come from Dunkirk Port in France. After dredging, marine sediments exhibit high liquidity, a black color and an undesirable smell. In Dunkirk, a part of sediments is stored in large basins to allow a decrease in water contents, by decanting then by mechanical turning of matter. After sampling on site, the sediments have been dried at 105°C in laboratory then milled to obtain fine and homogeneous powder. The physical characteristics of sediments are shown in table 1. On the environmental plan, chemical tests have shown that the sediments of the study are not polluted even if they contain high proportions of chlorides and nitrates, induced by their origin.

Table1. Characteristics of sediments

Physical characteristics	Mean values
Initial water content (%)	25.47
Dry density (kg/m^3)	2440
Loss on ignition (%) at 550°C	12.80
Methylen value (g/100g of dry sediments)	2.90
Plastic limit (%)	16
Liquid limit (%)	30
Plastic index (%)	14
D50 (µm)	23
D10 (µm)	2
D90 (µm)	161
GTR classification	A2

The cement used is denominated CEM III/C 32.5 N LH CE PM-ES NF. This cement is resistant to aggressive environments (sea water or/and sulphate presence). The cement contains mainly granulated blast furnace slag (81-95%), clinker (5-19%), and secondary components (0-5%).

A second cement has been chosen in this study, known as CEM I 52.5 R CE CP2 NF. This cement is generally chosen to obtain a high level of resistance and rapid setting for concrete. The cement contains mainly clinker (95-100%) and secondary components (0-5%).

Finally, the superplasticizer (SP) used in some formulations is a modified polycarboxylate. It can be found in liquid form and contains 30.3% of dry extract.

Mixing procedure

The mixing is done with a planetary mixer, having a capacity of 20 liters. The procedure used for the preparation of sediment-cement mixes follows this sequence:

- Dry matters are placed in the bowl. A hand mixing is done to homogenize the dry mix.
- The mixer is started and water is introduced immediately to avoid loss of dry matter. The duration of water introduction is 30 seconds.
- The mixing continues for 60 seconds then the mixer is stopped. The bottom of the bowl and the inner sides of the bowl are scraped.
- The mixer is restarted for a last mixing phase for 90 seconds to obtain a homogeneous grout.

The whole mixing sequence is done at a speed of 140 rpm.

For formulation containing SP, the admixture is added in the water previous the incorporation in the mixing bowl. The percentage of SP is fixed to 1.3% of dry extract according to the total dry mass. Water in SP is deduced of the total water quantity to introduce in the bowl.

Tests protocols

Rheological parameters are measured with the Haake viscotester VT550 equipped with a FL10 vane rotor. Tests were performed with three different strain rates (10, 50, 100 1/s) for each formulation. The tests are done from the same mixing but for each test on the same mix, the grout in the beaker is replaced. A plastic beaker with a volume of 1 liter is used to do tests and it is fully filled. As the edge effects can have large influence on measurements, comparative tests have been done with a beaker of 5 liters. Results have given similar values. To avoid a large consumption of materials, the beaker of 1 liter is kept.

Flow behavior is studied by measures of Marsh flow time and spread diameter according to the standard NF EN 445 [12]. The flow time, measured by Marsh cone with a nozzle diameter of 8 mm, has to be less than 15s [1]. The spread diameter, measured by the mini-slump cone, is fixed at 120 mm ± 20mm for a satisfying fluidity.

For a stable grout, the static bleeding, measured according to the standard NF EN 445 [12], has to be inferior to 2% after 2 and 24 hours [11].

The setting time is measured by Vicat test according to the standard EN 196-3 [13].

No targeted values are fixed for mechanical performances, considering the chosen application field. Flexural and compressive tests have been done at several maturities (3, 7, 28 and 90 days) on specimens cured in wet conditions. Mechanical tests are done with an electromechanical testing machine which has a force capacity of 50 kN. The tests speed is 1.27 mm/min for flexural and compressive tests.

Shrinkage has been measured, according to the standard NF P 15-433 [14], on samples of each formulation, cured in wet conditions and in ambient air (20°C, 50% HR).

RESULTS

Studied mixes and their fresh properties

Three percentages of sediments according to dry mass have been targeted: 50%, 70% and 85%. The complement of dry matter is cement.

A preliminary study has been done to determine the water / dry matter ratio (W/DM) to satisfy the fixed criteria of flow. Besides, specimens have been manufactured for mechanical tests. This preliminary study has shown that the unmolding of the specimens for mixes with 85% was complicated induced by an absence of significant setting even three days after manufacture. Setting time by Vicat test has been false. The setting was due to the drying of the top side of the sample. By consequence, the main experimental campaign has not been done on mixes with 85% of sediments.

The experimental campaign has been done on the mixes shown in Table 1. Their fresh properties are also shown in this table.

Cement type A is CEM III/C 32.5 N LH CE PM-ES NF and cement type B is CEM I 52.5 R CE CP2 NF.

F0 is a reference mix without sediments to know the variation of properties in incorporating sediments. F1, F1' and F2 are mixes with 70% of sediments. F3, F3' and F4 are mixes with 50% of sediments. F1, F1' and F5 have an identical sediment proportion. But F5 is compounded of the cement type B. F2 and F4 contain superplasticizer.

All the W/DM ratios have been fixed to respect the targeted spread diameter (120 mm ± 20 mm). The Marsh flow time is respected for all the cement/sediments grouts without SP. For F0, all the criteria are not respected. To decrease the flow time, a little increasing of W/DM can be done. However, for this W/DM, this grout is not stable with a static bleeding largely superior to 2% at 2 hrs and 24 hrs. F1, F1' and F3 respect the criteria. F3' is not stable with a high static bleeding whereas the value of W/DM is lower than the W/DM of F3. With superplasticizer, the flow time is very high which induces a non-validation of F2 and F4. Finally, F5 respect the flow and stability criteria.

With regards to setting time, the values indicate a longer time with the higher proportion of sediments. Large differences can be observed between F1 and F1' that could be linked to a high sensitivity to the water content. The superplasticizer presence induces a decreasing of setting time if the comparison is done between F1 and F2 then between F3 and F4. For F3 and F3' the setting time is relatively similar despite the difference of W/DM. The setting time of F5 is low in comparison to F1 or F1'. The capacity of rapid setting of CEM I 52.5 R is verified for this type of mixes.

Rheological tests

The results of rheological tests are shown in Fig. 1. On the left, the evolution of maximum shear stress according to strain rate is fitted. On the right, the evolution of shear stress at the equilibrium is fitted. The comparison with rheological models is done from the right graphic. The appearances of all the curves show that the studied grouts follow the Hershel-Bulkley model. The Herschel–Bulkley fluid is a generalized model of a non-Newtonian fluid, in which the strain experienced by the fluid is related to the stress in a non-linear way.

Table1. Description of mixes and fresh properties

Mix	Cement type	Dry matter		W/ DM ratio	SP	Measured spread diameter (mm)	Marsh flow time (s)	Static bleeding (%)		Setting time (min)
		Cement proportion (%)	Sediment proportion (%)					2 hrs	24 hrs	
F0	A	100	0	0.55	NO	117	19.2	8	5	760
F1	A	30	70	0.75	NO	119	13.5	2.2	0	1830
F1'	A	30	70	0.7	NO	108	15	1.5	0	1095
F2	A	30	70	0.5	YES	137	41.3	7.4	3.2	1590
F3	A	50	50	0.7	NO	140	11.8	2.1	0.7	1215
F3'	A	50	50	0.65	NO	119	13.2	3.4	2.5	1245
F4	A	50	50	0.4	YES	140	64.1	/	1.6	820
F5	B	30	70	0.73	NO	126	14.2	1.95	0	910

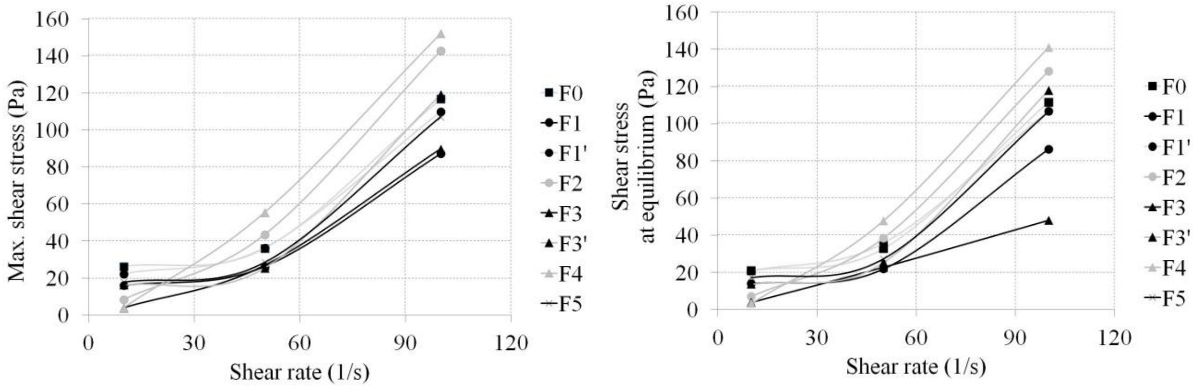


Fig. 1 Rheological tests.

The equation of the Herschel-Bulkley model is commonly written as:

$$\tau = \tau_0 + K.\dot{\gamma}^n \qquad (1)$$

With τ: Shear stress (Pa)

τ_0: Yield stress (Pa)

K: Consistency (Pa.s^n)

n: Flow behavior index

The analyses of rheological results give the values of the model parameters detailed in Eq. 1. These values are shown in Table 2. In the last column, the correlation coefficient is done to verify the compatibility of the model with the experimental results.

Table 2. Parameters of Herschel-Bulkley model

Mix	τ_0 (Pa)	K	n	R^2
F0	20	0.0071	2.004	0.98
F1	13	0.0096	1.866	0.96
F1'	20	0.0095	1.9474	0.99
F2	0	0.3799	1.2326	0.98
F3	0	0.2984	1.104	1
F3'	13	0.003	2.2174	0.98
F4	0	0.0743	1.6435	1
F5	17	0.0008	2.4593	0.98

All the correlation coefficients are close to 1, which indicate the compatibility of the model with the behavior of the studied cement/sediment grouts. The yield stress is fixed from the experimental curves. Knowing τ_0, a graphic is done and a trend curve is fitted according to a power law so as to have the Hershel-Bulkley parameters. With τ_0 = 0 and n close to 1, as for F2 and F3, the behavior tends to Bingham model. For the others mixes, n is around of 2 and K is superior to 0, which should indicate a shear-thickening behavior.

The determination of Hershel-Bulkley parameters is sensitive to the value of τ_0. For example, if τ_0 is considered equal to 2 Pa for F3, the values of K and n become respectively equal to 0.0684 and 1.43, with a correlation coefficient of 0.996. Complementary studies should be necessary to confirm the values even if the choice of the model seems adapted.

Mechanical tests

The results of flexural and compressive tests are shown in Fig. 2 and Fig. 3. The results show a large decrease in grout resistance with the addition of sediments in comparison to F0.

The resistance of specimens, stored in water, increases gradually up to 90 days after the mixing.

The mixes with 50% of cement have slightly higher mechanical performances. The addition of superplasticizer increases significantly the resistance for a sediment proportion of 50 %, which is not observed with a sediment proportion of 70%.

In opposition to its class of resistance, the CEM I 52.5 R CE CP2 NF cement has given lower mechanical performances than the CEM III/C 32.5 N LH CE PM-ES cement. The resistance to aggressive environment of the CEM III/C 32.5 N LH CE PM-ES cement gives a better compatibility with the sediments which, coming from the sea, can disturb the hydration of classic cement.

To study the influence of curing conditions, tests have been done on specimens, stored in ambient air up to 90 days. These tests have been done with the F3' mix. In Fig.3 and Fig.4, the results are indicated with the F3'aa reference. The values show a large decrease of flexural resistance in comparison to F3'. The evolution of resistances according to time shows that the flexural resistance decreases after 7 days and, for the compressive strength, after 28 days. The level of compressive strength is close to those of F3'. As the formation of hydrates for the CEM III/C 32.5 N LH CE PM-ES cement is slow, the curing in ambient air induces a lack of water and weakens the mix.

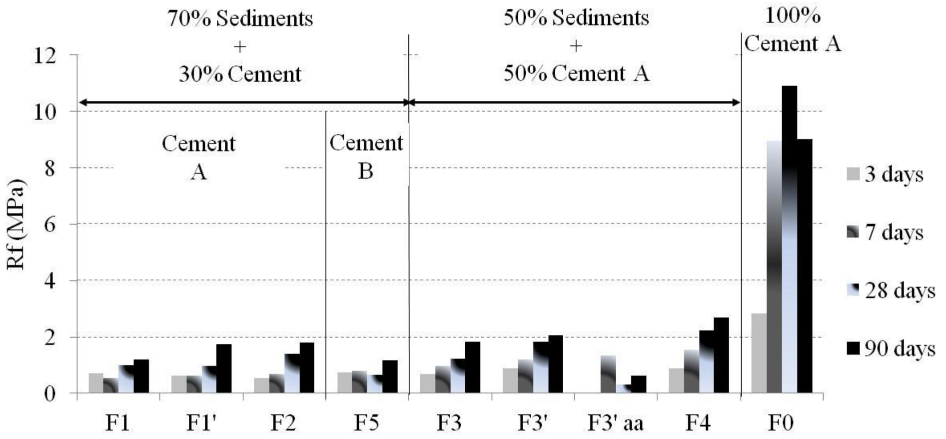


Fig. 2 Flexural tests.

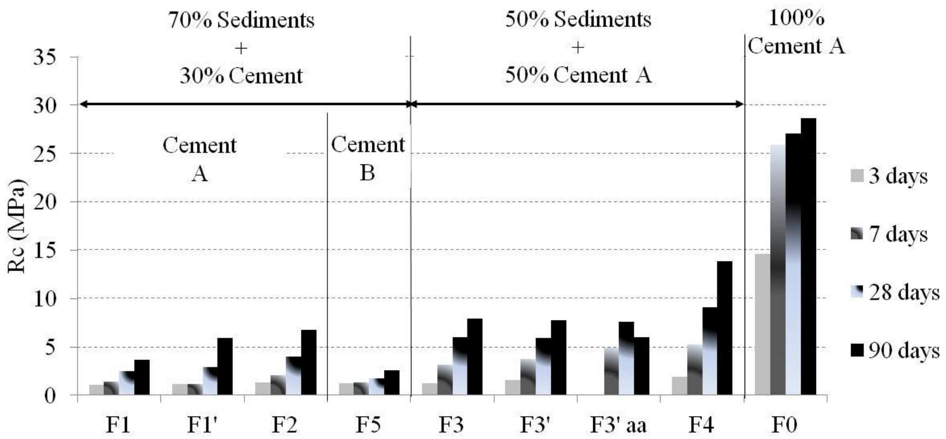


Fig. 3 Compressive tests.

Shrinkage tests

The values of shrinkage are shown in Fig. 4.

Stored in ambient air, the shrinkage of specimens is very high for all the mixes with sediments. The higher the proportion of sediment is, the higher shrinkage is. The decrease of the W/DM ratio allows a low decrease of shrinkage. With the superplasticizer, for the two studied proportions of sediments, the shrinkage is largely decreased. The shrinkage of the mix with the CEM I 52.5 R CE CP2 NF cement is similar to those of the mix with CEM III 32.5 N LH CE PM-ES. The cement does not seem influent for the shrinkage of this formulation.

Stored in water, the volumes of specimens increase slightly. All the mixes evolve similarly, except F4 which has a higher elongation.

Air curing and water curing represent extreme conditions. The in-situ shrinkage will be into this interval of obtained values according to the use conditions of the grouts.

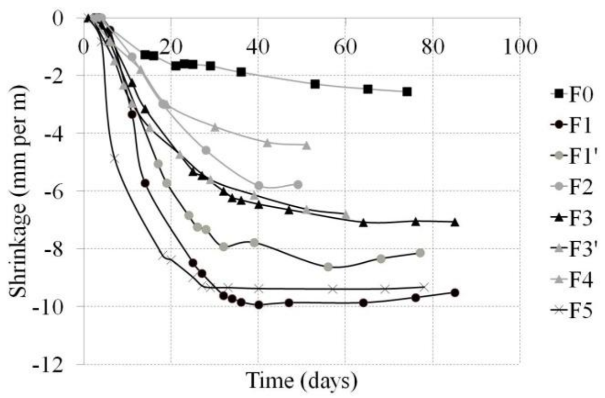
CONCLUSION

This work aims at studying the behavior of grouts including cement and marine sediments. The whole experimental campaign has been conducted for two proportions of sediments in dry matters: 70% and 50%. Superplasticizer has been included for two mixes.

The results show that a low variation of water content can induce large variation of flow behavior, in particular for the mixes with a sediments proportion of 70%. The rheological tests show that the mixes behave as Hershel-Bulkley fluid. New tests should be necessary to confirm the values of model parameters.

The addition of sediments in cement grout induces large decreasing of mechanical strengths. A cement resistant to an aggressive environment gives better results than a classic cement, even if the class of resistance is higher.

The studied mixes have a large shrinkage with air-curing conditions.



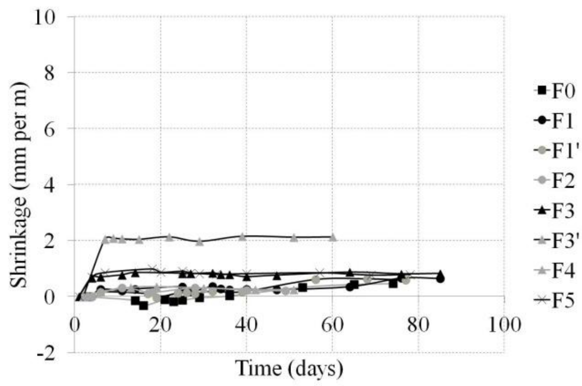


Fig. 4 Shrinkage tests (left – air curing; right – water curing).

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