Study of sealing and reclam ation mixtures is very
remediation work is most frequently used sealing
mixtures, because of stability and durability. [2] For the
decisive factor in the application of this type of sealing
strength. However the determination of strength is a
order of 1x10-7 cm.s-1, with a characteristic low
bentonite provides sufficient impermeability, in the
mixtures.[1] Sealing compound based on soil and
order to obtain better properties of the resulting
interactions between cement and bentonite show that it is possible to consider about
refund or reduction of cement with other binders in
in order to obtain better properties of the resulting
mixtures.[1] Sealing compound based on soil and
bentonite provides sufficient impermeability, in the
order of 1x10-7 cm.s-1, with a characteristic low
strength. However the determination of strength is a
decisive factor in the application of this type of sealing
mixtures, because of stability and durability. [2] For the
remediation work is most frequently used sealing
material on the bases of "cement-bentonite." These
mixtures show a higher strength with sufficiently low
permeability reaching values about 1x10-6 cm.s-1.
Portland cement, used as a binder, is often replaced by
other materials, which helps to improve the properties
of sealing compounds as well as simultaneously
improves financial aspects of remediation work by
reducing the cost of the binder component. The typical
replacement is blast furnace slag and fly ash from the
combustion of solid fuels (by-products of coal
combustion). Among the important factors which
characterize the quality of the above mentioned sealing
mixtures is undoubtedly strength, durability,
compatibility and permeability. Experimental work was therefore conducted to assess the use of cement, fly ash,
gravel and bentonite in the form of artificial self-hardening sealing mixture. The results of the work show a good
compatibility between the bentonite and cement during its fly ash replacement. Compactness of the structure was
confirmed by studying of permeability and SEM microscopy, which in the system of ash-cement-bentonite matrix
allowed assessing successive microstructure development of hydrating gel.

1 Introduction

Study of sealing and reclam ation mixtures is very
extensive. In recent years it has been directed mainly on
the application of bentonite and cement for making
sealing materials, such as in-situ effective reclam ation
technologies for redevelopmen t or reclam ation work in
contaminated areas. Interactions between cement and
bentonite show that it is possible to consider about
refund or reduction of cement with other binders in
in order to obtain better properties of the resulting
mixtures.[1] Sealing compound based on soil and
bentonite provides sufficient impermeability, in the
order of 1x10-7 cm.s-1, with a characteristic low
strength. However the determination of strength is a
decisive factor in the application of this type of sealing
mixtures, because of stability and durability. [2] For the
remediation work is most frequently used sealing
material on the bases of "cement-bentonite." These
mixtures show a higher strength with sufficiently low
permeability reaching values about 1x10-6 cm.s-1.
Portland cement, used as a binder, is often replaced by
other materials, which helps to improve the properties
of sealing compounds as well as simultaneously
improves financial aspects of remediation work by
reducing the cost of the binder component. The typical
replacement is blast furnace slag and fly ash from the
combustion of solid fuels (by-products of coal
combustion). Among the important factors which
characterize the quality of the above mentioned sealing
mixtures is undoubtedly strength, durability,
compatibility and permeability. It has also been studied the behavior of components
during setting and hardening process of cementitious
materials, together with a description of CSH gel
formation. [3,4] From this work it is apparent that there
has been the development of strength of mixtures with
addition of additives of blast furnace slag or fly ash type. At the same time it is shown the connection between
CSH gel phases and the newly formed structure of foil
type. Change in morphology has a positive effect on the
stability of cement-slag hydrated products. In the
context with the properties of fly ash has also been
confirmed that there is a higher materials resistance
with fly ash and silica fume-cement compared to
conventional mixtures. The content of CaO in ashes has
participated in the improvement of initial strength
development. Higher content of silica and CaO also
contributed to higher mixtures resistance against
sulphates. [5,6]

During mixing of cement with bentonite could be
initialized process of ions exchange, since they are
present in the solutions as for example calcium ions
released during the hydration reaction of cement within
the setting phase. As a result of exchange capacity of
bentonite might be a situation where calcium ions are
bonded into the interlayers of clay, with a corresponding modification to the Ca - bentonite.
Ca-bentonite, then do not show such rheological
properties as Na-bentonite (viscosity, swelling). [7] As
indicated in work of Garvin and Hayles, water loss in
interlayers, increasing the permeability and
microstructure change of cement – bentonite mixtures,
might be attributed to the concentration of calcium ions
and to the high values of pH. Various approaches to
prevent negative reactions between the cement and
bentonite include application of colloid mixtures in
form of additives to bentonite, and/or reduce the amount
of cement. [8,9] On the structure of cement-bentonite
mixtures and subsequent build barriers can also have an
impact some organic substances that may contribute to
the increased porosity of materials. [10]

Abstract. Among the important factors characterizing the quality of sealing mixtures is strength, durability,
compatibility and permeability. Experimental work was therefore conducted to assess the use of cement, fly ash,
gravel and bentonite in the form of artificial self-hardening sealing mixture. The results of the work show a good
compatibility between the bentonite and cement during its fly ash replacement. Compactness of the structure was
confirmed by studying of permeability and SEM microscopy, which in the system of ash-cement-bentonite matrix
allowed assessing successive microstructure development of hydrating gel.

1 Introduction

Study of sealing and reclam ation mixtures is very
extensive. In recent years it has been directed mainly on
the application of bentonite and cement for making
sealing materials, such as in-situ effective reclam ation
technologies for redevelopmen t or reclam ation work in
contaminated areas. Interactions between cement and
bentonite show that it is possible to consider about
refund or reduction of cement with other binders in

This is an Open Access article distributed under the terms of the Creative Commons Attribution License 4.0, which permits unrestricted use,
distribution, and reproduction in any medium, provided the original work is properly cited.
2 Material and methods

For the production of mixtures was used common type of Portland cement PC (CEM) - 42.5, ash from the combustion of solid fuels (fly ash from combustion of energy coal from local power plant Dětmarovice) and bentonite, which was represented by Na-bentonite type NK 80 from Minelco company.

The studied mixtures were subjected to the tests of resistance to compressive stress according to the standard for determining the strength of concrete (DIN EN 12390-3). For determining the compressive strength of the samples was used ELE AUTOTEST 2000. In accordance with the norm DIN EN 12390-3 Testing hardened concrete - Part 3: Compressive strength of test specimens, the laboratory samples were tested after 7 days, 28 days and 56 days. With the use of the electron microscopy SEM were finally analysed microstructural properties of both raw materials and setting matrix. For this purpose it was used an electron microscope FEI Quanta 650 FEG.

For the production of experimental samples of sealing mixtures were used the following group of materials: a) Portland cement (PC), b) fly ash from the combustion of solid fuels (P) c) clay component - Bentonite (B), d) the aggregate: natural aggregates (gravel) secondary aggregates (recycled concrete) e) water.

In the following table 1 is the sum of the chemical composition of fly ash and bentonite. As a cement was used commercially available Portland cement (CEM) – 42.5.

For testing purposes of physical and mechanical properties of self-hardening sealing materials was created a total of 12 different mixtures with different presence of raw materials (see Table 2).

### Table 1. Chemical composition of fly ash and bentonite

| Sample   | Na₂O [mass %] | MgO | Al₂O₃ | SiO₂ | P₂O₅ | SO₃ | K₂O | CaO | TiO₂ | Fe₂O₃ |
|----------|---------------|-----|-------|------|------|-----|-----|-----|------|-------|
| Bentonite| <1            | 0,39| 32,84 | 47,58| 0,06 | 0,059| 1,69| 0,33| 0,66 | 2,17  |
| Fly Ash  | 0,66          | 2,17| 19,23 | 40,78| 0,13 | 0,26 | 1,82| 5,78| 1,01 | 8,60  |

### Table 2. Composition of self-hardening mixtures

| Material | Mixtures | Quantity [weight %] |
|----------|----------|---------------------|
|          | V1  | V2  | V3  | V4  | V5  | V6  | V7  | V8  | V9  | V10 | V11 | V12 |
| PC       | 16,7| 16,7| 16,7| 10,0| 10,0| 6,7 | 6,7 | 10,0| 10,0| 10,0| 13,4| 13,4|
| FA       | 0   | 0   | 0   | 6,7 | 6,7 | 6,7 | 6,7 | 10,0| 10,0| 10,0| 13,4| 13,4|
| SoB      | 16,7| 16,7| 16,7| 16,7| 16,7| 16,7| 16,7| 16,7| 16,7| 16,7| 16,7| 16,7|
| W        | 8,4 | 8,4 | 8,4 | 8,4 | 8,4 | 8,4 | 8,4 | 8,4 | 8,4 | 8,4 | 8,4 | 8,4 |
| B        | 0   | 2   | 4   | 0   | 2   | 4   | 0   | 0,5| 1,0 | 1,5 | 0,5 | 1,0 |
| A        | 83,3| 81,3| 79,3| 83,3| 81,3| 79,3| 82,8| 82,3| 81,8| 82,8| 82,3| 81,8|

PC: Portland Cement, FA: Fly Ash, SoB: Sum of Binder, W: Water, B: Bentonite, A: Aggregates

Representation of cement, fly ash, bentonite and gravel is summarily shown without the inclusion of water. Water was added to the remaining substances while was maintained the coefficient of water / cement (binder) equal to 0.5. Dimensions of the hydrated specimens for physical and mechanical test were 100 x 100 x 100 mm.

3 Results and discussion

Strength values have provided insight into the growth of strength from 7 on up to the final test carried out in 56 days. Strength development of laboratory samples of each mixture is shown in Figure 1.

From the time point of view is obvious that in setting and hardening is increasing trend of compressive strength. The measured strength values of the samples ranged from 0.3 MPa to 48.4 MPa. On the resulting strength values had a great impact the proportion of fly ash in each mixture. With decreasing weight of cement compounds, respectively, an increasing proportion of fly ash the compressive strength of laboratory samples decreased.
The achieved results of prepared materials could be divided into two groups. The first group consists of materials with 0% and 40% of fly ash quantity in binding compounds. Into the second group were included mixtures with 60% and 80% of fly ash. The results of the first group after 7 days of testing were in the order of tens, while their continued in gaining of the strength also in testing after 28 and 56 days. The results of strength of those mixtures in which the fly ash was presented by 60% and 80% reached values after 7 days and after 28 and 56 days in the order of one tenth of MPa.

After 56 days the highest strength has reached a mixture consisting of 100% of the cement content as a binding component with 2% of the proportion of bentonite. In the second group of materials is from the results evident, that within the same amount of ash content of 60% or 80% were achieved similar strength regardless of the mass proportion of bentonite. As well, in the second group of mixtures is obvious that there is greater volatility of strength results. This is seen in Figure 1, where are included the total deviation calculated on the basis of previous measurements of the strength. From the perspective of bentonite and its effect on the strength is therefore necessary to take into account also the amount of fly ash in the tested materials.

4 The structure of materials and materials compatibility

In Figure 2 can be seen binding of bentonite to the basic matrices of CSH gel. In contact phases of aggregate components and binding compounds is occurred filled space by plates of bentonites, which can be observed in relation to CSH gel and separately as well.

![Figure 2. SEM image of the cement-bentonite matrices](image)

Already 2% amount of bentonites in the formed matrices could result in their involvement in the hydration reaction. With the increasing proportion of ash in the formed tested matrices, although there is a reduction of the total strength of samples, but there is also a reduction in porosity. CSH gel of the basic matrices with a share of fly ash more than 60% and with the subsequent addition of bentonite are positively involved in hydration which leads to the formation of compact, low permeable structure.

Based on the experimental results related to the complement tests of permeability can also be noted that, as a mixtures with low cement content and mixtures with fly ashes above 60% and bentonite around 2% have very low permeability, which is in the order of the values below 10-8 cm.s-1 and can therefore serve as a good insulating material.

5 Conclusions

An important additive that was applied during laboratory testing was clay compound bentonite. Within the laboratory testing of produced sealing materials therefore attention was concentrated on these two aforementioned elements whose in various combinations contribute to the development of the final state of materials. In terms of overall summary can be viewed on the experimental data as follows:

- Influence of fly ash on compressive strength of prepared samples was significant. Within the strength testing was stated that between 40% and 60% of fly ash content in binding there is the biggest drop in strength. At higher proportions of 60% fly ash and 80% content the differences in final compressive strength were very small, in the order of one tenth of MPa.
- Durability of materials that were produced based on fly ash-cement-bentonite system was assessed as good. During testing of durability of materials against aggressive agents such Na$_2$SO$_4$ solution was observed higher resistance in samples where the fly ash content was above 60%.
- SEM structural images refer to the gradual formation of the basic matrices, leading to a compact structure resistant to aggressive environments.

Acknowledgements

This publication has been created within the project Support of VŠB-TUO activities with China with financial support from the Moravian-Silesian Region and in connection with project Institute of clean technologies for mining and utilization of raw materials for energy use, reg. no. CZ.1.05/2.1.00/03.0082 supported by Research and Development for Innovations Operational Programme financed by Structural Founds of Europe Union and from the means of state budget of the Czech Republic.
References

1. EPA – United States Environmental Protection Agency: Engineering Bulletin: Slurry Walls, EPA/540/S-92/008, October (1992).
2. B. K. Andromalos M. J. Fisher: Design and control of slurry wall backfill mixes for groundwater containment, - In.: 2001 International Containment and Remediation Technology Conference and Exhibition, Orlando, Florida, June (2001).
3. M.D.A. Thomas, M.H. Shehata, S.G. Shashiprakash, D.S. Hopkins, K. Cail: Use of ternary cementitious systems containing silica fume and fly ash in concrete, Cement and Concrete Research, Volume 29, Issue 8, August (1999), Pages 1207-1214
4. T. Chappex, K. Scrivener: Alkali fixation of C–S–H in blended cement pastes and its relation to alkali silica reaction, Cement and Concrete Research, Volume 42, Issue 8, August (2012), Pages 1049-1054
5. I.G. Richardson: The nature of C-S-H in hardened cements, Cement and Concrete Research, Volume 29, Issue 8, August (1999), Pages 1131-1147
6. D.R.G. Mitchell, I. Hinczak, R.A. Day: Interaction of silica fume with calcium hydroxide solutions and hydrated cement pastes, Cement and Concrete Research, Volume 28, Issue 11, November (1998), Pages 1571-1584
7. D. Koch: Bentonites as a basic material for technical base liners and site encapsulation cut-off walls, - In.: Applied Clay Science, Volume 21, PII: S0169-1317(01)00087-4, Elsevier Science B. V., July (2002), pp. 1-11.
8. S. L. Garvin, C. S. Hayles: The Chemical Compatibility of Cement-Bentonite cut-off wall material, - In.: Construction and Building Material, Volume 13, PII: S0950-0618(99)00024-0, Elsevier Science Ltd., (1999), pp. 329-341.
9. R. Metcalfe, C. Walker: Proceedings of the International Workshop on Bentonite-Cement Interaction in Repository Environments, POSIVA, Working Report 2004-25, 14-16 April 2004, Tokyo, Japan, 2004, p. 196.
10. PCA – Portland Cement Association: Cement-Bentonite Slurry Trench Cutoff Walls, Concrete information PCA, Portland Cement Association, IS227.01W, Illinois, (1984), pp. 12.