Proceedings

Shotcrete for Underground Support XI

Engineering Conferences International   *Year* 2009

EXPERIENCES WITH POLYMER-MODIFIED SHOTCRETE

Gerhard Pittino* Robert Galler†
Klaus Bonin‡ Jürgen Bezler**

*University of Leoben, Austria, pittino@unileoben.ac.at
†University of Leoben, Austria, robert.galler@unileoben.ac.at
‡Wacker Polymer Systems GmbH & Co. KG, Germany, klaus.bonin@wacker.com
**Wacker Polymer Systems GmbH & Co. KG, Germany, juergen.bezler@wacker.com

EXPERIENCES WITH POLYMER-MODIFIED SHOTCRETE

Pittino Gerhard, Head of Technicum Material Testing
Galler Robert, Head of Chair of Subsurface Engineering (SE)
Department Petroleum Engineering and Mineral Resources, University of Leoben
Erzherzog-Johann-Strasse 3, A-8700 Leoben, Austria
T: 0043-3842-402-3401; F: 0043-3842-402-6602; E: subsurface@unileoben.ac.at

Bonin Klaus, Technical Manager in applied technology “Construction Polymers”
Bezler Jürgen, Head of applied technology Europe/NME “Construction Polymers”
Wacker Polymer Systems GmbH & Co. KG
Johannes-Hess-Strasse 24, 84489 Burghausen, Germany
T: 0049-8677-83-8134; F: 0049-8677-83-5909; E: klaus.bonin@wacker.com

ABSTRACT

Adhesive mortar for tiles can be significantly improved by modification. Why should sprayed concrete not benefit similarly for various applications? This question has been investigated through large-scale tests in a tunnel cross passage, in an access gallery of a salt mine and in a mining gravity shaft. In-situ tests are necessary because the sprayed concrete mix and the process engineering have a significant influence on the quality of the sprayed concrete. The fresh concrete properties and the properties of the sprayed concrete like early strength development, the ability to creep, adhesion, density and resistance to abrasion are all investigated.

INTRODUCTION

Sprayed concrete technology is responsible for the successful application of sprayed concrete. Some areas, like for example the mix recipe for wet-mix sprayed concrete can be formulated in the laboratory, but the complex interaction of dosage, mixing, transport and nozzle systems together with the method of application can only be properly evaluated by a large-scale trial.

This paper describes three large-scale tests or applications, which placed partially different requirements on the sprayed concrete.

The in-situ test in a tunnel cross passage (chapter 2) was intended to investigate whether the requirements for wet mix and the early strength development of a polymer-modified sprayed concrete could be achieved according to a J_2. In order to evaluate the creep behaviour, the requirements for the testing process in connection with the problem of sample taking are defined and a mobile pressure testing device is described. A long-term test is evaluated using the flow rate method, which describes the long-term behaviour on the basis of measurements of displacement or strain.
The access galley of a salt mine (chapter 3) was supported with modified sprayed concrete with particular requirements being placed on the adhesion and density. The project and the properties of the sprayed concrete are described.

A further in-situ trial (chapter 4), accompanied by laboratory tests, was intended to investigate the effectiveness of the modification of steel fibre sprayed concrete with the intention of improving the resistance to abrasion of the side walls of a gravity shaft in the mine.

IN SITU TRIAL IN A TUNNEL CROSS PASSAGE

The guidelines for sprayed concrete essentially require good workability and rapid early strength development. The particular feature of sprayed concrete in tunnelling is that the young concrete is subjected to large deformations while still hardening. In order that deformation can be absorbed, sprayed concrete is also required to be ductile and be able to creep. To estimate the actual load-bearing capacity of sprayed concrete through the degree of utilisation, knowledge is required about the development of its stresses and strength with time (1). The calculation of stress is performed today by measuring displacement or strain and using a stress-strain relationship determined in long-term compression tests.

During the lining work on the site of the north section of the S 35 Brucker expressway between the Zlatten reservoir and Mautstatt, the application of sprayed concrete and accompanying tests were performed in a cross passage of the Kirchdorf tunnel with the purpose of investigating the workability (Fig. 1), early strength development (Figs. 2, 3) and creep behaviour (Figs. 4 to 9) of a modified sprayed concrete.

The wet spraying process by dense-stream concrete conveyance, taking into consideration the delivery and waiting time in the tunnel site of about 1 hour, requires consistency corresponding to a slump flow (spread) between 55 cm and 60 cm. The required consistency was achieved through preliminary tests in the laboratory and the ready-mixed concrete plant (Table 1). Table 1 also shows the results of wet mix immediately before the application.

Tab. 1: Fresh concrete properties:
slump flow (spread), void content and fresh concrete density

		Preliminary test	Mix before application
Immediate slump flow	(cm)	58	-
Slump flow after 1h	(cm)	55	57
Void content	(%)	3.0	5.7
Fresh concrete density	kg/m^3	2335	-

Fig. 1: a) Flow table, b) Air meter c) Cylindrical steel forms

The early strength development of the applied modified sprayed concrete was determined using the penetration needle method (PNV) and the bold-driving method (BSV), with a Hilti DX 450 L piston tool (Fig. 2a) and a Hilti Mark-V pull-out device (Fig. 2b) being used in accordance to the sprayed concrete guideline (2). The results according to J_2, are shown on a diagram with logarithmic scale in each direction (Fig. 3b).

The concrete was modified in laboratory spraying tests so that the compressive strength corresponded to the required early strength class J_2. Because initially the strength reduction resulting from the use of accelerator (EB) was not to be investigated in the in-situ test, zero-concrete (sprayed concrete without accelerator) was not used.

The sprayed concrete guideline gives calibration curves for the penetration needle and bold-driving methods for common types of sprayed concrete, but also recommends that a calibration is done in the case of deviations, like for example in the hardness of the rock grains. In order to be able to estimate the relationship between cube strength and uniaxial compressive strength (UCS), the wet mix was filled into cylindrical steel forms (Fig. 1c) and mortar boxes and tested at predetermined times. The curve for zero-concrete is shown in Fig. 3a. Because the UCS were determined using cylindrical samples or drilled cores with a length-diameter ratio of 2, the relevant values in Fig. 3 are to be increased by 12.5%. Nonetheless a special calibration would be necessary if of interest.

Fig. 2: Determination of early strength using a) bold-driving and b) pull-out device

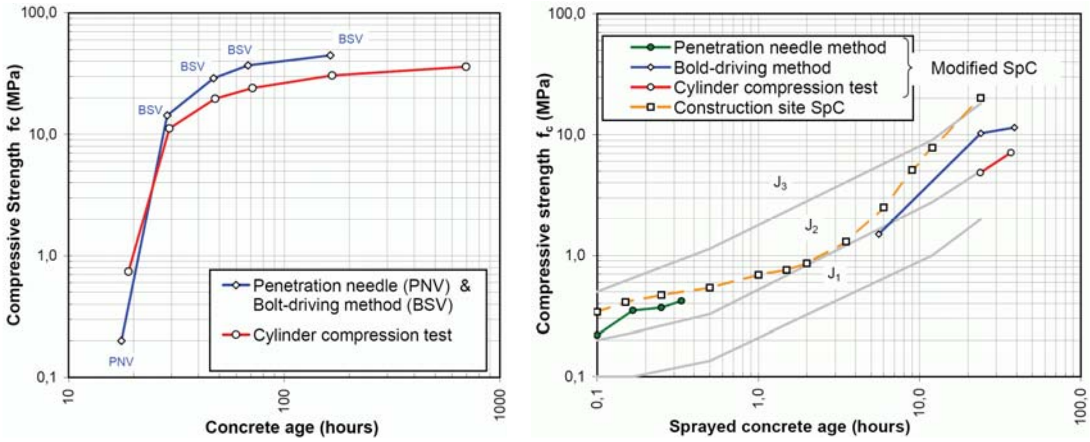

Fig. 3: Early strength development evaluated by means of penetration needle and bold-driving methods and cylinder compression tests.
a) Wet mix poured in formwork, b) Sprayed concrete on the tunnel sidewall

Fig. 4: a) Test box equipped with SSM-1 for shrinkage test, b) Formwork installation, c) Steel formwork with sprayed-in formwork

There is a not inconsiderable reduction of stress in sprayed concrete due to relaxation. The calculation of stress requires the prediction of the time-dependent behaviour of the material, a time-dependent constitutive model. The determination of the material parameters intended by the constitutive model is done through long-term tests, with the requirements for the testing process mainly affecting the production of the specimens and the properties of the specimens conversely determining the requirements for the test. Specimens cannot be taken by coring until after about eight hours or after a corresponding development of strength, 10 MPa according to (2). Spraying into special steel formwork and installation of the samples in the laboratory or in in-situ presses also have disadvantages. Mobile compression test equipment (Fig. 5) has now made it possible to come nearer to the ideal situation:

- The specimen is made at the same time as the tunnel shell (Fig. 4b)
- Specimen is geometrically defined and corresponds to the quality of the tunnel lining
- Loading direction of the specimen corresponds to that of the tunnel shell

- Loading can be applied straight after the production of the specimen
- Climatic conditions correspond to those in the tunnel

Two methods based on the measurement of displacement and strain are used at the moment to describe the time-dependent behaviour of sprayed concrete:

- The flow rate method and
- The time-hardening model.

Fig. 5: a) Mobile compression test equipment, b) specimen with loading (hydraulic cylinder) and measuring device (LVDT) in the tunnel side wall

Fig. 6: a) Sampling by coring and b) long-term test rig

The extended flow rate method according to Aldrian (1) separates the deformation of a loaded sprayed concrete sample into immediate and long-term deformations (Fig. 8).

The immediate deformation is divided into an elastic component, which returns to the original form straight after loading, a permanent plastic component and a compaction component, which can be determined after the first loading of the specimen.

The long-term deformation is divided into load-dependent creep deformation with permanent viscous and reversible viscoelastic strains and load-independent deformations, the shrinkage and temperature strains (1).

$$\varepsilon_3 = \varepsilon_2 + \underbrace{\frac{\Delta\sigma}{E_{28} \cdot V^*_{(t_2,\alpha)} \cdot f}}_{\substack{\text{Immediate}\\ \text{strain}\\ \text{increment}}} + \underbrace{\sigma_2 \cdot \Delta C \cdot \left(e^{8\alpha_2 - 6} + 1\right)}_{\substack{\text{Viscous}\\ \text{strain}\\ \text{increment}}} + \underbrace{\left(\sigma_2 \cdot C_{d\infty} - \varepsilon_{d_2}\right) \cdot \left(1 - e^{\frac{-\Delta C}{Q}}\right)}_{\substack{\text{Viscoelastic}\\ \text{strain}\\ \text{increment}}} + \Delta\varepsilon_{sh} + \Delta\varepsilon_t \quad (1)$$

The time-hardening model according to Boresi-Deere (2) or the ABAQUS potential equation represents a simple creep model, with the material parameter a and A, stress exponent n and time exponent m. An example for the identification of the parameters is given in (3).

$$\varepsilon_{cr}(t) = a \cdot \sigma^{\,n} \cdot t^{\,m} \quad (2)$$

Constant stresses of 4.0 MPa und 9.5 MPa and the resulting longitudinal compression strain for four creep tests with a degree of utilisation of 61% at the start of loading are shown as average value curves in Fig. 7a. Fig. 7b shows the shrinkage strain.

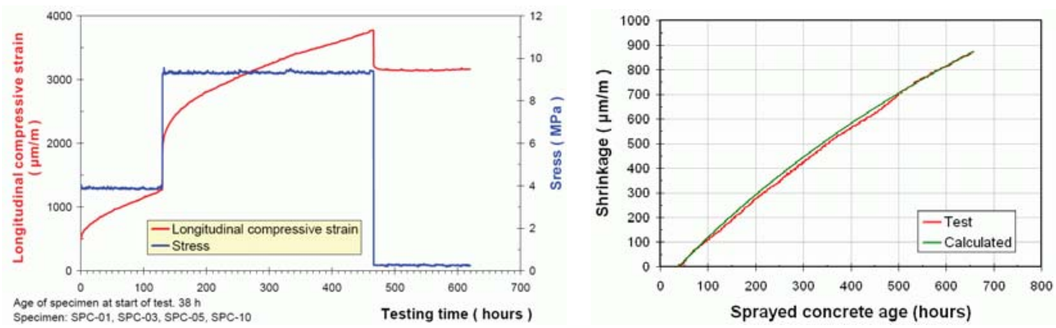

Fig. 7: Average value curves of the a) longitudinal compressive strain and stress and b) shrinkage strain

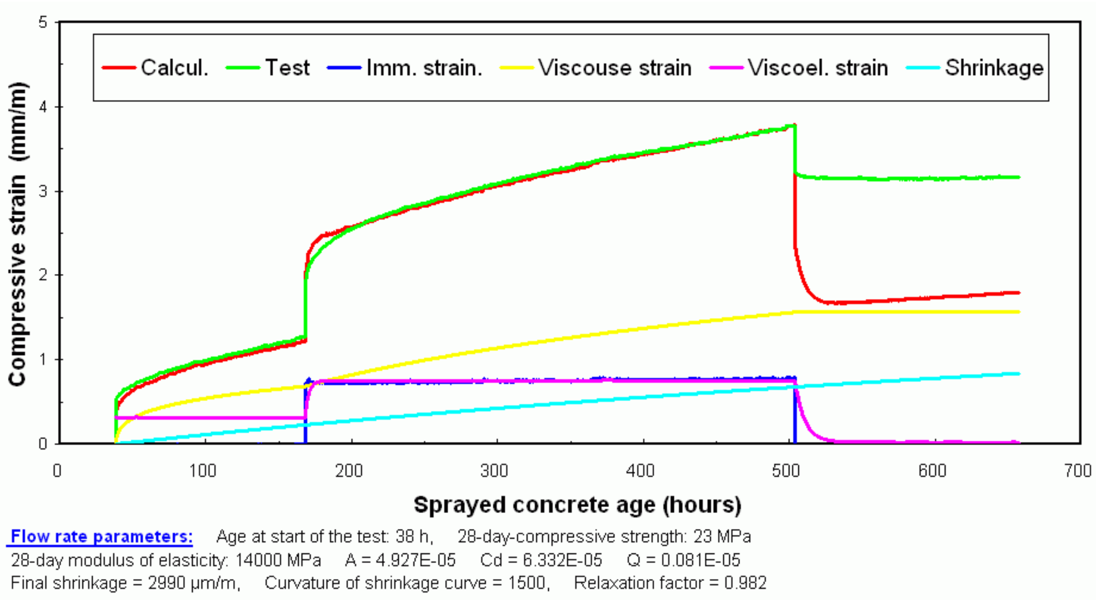

Fig. 8: Flow rate parameter identification for
the average value curve for longitudinal compressive strain

The determination of the flow rate parameters (Fig. 8) is iterative, i.e. the parameters are varied until the calculated strain curve best matches the test curve resulting from the given loading history. Fig. 8 also shows the strain component of the immediate strain, viscous and viscoelastic strain as well as the shrinkage strain. The flow rate parameter A and the value of the reversible creep deformation Cd essentially describe the creep deformation.

Because the temperature has an influence on the creep of a specimen and the sensors for the strain measurement also show temperature drift despite compensation for temperature, long-term tests will be run isothermally in the future, or the influence of the temperature will be purposefully investigated. For this purpose, the chair of Subsurface Engineering has purchased a climate simulation cell (Fig. 9) as part of the EFRE basic research, with the internal dimensions (LxWxH) 6 m x 3 m x 3 m, a temperature range from -15°C to 80°C and a relative humidity range from 10 % to 90 %. Initially, two long-term compression test rigs for a maximum sample size of 20 cm x 20 cm x 40 cm are installed in this, although it is also possible to test two smaller samples per test rig for load-controlled creep tests. The hydraulic equipment is designed for 70 MPa and can produce a compression force of 1000 kN with its hydraulic cylinders.

Fig. 9: a) Climate simulation cell with b) hydraulic equipment and
c) long-term test rigs

APPLICATION OF POLYMER-MODIFIED SPRAYED CONCRETE IN THE STETTEN SALT MINE

The Stetten salt mine (Baden-Württemberg) belonging to Wacker Chemie AG has produced salt from underground workings for over 150 years. The uses are many, with the salt mostly being used as road salt in the winter or for the chemical industry in the production of caustic soda and chlorine. The cavities produced by mining the salt can be backfilled again for safety reasons. The two existing access galleries are not accessible to standard vehicles on account of their profile. For this reason, construction of a new access for regular trucks was started in June 2007. The method of tunnelling chosen for the 905 m long access gallery with a gradient of 10% was drilling and blasting.

The intention of the application of modified sprayed concrete in the mine was to investigate its properties and their improvement. Laboratory tests into the fundamentals were carried out as preparation for the practical application of this sprayed concrete technology. The newly developed polymer-modified sprayed concrete was used for the first time under realistic conditions for application trials in October 2007. These trials showed, in addition to the reduction of rebound, some further interesting properties of additional benefit (adhesion and imperviousness) and made possible more extensive use in the tunnel at the start of 2008.

After the first months of tunnelling in the Stetten salt mine had run smoothly, uncontrolled water inflow occurred after about 450 m of tunnel length. The water made necessary, in addition to the use of sprayed concrete reinforced with steel mesh, extensive advance support with injections (Fig. 10).

These unfavourable conditions led to a reduction of the advance rate from 140 metres per month (m/M) to 50 m/M, and in January 2008 the work almost came to a standstill with an advance of only 10 m/M. The breakthrough planned for April 2008 was delayed by the problems by about three months (Fig. 11).

Fig. 10: Water flow out of the working face supported with sprayed concrete

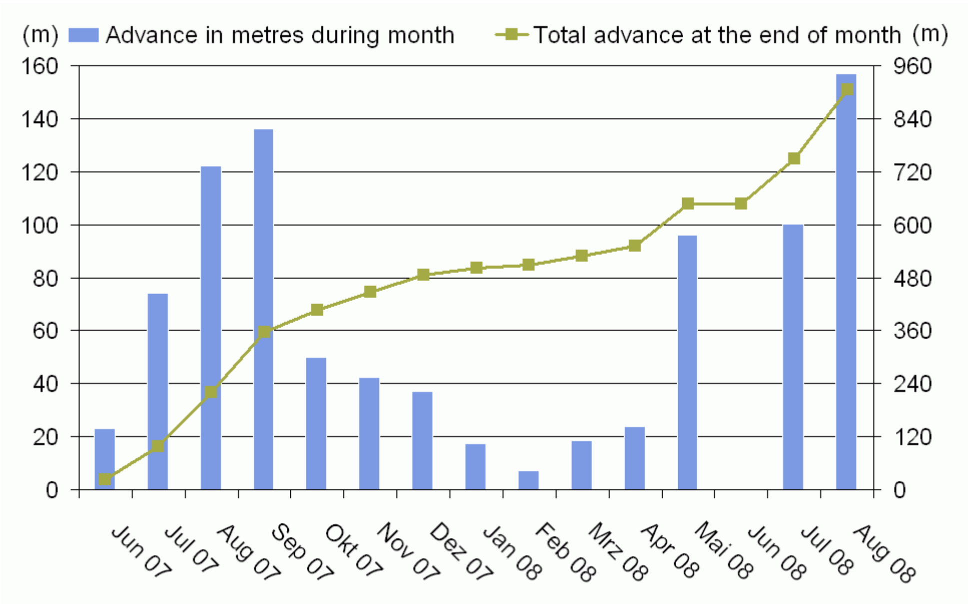

Fig. 11: Advance rates at Stetten

The wet-mix sprayed concrete originally intended for the project fulfilled its function as support under dry conditions, but showed weakness in the adhesion on wet background. The damage shown in Fig. 12, produced by wetness and water pressure, made the application of sprayed concrete more difficult and led to a local weakening. This made localised additional spraying necessary.

In order to avoid stopping work, it was decided to use polymer-modified sprayed concrete with improved properties. The critical stretch was altogether 100 m long, of which approx. 50 m were particularly critical.

Fig. 12: Typical damage to unmodified sprayed concrete due to formation water pressure

In the preliminary tests, the admixtures were added as powder or also in aqueous form at the mixing plant. For the large-scale application, the aqueous variant was used, which in this case produced advantages of handling in the mixing plant.

Altogether 15 m³ of admixture were used with a dosage of 40 litres to a cubic metre of concrete. It was possible to deliver the wet-mix of polymer-modified concrete produced like this to the construction site without any disadvantages in mixing or transport. On inspection of test surfaces in the side wall, the standard concrete (right in Fig. 13) showed many wet patches, which could be explained with the observations during the spraying of the concrete. The polymer-modified sprayed concrete (left in Fig. 13) in contrast had much better adhesion on a wet substrate, and is also denser and tends to form less cracks altogether.

The monitoring of the characteristics of the fresh concrete also shows the uniformity of the mixes regarding the suitability for transport. For this property, stable behaviour of slump flow (spread) is favourable (Table 2).

Tab. 2: Fresh concrete properties and cylinder compressive strengths (f_{cyl}) measured on drilled cores with 100 mm diameter and 200 mm height

	Reference mix	Modified mix	Modified mix
Admixture	none	aqueous	powder
Admixture to cement (%)	0	5 (bulk)	5 (bulk)
W/B ratio	0.47	0.47	0.47
Temp. fresh concrete (°C)	12	20	12
Immediate slump flow (cm)	58	55	58
Slump flow after 1h (cm)	58	55	58
f_{cyl} after 1d (N/mm²)	16.6	10.5	15.3
f_{cyl} after 7d (N/mm²)	17.0	22.1	17.1
f_{cyl} after 28d (N/mm²)	36.9	39.8	35.6

Fig. 13: Area of side wall with local application of polymer-modified sprayed concrete (left) and reference sprayed concrete (right)

LARGE-SCALE TRIAL OF THE USE OF POLYMER-MODIFIED SPRAYED CONCRETE AS LINNING MATERIAL FOR GRAVITY SHAFTS

The Erzberg in the Steiermark is the largest opencast mine in Central Europe and the largest deposit of siderite in the world. The valuable mineral is a carbonate iron ore called siderite or iron spar, which is complicated with very variable intensity with an iron magnesium carbonate, the ankerite. The scratch hardness (Mohs hardness) of siderite and ankerite is characteristically 4. Because there is a sliding transition (transitional porphyroid) between the porphyroidal deposit underneath and the formation containing the ore, part of the foot has to be excavated with the ore (4). Petrography regards the porphyroid as a metamorphous flood tuff, which was created in the Ordovician through sedimentation out of a glowing cloud of lava (5). The mineral composition of the porphyroid is mainly quartz, feldspar, mica and chloride. Considering the Mohs hardness, then it can be seen that the minerals in the barren rock like for example the quartz (Mohs hardness 7) or the feldspar (Mohs hardness 6.5) have a considerably higher Mohs hardness than the ore. This means that the barren spoil contributes considerable more to the wear of the lining material in the gravity shafts at Erzberg than the ore.

In addition to the hardness, the strength, size, shape, structure (hard phases within a grain, splittability), grading curve of the collective and system properties like relationship of the hardness between grain and material are also decisive properties, which influence the abrasiveness of the rock grains and their effect of wearing the lining material. From the tribilogical point of view, the rock grains, which lead to the wear on the lining material, are the abrasive. The lining material is considered to be the ground body (Fig. 14) (6).

The lining of the gravity shaft is affected by micro-chipping and scratching. This form of wear is described as abrasive wear. The resistance, which a material has against such wear, is called abrasion resistance. Materials used for the lining include wear plates of steel and sometimes granite blocks.

Because of the expensive process of replacing the wearing plates or granite blocks, which means stopping operation while it is performed, VA Erzberg GmbH looked for alternatives for the lining of the shafts. As part of this process, the application of steel fibre sprayed concrete was investigated in in-situ trials and accompanying laboratory tests.

Fig. 14: Types of wear on the lining material

The type of wear on the surface of the solid body caused by the abrasive, the primary broken rock, in the gravity shaft of the Erzberg can firstly be described as impact or collision loading because the rock broken by the breaker falling by gravity and any deviation from the breaking process meets the lining of the gravity shaft with considerable speed. The second type of wear is from the continuous transport of the material through the extraction point at the foot of the shaft. The removal of the broken rock causes a sliding of the rock grains along the lining, which causes compression loading. The impact and collision loading leads to wear through abrasive impact. In contrast, the sliding of the rock grains along the lining causes abrasive wear.

The use of modified steel fibre reinforced shotcrete is expected to produce very high wear resistance. Because the concrete reaches about 80 % of its final strength after about 30 hours, it is certain that the broken rock can be transported through the gravity shaft again without problems after only a short interruption. If repair works are performed at the weekend, then operational stoppages can belong to the past. The problem that destroyed and unattached steel elements cause damage in the following areas of processing is also solved.

The steel fibre content was 40 kilogrammes per tonne dry component (TM) at the start of the trials. Steel fibre reinforced shotcrete (SFRS) containing black dye was applied directly onto the substrate in order to be able to monitor the localised wear. Uncoloured concrete was sprayed on top (Fig. 15).

There is information in the specialist literature about the wearing behaviour of steel fibre reinforced concrete, comparable with the SFRS, and its possible areas of application. The Internet page Beton.org, which is a service of the German cement and concrete industry, makes the following statements:
"Reduction of the wear depth: the effects of wear, for example of floors, can be reduced by up to 25 % with a dosage of 1.0 Vol. % steel fibres."

“Higher resilience/impact resistance: the impact resistance is defined as how often a defined weight has to contact the concrete surface until it breaks. The impact resistance of steel fibre reinforced concrete is up to 20 times higher than comparable plain concretes.”

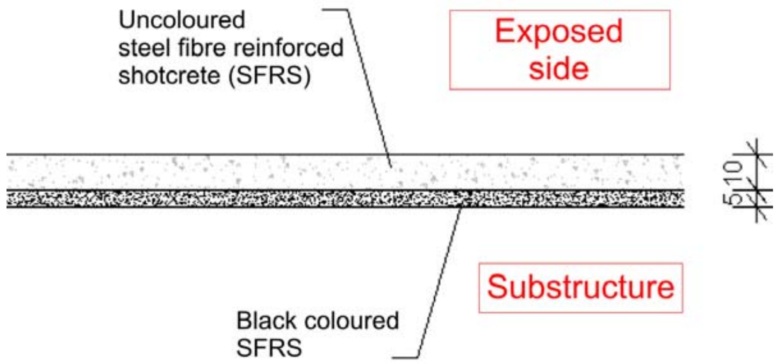

Fig. 15: Wear monitoring with differently coloured layers of sprayed concrete

Because of the similarity of steel fibre reinforced concrete and SFRS, an attempt was made to use this experience at Erzberg. Firstly a black coloured layer of sprayed concrete was applied directly to the surface of the substrate. A thickness of 5 cm was decided for this black coloured layer of sprayed concrete, which ensured a reliable wear indicator of black SFRS.

To check the material behaviour of the SFRS used at Erzberg, accompanying laboratory and on-site tests were carried out. All sprayed concrete samples were produced in the works of the Schretter & Cie company and delivered to Leoben or to the VA Erzberg GmbH.

The purpose of the in-situ tests was to investigate the knowledge about resistance to abrasion and the compatibility of the sprayed concrete with the rock types excavated at Erzberg, and to produce quantitative test results. In addition to the types of SFRS applied in the gravity shaft, tests on other types of SFRS were carried out near the processing plant using quartz sand as aggregate and with the subsequent addition of admixtures from the company Wacker Chemie. The W/B ratio of these types of SFRS was altered compared to the SFRS being used in the gravity shaft to improve the matrix properties of the sprayed concrete.

These in-situ tests with alternative types of SFRS were intended to evaluate whether the improvement of the matrix properties and the use of abrasion-resistant aggregates (quartz sand) including the use of admixtures had a positive effect on the wear behaviour.

The purpose of the material tests in the laboratory was to determine whether the increase of the steel fibre content from 40 kg to 60 kg steel fibres per tonne TM leads to an improvement of the material properties and thus possibly to an improvement of the abrasion resistance of the SFRS. Fig. 16 shows the sampling from the delivered test bodies and the distribution of the various types of test.

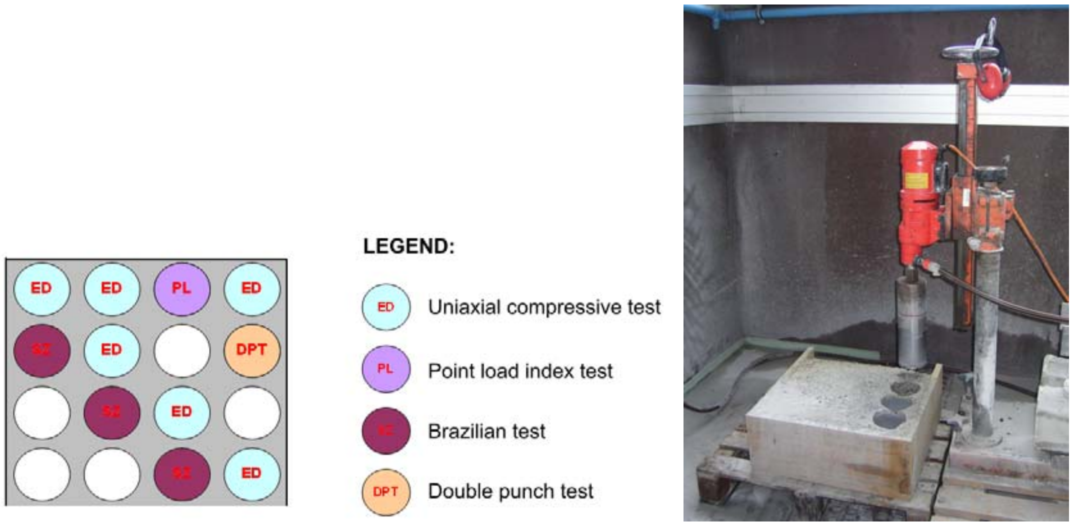

Fig. 16: Sampling in the laboratory.

The arithmetical mean of the material properties determined in uniaxial compression tests are rather higher for the test bodies with 40 kilogrammes of steel fibres per tonne TM then for test bodies with 60 kilogrammes of steel fibres per tonne. Thus the increase of the steel fibre content does not positively affect the material properties (Table 3) determined in a uniaxial compression test (Fig. 17a).

Tab. 3: Comparison of the arithmetical mean of the material properties determined in the uniaxial compression test with differing steel fibre contents

Average	STF 40	STF 60	Difference (STF60-STF40)
E modulus (MPa)	29260	28770	-490
V modulus (MPa)	26000	25320	-680
Poisson’s ratio	0.13	0.12	-0.01
UCS (MPa)	60.2	56.4	-3.8

From the arithmetical mean of the results of the Brazilian cylinder splitting test (Fig. 17b), it can also be seen that increasing the steel fibre content leads to no increase of the indirect tensile strength (Table 4).

Tab. 4: Comparison of the indirect tensile strength in MPa with changing steel fibre content

Sample	STF 40	STF 60	Difference (STF60-STF40)
21-T1	5.57	5.83	0.26
21-T2	4.71	5.78	1.07
21-T3	6.15	5.60	-0.55
32-T1	5.85	4.75	-1.10
32-T2	5.58	4.92	-0.66
32-T3	4.67	5.12	0.45
43-T1	4.85	4.97	0.12
43-T2	5.92	4.99	-0.93
43-T3	7.09	3.90	-3.19
Mean	5.60	5.09	-0.51

The point load indices determined in the point load tests are shown in Table 5. The increase of the steel fibre content also leads to no increase of the point load index determined in the point load test (Fig. 17c).

Tab. 5: Comparison of the point load index with changing steel fibre content

Sample	STF 40	STF 60	Difference (STF60-STF40)
13-T1	4.33	4.51	0.18
13-T2	4.90	4.56	-0.34
13-T3	4.74	4.48	-0.36
Mean	4.66	4.48	-0.18

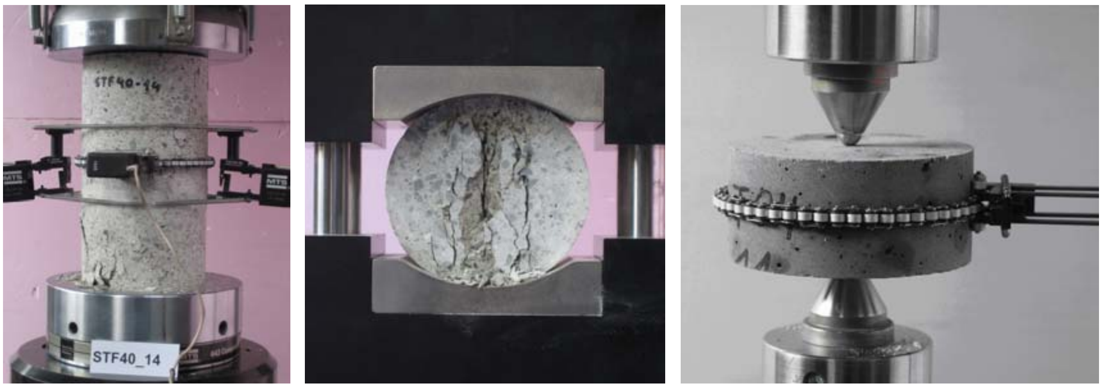

Fig. 17: a) Uniaxial compression test, b) Brazilian test, c) Point load test

In order to make the connection between the test results obtained in the laboratory and the requirements of the VA Erzberg GmbH, on-site tests were carried out on the premises of VA Erzberg GmbH. The purpose of these tests was to evaluate the material behaviour for the exposure conditions typical at the Erzberg (type of exposure, type of rock). In order to do this, the company Schretter & Cie manufactured test slabs with various mixes of sprayed concrete and hung them at a material transfer location in the processing plant. This caused the test slabs to be exposed to extreme wear (Fig. 18).

The test data, which were recorded, were the length of time the sprayed concrete slabs were exposed, the mass of broken rock conveyed over the slabs and the mass of the slabs before and after the test. Through determining the mass of the slab before and after the test, the loss of mass can be calculated and this can be used as a measurement for the evaluation of the abrasion resistance.

In order to evaluate the abrasion resistance of the SFRS from the company Schretter & Cie in the first series of tests, two slabs each were made containing 40 kilogrammes and 60 kilogrammes of steel fibres per tonne TM. After 110 hours, about 21,000 tonnes of broken rock had passed the SFRS slabs. The wear was immensely high, so the first test had to be broken off after 110 hours.

Fig. 18: In-situ tests with test slabs at a material transfer location in the processing plant to investigate the wear behaviour

For operational reasons, however, the slabs could only removed after a material flow of 270,000 tonnes, a test duration of 12 weeks. On removing the slabs, it became apparent that two slabs had been fully destroyed during the test and it was clear that the type of SFRS used on the first series of tests was not capable of coping with the exposure.

The In-situ tests in the next test series were done using a lower W/B ratio, using quartz sand as aggregate and, for two of the test slabs, with the use of admixtures from the company Wacker Chemie. Macroscopic observations showed that the wear effects after 100 hours and a material flow of 20,000 tones were not so pronounced in comparison to the first test series, and the wear patterns were more uniform. After 270,000 tonnes of material had passed, the slabs were removed again.

Comparison of the in-situ test series: Although the results according to the weight loss method showed no major difference, there are some factors, which point to a higher abrasion resistance of the SFRS slabs in the second test series. As already mentioned above, the wear patterns of the slabs in the second test series appear much more uniform after 100 hours; additionally, when the test slabs were removed after a material flow of 270,000 tones, all four SFRS slabs were intact, in contrast to the first test series. This showed that the use of quartz sand as aggregate, the addition of admixtures from the Wacker Chemie and the alteration of the W/B ratio had a positive effect on the wear behaviour.

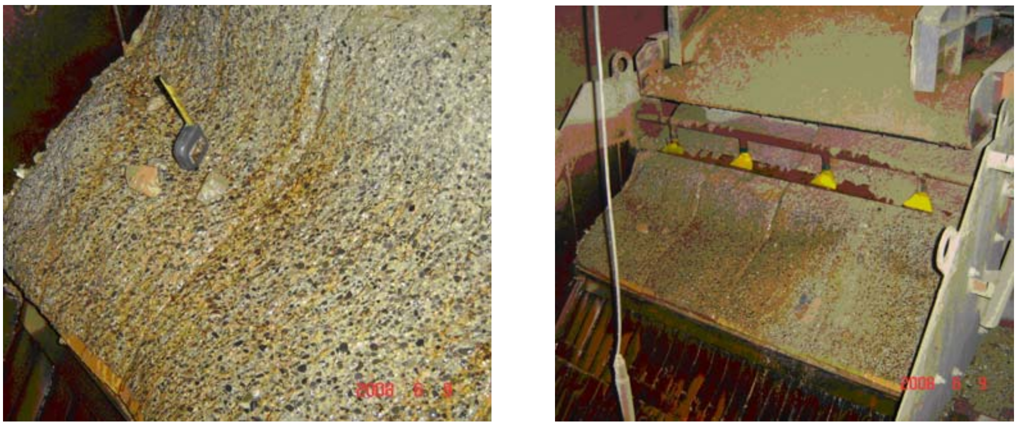

Fig. 19: Wear patterns of the test slabs after the second test series

SUMMARY

The use of polymer-modified sprayed concrete under construction site conditions, in this case the use in a cross passage and access gallery, and under operating conditions in mining proved successful.

The in-situ test in the tunnel cross passage with the related preliminary tests and accompanying test programme showed that the polymer-modified sprayed concrete fulfilled its purpose. This, and modification in the direction of increased creep capacity will be the subject of further tests.

During the construction of the access gallery, the standard sprayed concrete showed deficiencies in the adhesion on a wet substrate and when affected by water under pressure. The change to polymer-modified sprayed concrete made it possible to continue the work and made it possible to complete the access gallery within an acceptable time.

In the in-situ test in the mine, the use of polymer-modified steel fibre sprayed concrete led to an increase of abrasion resistance. The comparison of the results of various laboratory tests on SFRS with differing steel fibre content showed no significant differences due to the sample size.

REFERENCES

(1) Pittino, G.; Gharehkhani, G.; Krenn, F.; Stelzer, G.; Golser, J.: Spritzbeton – der etwas andere Beton, Untersuchungen zum Materialverhalten und Prüfung *(Sprayed concrete – the rather different concrete, investigations into material behaviour and testing)*. Beton- und Stahlbetonbau 99 (2004) Heft 2, S.97-102.

(2) Richtlinie Spritzbeton *(Sprayed concrete guideline)*: Österreichische Vereinigung für Beton- und Bautechnik (ÖVBB). Vienna 2004.

(3) Pittino, G.: Tragverhalten des Gesamtsystems „Alpines Salzgebirge – Grubengebäude – Laugungsrückstand“ *(Load-bearing behaviour of the total system „Alpine salt mine – mine building – leaching residue“)*. Dissertation MU-Leoben, 2002.

(4) http://www.abenteuer-erzberg.at, am 18.03.2008.

(5) http://www.mineralienatlas.de/lexikon/index.php/Porphyroid, am 18.03.2008.

(6) Uetz, H.: Abrasion und Erosion: Grundlagen, betriebliche Erfahrungen, Verminderung *(Abrasion und Erosion: fundamentals, operational experience, reduction)*. Carl Hanser Verlag. 1986.