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TECHNICAL AND COMMERCIAL EVALUATION OF MODIFIED SHOTCRETE IN TUNNEL CONSTRUCTION

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ABSTRACT

Rebound is a significant factor when evaluating the quality and performance of a construction site using shotcrete. Rebound modifies the characteristics of shotcrete and must be disposed of. Thus a reduction in rebound becomes both a technical and a commercial objective.

Based on many years of experience with polymers in mortar applications, different polymer modified systems were developed for shotcrete applications and investigated in extensive full size trials. The investigations fully confirmed expectations as regards a reduction in rebound. At the same time the recently developed polymer has a retardant effect, giving the concrete other improved properties. Parallel to the technical investigations, the commercial aspects of this polymer on the use of shotcrete were examined. The properties of the additional polymer on shotcrete meet the high performance levels required by the J2 curve.

INTRODUCTION AND OBJECTIVES

The type of polymer under consideration in this investigation is currently used in many construction chemistry applications. Since this polymer increases both adhesion and thixotropy, there is interest in examining the reactions of this polymer in shotcrete. An effect on the rebound of the shotcrete was expected.

The primary goal of the investigation was thus to determine what quantity of polymer was required in a shotcrete mixture to reduce the amount of rebound, whilst at the same time meet the relevant concrete properties.

The investigations were limited to wet mix shotcrete. For the current investigation, it was postulated that there would be a relative improvement in the rebound ratio of a reference shotcrete of more than 50%.

The commercial importance of the polymer was highlighted.

DESIGN OF THE EXPERIMENT

Procedure

The following procedural steps were laid down for the test series:

1. Development tests
2. Application tests
3. Commercial investigation on the basis of results from preceding tests

The development tests involved different concrete mix designs being applied to standardized test surfaces, in order to work out the effect on the properties of the shotcrete. Using statistical methods in the design of experiments, a series of tests was carried out so that the characteristic values determined could be used to make decisions regarding further trials. This was the basis for the test work reproduced in Table 1. For each test, 2-3 m^3 of concrete was made. To ensure a homogeneous mixture, only the "midstream" concrete was used. Determining the early strength allowed a trend statement to be established regarding the mechanical strength of the concrete. This shortened the time required to reach the first statement.

Table 1: Planned test work

	Number of tests	Number of test series	Remarks
Development tests	1	1	Definition of reference characteristics
	5	2	Minimizing rebound
Application tests	1	2	Polymer material variations

In the application tests on real rock surfaces, the reproducibility of the development test results should be demonstrated in a pilot trial.

All tests were carried out by comparing to a reference concrete ("0-mixture"), which had been made without any polymer. Where there were deviations from this basic concrete, the mix design had to be changed. The tests began with the reference concrete.

The commercial investigation that took place at the end of the exercise demonstrated the commercial potential of the polymer modified concrete.

Location of tests

The development tests were carried out in a side gallery of the fire gallery, while the application tests were conducted in the highway profile of the Hagerbach Test Gallery (*Figure 1*). The climatic conditions remained constant in the test area at around 16°C and a relative humidity of approximately 85%.

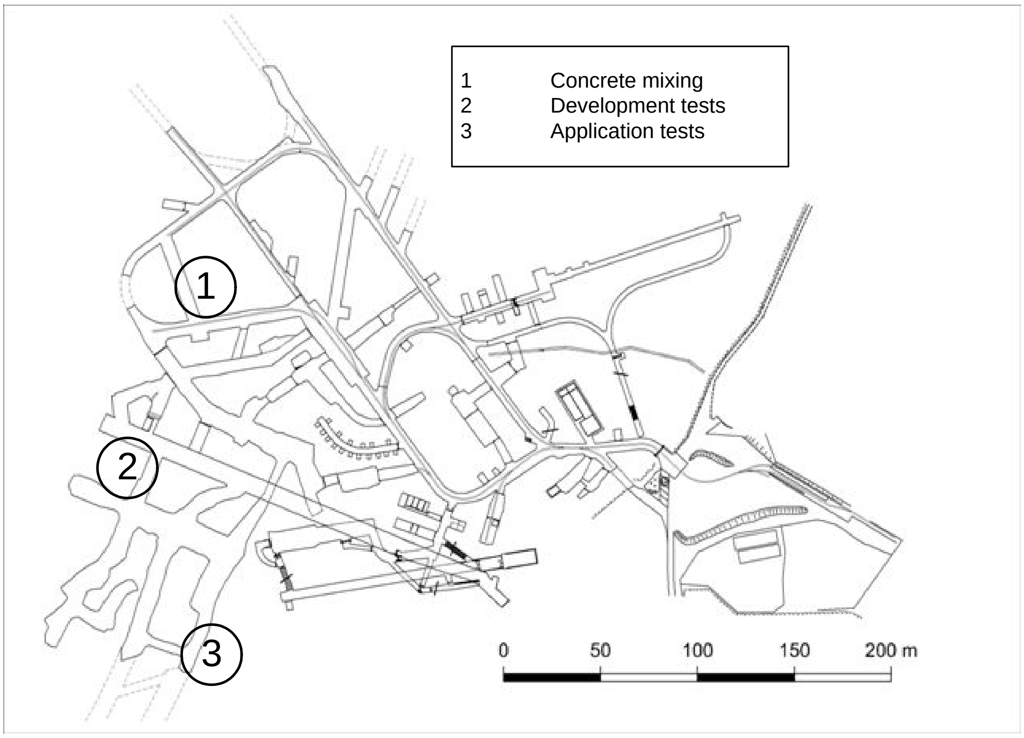

Figure 1: Hagerbach Test Gallery showing locations where the work was carried out.

Test equipment

The concrete was produced in a pan mixer in batches of 1 m^3. All test parameters were recorded on a mixing report.

Next, the finished concrete was driven to the test area field with a mobile mixer with a mixing drum. The mobile mixer has a capacity of 3 m^3 and the rotational speed is infinitely variable.

A shotcrete pump was used to supply, pump and spray the concrete.
A telescopic spraying arm was used to apply the shotcrete. The robotic nozzle was controlled with an electrical remote control.

PROGRESS OF DEVELOPMENT TESTS AND RESULTS

Introduction

In this chapter the results of the development tests are reproduced and interpreted. The main message relates to rebound and strength development. Where appropriate, information gained in carrying out further tests is also called upon.

The following nomenclature is used in the Figures and tables:

FLZ -FMVZ - 2.5 – 1

The first three letters represent the type of polymer used, e.g. FLZ for liquid polymer and FSZ for solid polymer, followed by the plasticizer, e.g. FMVZ for a plasticizer with a retardant effect and FM for a normal plasticizer, and then followed first by the percentage of polymer in the cement and finally by the percentage of plasticizer.

Raw materials and recipes

The following cements, admixtures and additives were used for the tests (Table 2):

Table 2: Raw materials for development tests

Material	Type	Designation
Cement	CEM I 52.5 R	CEM A
Aggregate	0/1	
	1/4	
	4/8	
Additive	Accelerator	SBE
	Flow material	FMVZ
		FM
	Polymer	solid FSZ
		liquid FLZ

Due to previous lab tests, a CEM I 52.5 R was used to ensure the comparability in these tests.

The cement supplied had the following phase composition (Table 3):

Table 3: Phase composition of CEM I 52.5 R

Cement phase	Ratio in CEM I 52.5 R [%]
C_3S	68.6
C_2S	8.0
C_3A cubic	3.6
C_3A orthorhombic	1.6
C_4AF	11.3
free CaO	0.5

The high portion of tricalcium silicate (C_3S) is worth noting as it suggests rapid hardening properties [2].

In the development tests, five mix designs were defined, each with different proportions of polymer and plasticizer. The basic mix design consisted of:

- 450 kg/m ^{3} cement
- 7% sand 0/1
- 58% sand 1/4
- 35% rock 4/8
- w/c = 0.48

The proportion of solid polymer and the plasticizer was varied as in Table 4:

Table 4: Variation of the proportions of solid polymer and FMVZ plasticizer

Solid polymer [% of cement]	FMVZ [% of cement]
2.5	1.00
3.5	0.87
5.0	0.50
7.5	0.33
10.0	0.00

The variation of the solid fraction and the FMVZ plasticizer is as per Table 5:

Table 5: Variation of solid polymer and FMVZ plasticizer

Solid polymer [% of cement]	FMVZ [% of cement]
1.7	0.83
2.5	1.00
3.3	1.17
4.2	1.33
5.0	1.50

In the lab tests, a plasticizer was used that had no retardant effect. In order to investigate its behaviour with the different polymers, it was agreed that additional tests should be carried out with this plasticizer (Table 6 and Table 7).

Table 6: Variation of liquid polymer and FM plasticizer proportion

Liquid polymer [% of cement]	FM [% of cement]
7.50	0.33
2.50	1.00

Table 7: Variation of solid polymer and FM plasticizer proportion

Solid polymer [% of cement]	FM [% of cement]
5.00	1.50
1.70	0.83

Concrete production with liquid polymer

Initially, the maximum polymer dosage of 10% polymer / cement content was selected in order to understand the behaviour of the liquid polymer.

The sequence of adding the components was as in previous shotcrete investigations:

1. Mix together all "dry" components:
   a. aggregate, when visually homogeneous then
   b. cement

2. Add all liquids:
   a. first mix water and plasticizer in a tank, then
   b. add water/ plasticizer solution to the solid materials, and then
   c. add liquid polymer by hand

When adding liquid polymer, it was observed that the power consumption of the mixer increased. After increasing constantly, it then fell. If the targeted power consumption was not reached, water was added.

The mixing process with the liquid polymer was not any different to previous methods used at Hagerbach Test Gallery. The mixing times were not different to those of other types of concrete.

As soon as the concrete mixture was visually homogeneous, the concrete was discharged into the mobile mixer.

Processing the solid polymer

Based on experiences with processing the liquid polymer, initially a similar method was used as for the liquid polymer:

1. Mix all "dry" components, cement, aggregate and solid polymer until visually homogeneous, then
2. Add all liquids, in this case water and plasticizer.

It was observed that the solid polymer spontaneously formed lumps when in contact with damp aggregate. The water and plasticizer that were added subsequently did not dissolve the lumps. This method would not result in a homogeneous concrete.

Therefore a second mixing sequence was chosen:

1. Mix cement and aggregate for at least ten seconds until visually homogeneous,
2. Dissolve the plasticizer and water in a tank, then
3. Add the water and plasticizer to the solids. Mix for at least three minutes (estimate based on the experience of how long it takes until the plasticizer and cement have reacted fully) until visually homogeneous and the power consumption is constant, in the range 34 to 38 A.
4. Add solid polymer, mixing time approximately three minutes until visually homogeneous and the power consumption is constant, in the range 34 to 38 A. If necessary add water in a controlled manner

This method produces a homogeneous and pump-able concrete.

CONCRETE APPLICATION

Immediately after making the concrete, the mixture is applied to a standardized plate. Comparing to a reference mixture, it should be possible to work out the effect of the polymer on the properties of the concrete under conditions that are close to reality. The focus was on the strength development and rebound in comparison to a reference mixture without polymer.

The first polymer mixture to be applied was FLZ-FMVZ-10-1. In order to ascertain the influence of the plasticizer, an additional mixture was made with the composition

FLZ-FMVZ-10-0, i.e. without plasticizer.

After the shotcrete had been applied, the plates were weighed. The mass of concrete applied was thus the change in weight compared to the original weight of the plate.

To ensure comparability of the weights, the rebound characteristic is established as follows:

$$RP_{rel.} = \frac{\dfrac{m_{reb}}{m_{plate\_after} - m_{plate\_before}}}{\dfrac{m_{reb,0}}{m_{plate\_after,0} - m_{plate\_before,0}}} \times 100$$

$RP_{rel.}$:= rel. rebound of the 0 - mixture [%]

m_{reb} := rebound [kg]

m_{plate} := mass of the plate [kg]

Indices : after / before after or before the spray test

0 = reference mixture

DEVELOPMENT TESTS – RESULTS AND DISCUSSION

Introduction

This series of tests was to work out the effects of polymer on the properties of the concrete compared to a commercially similar, arbitrarily selected reference mixture under conditions that are close to reality.

Effect of polymer on rebound

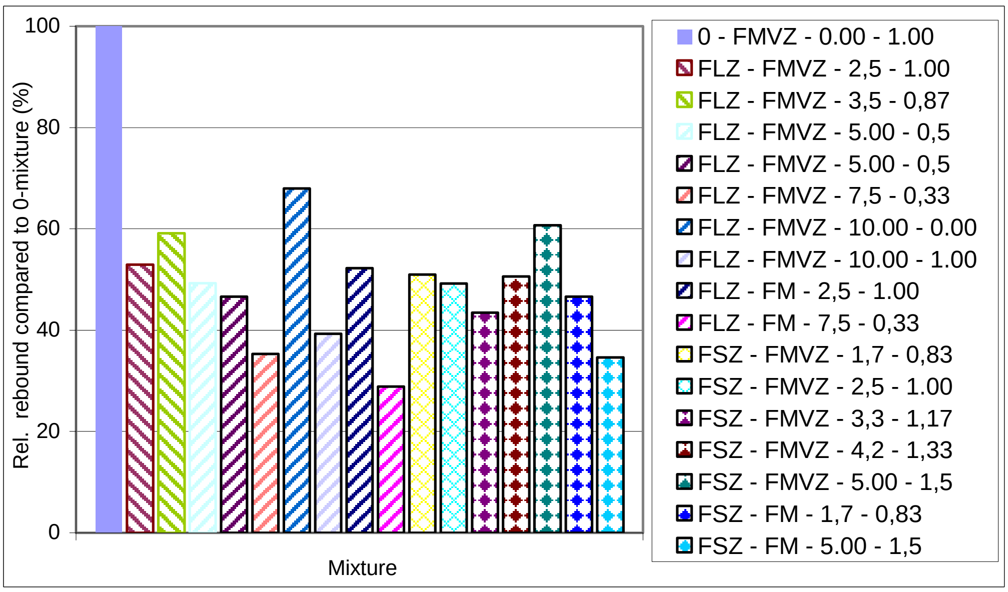

Figure 2: Relative rebound compared to 0-mixtures

The addition of the polymer, no matter which variation was chosen, reduces the rebound. Both polymer modified concrete types show a decrease in rebound as the polymer content increases until a minimum is reached after which it rises again. The smallest relative rebound, at 71% compared to the 0-mixture, was achieved by the FLZ-FM mixture. There are interactions between the polymer and the plasticizer, which also affect the rebound. All types of concrete using FM plasticizer exhibit less rebound than those using FMVZ plasticizer (*Figure 3).*

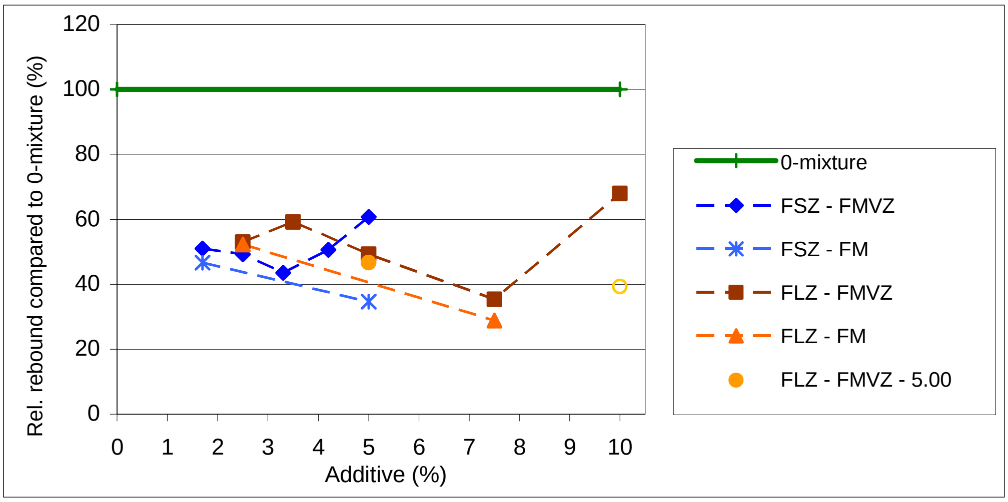

Figure 3: Relative rebound versus polymer content

Effect of polymer on strength development

The strength development of the concrete modified by polymers and the reference concrete are shown in Figure 4. In the case of the reference mixture, the strength develops at a constant rate over the entire period associated with early strength. The J1 and the J2 curves have been drawn in for guidance [1]. Achieving this strength was not a goal in selecting the reference mixture, as no strength requirement was laid down. Adjusting the strength is usually carried out at the construction site by varying the parameters such as the type of accelerator or its proportion.

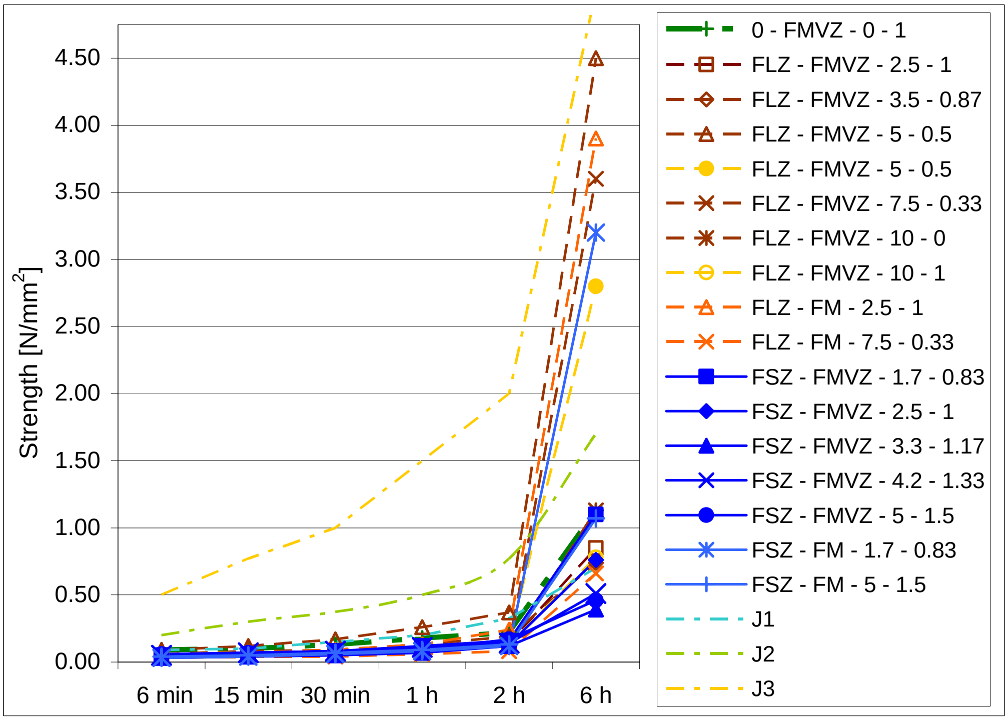

Figure 4: Comparison of early strength development with J-curves

The investigations that were carried out demonstrated that during the first two hours, the mixture with 5% liquid polymer and 0.5% FMVZ of cement content had a strength development that was higher than the reference mixture.

During the first hour, all mixtures were below the strength development of the reference mixture. After one hour the strength of the FLZ-FM-2.5-1 mixture jumps above the strength of the reference mixture.

After two hours, the strength of the following mixtures rose exceptionally rapidly, far above the level of the reference mixture:

1. Both concretes with 5% solid polymer and 0.5% FMVZ of cement content
2. FLZ-FMVZ-7.5-0.33
3. FLZ-FM-2.5-1 and
4. FSZ-FM-1.7-0.33

After six hours, all of the above mixtures had reached strength values above that of the reference mixture and in the range between J2 and J3. Thus the development tests demonstrate the trend towards meeting the demanding levels required by the ÖVBB (Austrian Society for Concrete- and Construction Technology) Guideline when the accelerator is dosed carefully. At 5% accelerator, the dosage was at the lower end of the dosing range.

Summary of the development tests

The development trials demonstrated that polymer reduces rebound significantly. Rebound causes the shotcrete to lose aggregate, and thus the cement content of the applied shotcrete rises. Generally the strength rises with increasing cement content, so as a rule, an increase in rebound gives a higher final strength, and this expectation tends towards being met (Figure 5).

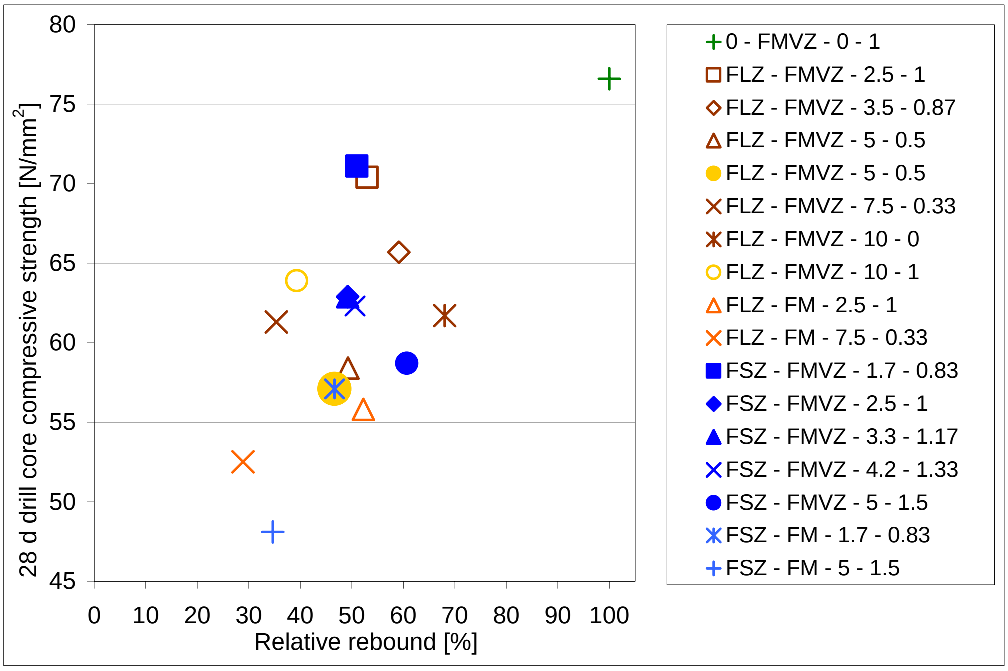

Figure 5: 28 day drill core compressive strength as a function of rebound

In this context it becomes clear that the mixtures modified with the highest proportion of solid and liquid polymers and pure plasticizer give the lowest rebound and, as expected, the lowest strength.

In the development tests, the change in strength showed that the mixture with 5% solid polymer performed best. This mixture could be worked for longer than the others, and exhibited a similar or better initial slump than the reference mixture. Considering the rebound values, this mixture met the goal of halving the rebound compared to the reference mixture. Concretes modified with liquid polymer were easier to work.

Thus it was decided to carry out the application tests with the FLZ-FMVZ-5-0.5 mixture.

APPLICATION TESTS

Introduction

In the phase that now followed, the application tests, the reproducibility of the results under the conventional conditions was shown as a pilot trial. In this series of tests, the potential to optimize the mechanical strength values and transfer the benefits to a standard concrete were demonstrated.

Test sequence

Two spraying tests were carried out using cement with 5% solid polymer and 0.5% FMVZ. One used CEM I 52.5 R cement and the other CEM I 42.5 N. In each test area, 1m^3 of concrete mixture was applied, one with 5% accelerator, similarly to the development tests, and one with 8% accelerator. The recommended dosing range of accelerator lies between 4% and 10% of the cement content, although the upper limit is practically never reached.

The production of the concrete and application of the shotcrete took place with the same machines, materials, methods and personnel. The factors that were varied were the CEM I 42.5 N cement and the dosage of accelerator.

Concrete production

The same raw materials were used for these tests as had been employed in the development tests. In addition, CEM I 42.5 N cement was used. The mix design was as in the development tests.

A solid polymer was used at a dosage of 5% of cement content and an FMVZ plasticizer with a dosage of 0.5% of cement content.

Using this mix design, one 3 m^3 batch of concrete was made using CEM I 52.5 R and one with CEM 42.5 N.

RESULTS OF THE APPLICATION TESTS

In this series of tests, the aim was to demonstrate the transferability of the knowledge gained in the development tests to the practical conditions existing on a construction site.

In these tests the following nomenclature applied:

1. Abbreviation for cement types: CEM-A for CEM I 52.5 R or CEM-B for CEM I 42.5 N,
2. Followed by a number representing the accelerator dosage

As two CEM I 52.5 R mixtures were manufactured, “/2” was placed after the abbreviation CEM-A to identify the second mixture.

A further objective was to highlight the non-conformity of the polymer-modified shotcrete. For this series of tests, a "standard cement" found on the Swiss market was used, one which is commonly used in Hagerbach Test Gallery. The results of this test series refer to the values achieved by the 0-mixture from the development tests.

As in the development tests, it was possible to lower the rebound significantly. The potential for this is illustrated in Figure 6, comparing the rebound to the actual rebound of the standard mixture.

The second concrete mixture, CEM I 52.5 R, demonstrated how rebound rises as the accelerator dosage is increased. The CEM I 42.5 N concrete and the first mixture of CEM I 52.5 R behaved contrary to this trend. The first concrete mixture using CEM I 52.5 R had a higher proportion of cement than the second mixture.

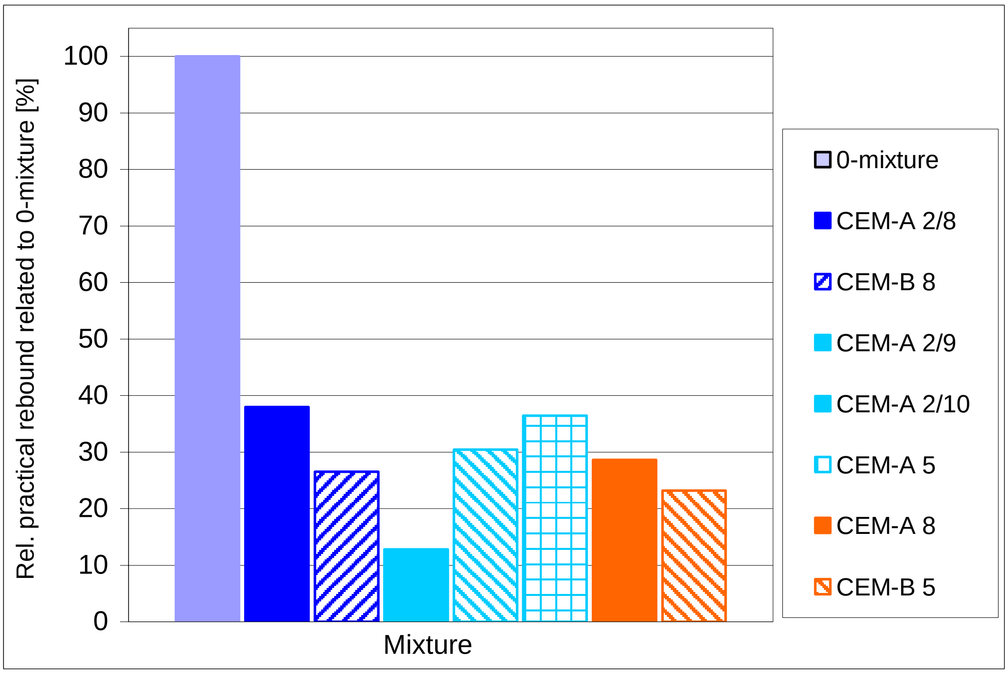

Figure 6: Relative rebound compared to rebound of the 0-mixture

The change in strengths of the mixtures based on CEM I 52.5 R corresponds to the changes in the development tests (Figure 7). After two hours, there is again a precipitous rise in strength. The concrete based on CEM I 42.5 N demonstrates a continuous strength development as is usual for this concrete.

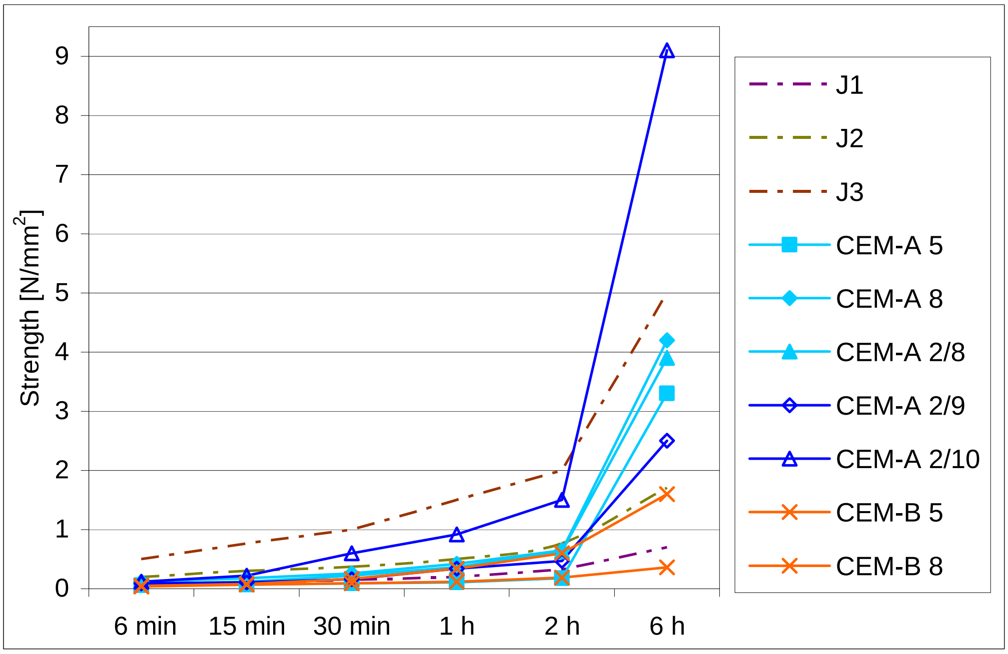

Figure 7: Early strength compared with J-curves

In the application tests the dosage of accelerator was varied in order to demonstrate its effect on strength development. As expected, an increase in the proportion of accelerator leads to an increase in the early strength. Here strength-values were achieved which in some cases were above the J3 curve. With an accelerator proportion of 8%, the CEM I 42.5 N concrete was close to the J2 curve.

A consideration of the change in early strength for CEM I 52.5 R confirmed the expectation that mixtures with higher cement contents have a higher strength.

Furthermore, other accelerators are available on the market that have the potential to have a faster strength development. One can thus predict that high strength specifications could be met by a polymer-modified concrete. The task is then to find the construction site recipes, depending on the application.

COMMERCIAL EVALUATION OF THE TECHNICAL POTENTIAL

In the following, the first, basic considerations are listed regarding the cost effectiveness of shotcrete applications with the help of the polymer and based on the test results. Here the influence of a reduction in rebound arising from the polymer acquires crucial importance.

The calculation is based on the following parameters:

1. Average unit price (UP) for spraying concrete (A)
2. Average UP for the transport of rebound material within the construction site (B)
3. Average UP for removal and disposal of rebound material (C)
4. Average efficiency for processing $1m^3$ of shotcrete (p) 0.65 h/m^3

The following unit prices (UP) have been used for the calculated estimates below:

Table 8: Calculation basis

Average unit price of reference shotcrete (A_1)	196	CHF/m^3
Average unit price shotcrete PS (A_2)	246	CHF/m^3
Transport of rebound material to dump, incl. landfill costs (C)	25	CHF/m^3
Transport of rebound material within the construction site (B)	2	CHF/m^3
Efficiency	0.65	h/m^3

For the price estimates, first the quantity of so-called design mix (V_{design}) must be calculated as a function of the rebound (r), i.e. the quantity of shotcrete that is required to actually apply 1 m^3 of shotcrete to the wall:

$$V_{design} = 1 + \frac{r}{1-r}$$

Using the average unit price of shotcrete, the costs (K_{design}) of the delivery of design mix gives

$$K_{design} = V_{design} \cdot A_n$$

With the volume of rebound

$$V_{rebound} = V_{design} \cdot r$$

Together with the unit prices noted above for transport, disposal and landfill give the cost K for

$$K_{rebound} = V_{rebound} \cdot C$$

Transport of rebound within the construction site (B)

$$K_{rebound} = V_{rebound} \cdot B$$

Additionally, using the efficiency p, the time required (T_{design}) to apply the shotcrete design mix can be estimated for the standard type CEM-B 5, CEM-B 8 and CEM-A 5 as:

$$T_{design} = p \cdot V_{design}$$

The summary of the results is shown in Table 9:

Table 9: Time and cost difference

	0-mixture	CEM-A 5	CEM-B 8	CEM-B 5
Rebound	13.0%	5.2%	4.1%	3.2%
Design mix [m^3]	1.149	1.055	1.043	1.033
Rebound [m^3]	0.149	0.055	0.043	0.033
Delivery of design mix [CHF/m^3]	225.3	259.4	256.5	254.1
Disposal of rebound at construction site [CHF/m^3]	0.30	0.11	0.09	0.07
Disposal of rebound at [CHF/m^3]	3.74	1.37	1.07	0.83
Working time [man hours/m^3]	0.75	0.69	0.68	0.67
Cost difference [CHF/m^3]]	0	-34.2	-31.2	-28.8
Cost difference [%/m^3]	0	-13.9	-12.7	-11.7
Time difference [min/m^3]	0	3.7	4.2	4.5

After due consideration and taking account of the calculation values shown in Table 9, when compared to the UP of the shotcrete, initially there appear to be no benefits, only additional costs. Considering the matter from a time point of view and taking account of the conditions, there is a time saving of around 3.7 min/m^3 (CEM-A 5 mixture) to 4.5 min/m^3 (CEM-B 5 mixture).

In order to quantify the time saving in monetary terms, the values shown in Table 9 have been calculated for a fictitious tunnel construction site. An example would be a tunnel construction site of a main road with safety galleries and a ventilation system.

The calculation is based on the assumption as laid out in Table 10.

Table 10: Conditions at a typical construction site

Tunnel cross section	84	m^2
Extent of the tunnel arch (rock surface)	20	m
Tunnel length	2’600	m
Thickness of shotcrete according to design	0.2	m
Average UP for construction of carcass for a main road tunnel	100’000	CHF/day

The time savings result in a profit as shown in Table 11.

Table 11: Resulting profit at a typical construction site

	0-mixture	CEM-A 5	CEM-B 8	CEM-B 5
m^3 shotcrete, theoretical, no rebound	10’400	10’400	10’400	10’400
Design mix – including rebound [m^3 shotcrete]	11’954	10’968	10’845	10’744
Costs of supplying shotcrete [CHF]	2’582’069	2’917’528	2’884’672	2’857’851
Costs of transporting rebound within construction site [CHF]	3.108	1.136	889	688
Costs of disposal of shotcrete (rebound) [CHF]	38’851	14’204	11’116	8’595

Total costs of shotcrete [CHF]	2’624’028	2’932’868	2’896’677	2’867’134
Shotcrete SAVING [CHF]	0	-308’840	-272’649	-243’106
Time saving for application of shotcrete [days]	0	42.2	47.0	50.8
Construction site cost saving [CHF]	0	4’223’907	4’699’593	5’079’54
Net profit [CHF]	0	3’915’066	4’426’944	4’835’948

This demonstrates that the additional cost of the polymer modified shotcrete saves time and the resulting savings give an appreciable profit.

SUMMARY

In this investigation, there are three questions that require an answer:

1. Can the addition of polymer lower rebound?
2. Does the polymer-modified shotcrete meet the demanding strength specifications?
3. What commercial potential arises from the technical potential?

Both, in the development tests and the application tests that followed, it was demonstrated that the use of polymer lowers rebound with both CEM I 52.5 R and CEM I 42.5 N concrete.

In the development tests, it was possible to reduce the rebound by up to 71% compared to the 0-mixture. This corresponded with a reduction in rebound for the CEM I 52.5 R concrete in the application tests under the most difficult conditions, on real rock of around 73.5%. The CEM-A 2/8 mixture lowered the rebound by around 87%.

In the application tests it was possible to demonstrate that the strength specifications could be achieved with a conventional accelerator with both CEM I 52.5 R and the CEM I 42.5 N concrete. The strength development of the CEM I 52.5 R concrete using cement with 5% liquid additive and 0.5% plasticizer with a retardant effect was the same in the application tests as in the development tests. The potential of this mix design demonstrated in the development tests was confirmed during the application tests. In the application tests when using this mix design and commercially available cement, it was possible to meet a high early strength specification (measured after 30 min) by increasing the proportion of accelerator.

On the base of the presented experiences on constructions sites a start in the market should be made with a CEM I 42.5 N based concrete. Initially based on this investigation the additive should be liquid with a proportion of around 5%. Minimum rebound was achieved within this range and this was the point at which it was possible to achieve an improvement in consistency and workability. The strength reached with this dosage is suitable for demanding applications.

Taking account of the remarks and calculations above, under certain conditions it is possible, to some extent, to achieve appreciable financial savings by using the polymer as a result of reducing both, the time and material consumption.

The polymer modified concrete has an interesting potential, both technical and commercial. Present investigations have shown that it is ready for the market. Further detailed investigations are essential to ensure that it is exploited fully.

LITERATURE

[1] Österreichischer Betonverein [Austrian Concrete Association}:
Guidelines for shotcrete. January 2004.

[2] Weigler H.; Karl S.:
Beton. ISBN 3-433-01332-2’ Publisher: Ernst & Sohn Verlag, Berlin 1989.

REFERENCES

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