RESEARCH OF THE SUBSTITUTION OF BONDING AND MODIFICATION MATERIAL IN THE GROUTING SYSTEM

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Summary

The cracks and caverns of different types belong to the most frequent failures within concrete, reinforced concrete and masonry structures. These can appear also in the bottom surface, in rocks and grounds under the structure. Very efficient method of these failures rehabilitation is the grouting with a medium which has better physical properties than the original structure. The paper describes the possibilities of grouting strategy and especially the development of new progressive materials containing different by-product (fly ash, washing wastes, foundry sand, slag etc.) under respecting the increase of quality. Attention was paid especially to properties of the fresh mixture namely to the setting time of modified materials and to the fulfilment of demanded physic-mechanical parameters of the hardened mixture. Particular formulae were designed following optimisation calculations for the broad utilization in practice.

Keywords: Rehabilitation, foundation, grouting technology and materials, waste raw materials.

1 Introduction

The grouting is the process of pumping the liquid with variable viscosity into the ground, into the fissured or loose ground, concrete or masonry in order to increase the density of these materials. The classical technology of grouting is well known for some centuries. The principle of this technology is the filling of pores and cavities by the grouting mixture. The mixing of the grouting mixture with the original material forms a composite which has new physical properties. This is most frequently the way to improve the strength and the imperviousness of the material. The grouting can also secure the lasting position of unstable objects. Another typical application is the waterproofing of cracks and gaps (to secure the water tightness of cracks and gaps).

The problem of building structures subsoil hardening, of filling the cavities and the formed caverns became to be a very topical subject in the Czech Republic, especially after the year 2002, when the Czech Republic suffered under extensive floods, which caused the significant disturbance of foundation subsoil. These problems can be successfully solved by the utilization of grouting technologies. This concerns the application of large scale grouting and possibilities are looked for to decrease the final price under keeping the demanded parameters for the grout mixtures. Considering the fact, that the floods came also in last year 2006, though they were not so great, the subject of large scale grouting is still very topical. The number of structures rehabilitated by grouting materials increases the demands on the research and development of new building materials.

Large-scale grouting in the ground work is connected with increasing demand to solve the question of large scale utilization of industrial wastes in the largest possible extent. The utilization of wastes would not only partially solve the problem with wastes disposal but the wastes application would have positive effect on the price of the work.

This paper represents the research and development of new grouting materials and strategies with the utilization of waste materials.

Special large scale grouting systems

- The problem of building structures subsoil hardening
- Cracks and caverns
- Filling the cavities
- Formed caverns under the structure

Objectives problems: building structures subsoil hardening, filling the cavities, caverns → successfully solved by the utilization of grouting technologies.

2 Basic characteristics of grouting

Basic characteristic of grouting are: good workability, volume stability, good penetration properties, good pump ability, great resistance against erosion, sufficient compression strength. And technological and technical variables are grouting material, curing time of the material, way of fastening, fastening of spacing distance, grouting pressure, grouting time for one connecting opening, grouted volume for one connecting opening and sequence of works. The paper presents the proposal and the verification of methods for utilization of waste materials (power plant fly ash, foundry sand, wastes after washing and blast furnace slag) as the substitution of binder and subsequently also as filler in the grouting mixture. The advantage of grouting mixtures filled by waste raw materials is the lower price and in the same time also the disposal of industrial waste. The processing of unutilized waste raw materials takes place in this way instead of depositing them in waste sites. The way of industrial wastes disposal by depositing them in waste sites is apart from the unfavourable effect to the environment demanding also economically. Attention was paid especially to properties of the fresh mixture namely to the setting time of modified materials and to the fulfilment of demanded physic-mechanical parameters of the hardened mixture. Particular formulae were designed following optimisation calculations for the broad utilization in practice.

3 Description of applied materials

For useful interpretation of the used materials were outlining the individual properties of these raw materials

Cement

Tab. 1 Main properties of applied cement

properties	unity	value
Specific surface	$cm^2.g^{-1}$	375
Initial setting time	min.	160
Final setting time	min.	230
Compressive strength – 2 days	N/mm^2	15.4
Compressive strength – 28 days	N/mm^2	38.6

Bentonite
Content of montmorillonite 65-80 %

Tab. 2 Chemical analysis of bentonite

SiO_2	Al_2O_3	Fe_2O_3	H_2O	TiO_2	MgO	CaO	K_2O	FeO	Na_2O	MnO
50.0 - 57.0 %	15.7 - 17.3 %	8.8 – 17.0 %	5.3 – 6.3 %	3.8 – 6.3 %	3.8 – 6.3 %	1.7 – 3.1 %	0.3 – 1.2 %	0.1 – 1.0 %	0.1 – 1.0 %	0.1 – 0.3 %

Quartz sand
Mass density 2 500 kg/m^3
Apparent density 1 650 kg/m^3

Fly ash (fossil- fuel power station Chvaletice Czech rep.)
Mass density: 2060 kg/m^3, specific surface: 270 m^2/kg

Tab. 3 Chemical analysis of fly ash

CaO [%]	MnO [%]	Al_2O_3 [%]	Fe_2O_3 [%]	sulfates [%]	SiO_2 [%]	Na_2O [%]	MgO [%]	K_2O [%]	TiO_2 [%]
1.79	0.03	28.93	6.08	0.2	56.82	0.32	1.31	1.79	2.02

Granulated blast furnace slag (company Trinecke Zelezarny, Czech Republic)
Mass density 2850 kg/m^3, specific surface 388, 7 m^2/kg

Tab. 4 Chemical analysis of granulated blast furnace slag

SiO_2	CaO	MgO	Al₂O3	Fe_2O_3	SO
40.34	37.53	12.96	5.54	0.27	0.57

Wastes from crushed aggregates washing in quarry
Mass density 2 811 $kg.m^{-3}$
Chemical analysis: $CaCO_3$ 1.79[%], MgCO3 0.03 [%], chlorides 28.93[%],element. sulfur 0.05[%].

Foundry sand
Chemical analysis SiO_2 91-98 %, bentonite 3-6 %, mass density 2 580 kg/m^3
Bulk density 1 360 kg/m^3

4 Description realized works

The research consisted of two main parts. First part solved the possibilities of filler substitution and the second stage was focused on bonding material substitution.

Formulae were designed with the substitution of filler by 10 till 50 % of waste materials. The reference mixture was the concentrate mixture (cement, bentonite, special admixtures) and quartz sand. We have performed the experimental verification of the partial substitution effect of filler by the grouting mixture. The filler (quartz sand) was substituted by waste materials (fly ash, foundry sand, wastes after washing and blast furnace slag). And in the second stage were particular formulae designed following optimization calculations for selected mixture which has the best properties. And these mixtures were modificated. The bonding material was substituted by fly ash. The fresh mixtures of all selected formulae were tested by following basic tests: consistency of the mixture, initial and final setting time, bending strength on test pieces, compression strength on test pieces, volume mass, shrinkage during hardening on test pieces (40/40/160 mm).

5 Result of first stage- substitution of filler by the grouting mixture

The main attention was concentrated on the properties of fresh mixture (workability, initial setting) and further on the fulfillment of demanded physical-mechanical properties of modified mixtures.

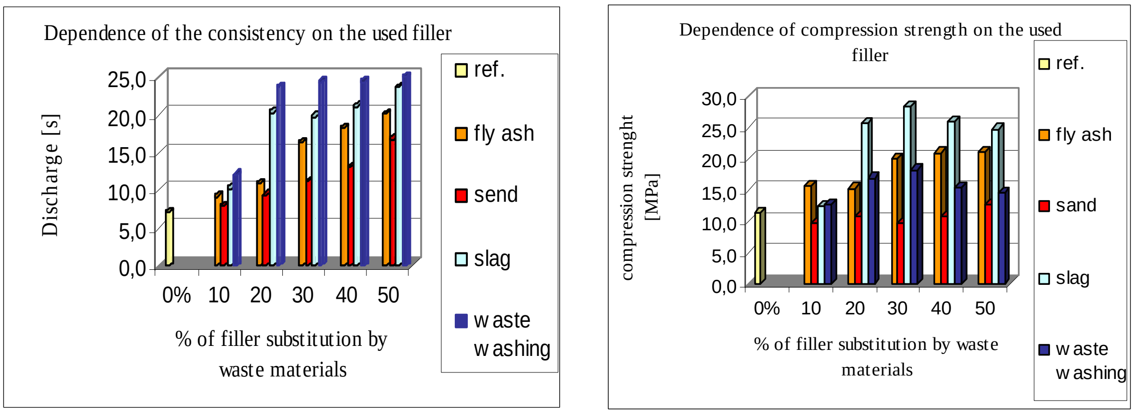

Fig. 1 a, b Dependence of the consistency and compression strength on the used filler

It was determined that the application of secondary raw materials caused the decrease of volume mass in all mixtures. The water/cement ratio of modified mixtures had to be modified by increasing portion of fine-grained particles (finely ground waste materials) in order to achieve the demanded workability. This was the reason of the determined water/cement ratio increase in all mixtures with waste materials. It was necessary primarily to solve the problem of filler substitution in grounding materials under maintaining the demanded physical-mechanical properties. It can be stated on the base of performed tests that the consistency of the mixture depends on the kind and quantity of applied filler. The fluidity of the mixture is the worse the more filler contains the mixture.

6 Result of second stage – substitution of bonding material by the grouting mixture

In the second stage were particular formulae designed following optimization calculations for selected mixture which had the best properties. And this mixture was modified. The bonding material was substituted by fly ash. There were designed two basic formulae with fly ash and slag filler substitution.

Tab. 5 Mixtures proportion – bonding and filler material was substituted by fly ash

sample	cement [kg]	additives [kg]	Fly ash (bending material [kg]	quartz sand [kg]	Fly ash (filler)[kg]	water [kg]
ref.	533	40	–	1066	–	430
P80	426	40	–	729	253	381
P80-10	383	40	43	729	253	381
P80-20	341	40	85	729	253	381
P80-30	298	40	128	729	253	381
P80-40	256	40	170	729	253	381

Tab. 6 Results of the tests after 7 and 28 days

sample	7 days			28 days		
	bulk density [kg/m^3]	bending strength [N/mm^2]	compression strength [N/mm^2]	bulk density [kg/m^3]	bending strength [N/mm^2]	compression strength [N/mm^2]
Sref.	1890	2.1	9.2	1820	5.2	14.7
SP80	1755	2.9	9.3	1730	3.3	17.5
P80-10	1745	2.2	8.6	1735	3.2	15.9
P80-20	1715	2.1	8.1	1695	2.8	14.8
P80-30	1695	1.9	7.3	1670	2.7	10.1
P80-40	1675	1.8	4.6	1650	2.6	8.9

Tab. 7 Mixtures proportion – filler material was substituted by slag

sample	cement [kg]	additive [kg]	Fly ash (bending material [kg]	quartz sand [kg]	slag (filler) [kg]	water [kg]
ref.	533	40	–	1066	–	430
S80	426	40	–	835	225	350
S80-10	383	40	43	835	225	350
S80-20	341	40	85	835	225	350
S80-30	298	40	128	835	225	350
S80-40	256	40	170	835	225	350

Tab. 8 Results of the tests after 7 and 28 days

sample	7 days			28 days		
	bulk density [kg/m^3]	bending strength [N/mm^2]	compression strength [N/mm^2]	bulk density [kg/m^3]	bending strength [N/mm^2]	compression strength [N/mm^2]
S ref.	1890	2.1	9.2	1820	5.2	14.7
S80	1820	1.9	12.1	1780	4.1	18.7
S80-10	1810	2.1	10.2	1790	4.1	16.9
S80-20	1800	2.0	8.6	1775	4.0	15.1
S80-30	1800	1.8	6.9	1770	3.6	12.3
S80-40	1780	1.6	6.0	1765	3.1	9.6

Tab. 9 a, b Initial and final setting time

sample	Initial setting time [min]	Final setting time [min]
S ref.	50	120
SS80	55	155
S80-10	60	165
S80-20	60	170
S80-30	65	170
S80-40	65	175

sample	Initial setting time [min]	Final setting ne [min]
S ref.	50	120
P100	45	115
P90	50	115
P80	50	120
P70	55	130
P60	60	130

Result X- ray analysis:

Tab. 10 Result X- ray analysis

sample	Mineral analysis
Ref.	calciumhydrosilicate II, portlandit, calcit, ettringit, monosulphat, aragonit, β-silica, spar, clay minerals
P80-20	calciumhydrosilicate II, calcit, aragonit, portlandit, ettringit, t, β- silica, spar, biotit, clay minerals

7 Conclusion

It was determined, that the application of secondary raw materials caused the decrease of volume mass in the case of all mixtures. The water cement ratio of modified mixtures must have been modified with the rising portion of fine particles (finely ground waste materials) in order to achieve the demanded workability. For this reason a significant increase of the w/c ratio was determined in the case of all mixtures with waste raw materials. It was first off all necessary to solve the question of filler substitution in grouting materials under maintaining the demanded physical-mechanical properties.

The grouting materials containing waste materials fulfill and in some properties significantly exceed the demanded values, expressed by the reference material. It was further proved that it is possible with the suitably selected substitution of the original filler by waste materials to manufacture grouting materials for utilization in practice which fulfill the given conditions. The greatest bending strength achieved the mixture with 20 % of blast furnace slag and the mixture with 40 % of fly ash. This is caused by the grain size composition of the filler (the nearer is this composition to the ideal grain size curve, the better strength values should show the formulae) and also by the perfect distribution of the grains (no sedimentation takes place). The formulae designed with the following filler proved to be most suitable: the substitution of 30 % of fly ash and 70 % of quartz sand and 20 % of slag and 80 % of quartz sand. The first stage shown very good results and in following research was provided that it is possible to substitute also bending material There were 40 % of bonding material (cement) decreasing in the modificated mixture (see **Tab. 6**, **7**).

The research describes the possibilities of development of new rehabilitation grouting materials containing different wastes (fly ash, washing wastes, foundry sand etc.) under respecting the increase of quality.

The given problems are solved in the framework of the research project MSM 0021630511 called: "Progressive Building Materials with Utilization of Secondary Raw Materials and their Effect on Service Life of Structures" and project FT-TA3/139 Complex system of rehabilitation of soil imperfections outside of building structures by the waste material based new grouting material. This support is gratefully appreciated.

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