# APPLICATION OF NOVEL BI-COMPONENT FIBERS IN SPRAYED CONCRETE

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## Abstract

*In tunnel and mining applications spraying of concrete is a well-established and economical alternative to conventional casting techniques. Further time and cost savings are achieved when fiber reinforced concrete is applied. Often steel fibers are used for such purpose. Corrosion risk, damage of water drainage foils through the stiff fibers and a relatively high fiber rebound, fibers falling off the wall upon spraying, are some of the drawbacks. A polymer fiber would not suffer from such, but so far other problems like creep or insufficient mechanical properties prevented from a wide application of such fiber types.*

*Recently developed structured bi-component polymer fibers were tested for spray applications as well. In field tests fiber-concrete was sprayed on well-defined artificial stone walls with a rock-type relief. The fiber content of the sprayed concrete and the rebound was measured. Low rebound and fast wall thickness increase, both decisive economic factors were observed.*

*Creep of fiber reinforced concrete under bending was studied in permanent load tests. Square plates and beams were used as specimens. In these laboratory tests it could be demonstrated that for this type of structured plastic fibers creep seems not to be a limiting factor.*

**Keywords: Sprayed concrete, bi-component fiber, rebound, fiber orientation, creep**

## 1. Introduction

Steel fiber reinforced shotcrete is widely applied in mining operations, for forming linings in various railway, road and water tunnels. Other applications include rock slope stabilization work, canal linings or post-strengthening of deteriorated concrete structures [1]. The material is more economical and technically equal to conventional shotcrete using wire mesh and allows modern excavating equipment to advance with fewer interruptions [2].

During the spray process the fibers and the material may not adhere completely on the wall, so that a certain rebound is observed. The relative losses for coarse aggregates and

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fibers have been found to be higher than for the rest and the properties of the sprayed concrete may be different when sprayed.

Austin [3] found no significant influence of fiber addition nor fiber geometry or fiber mass on the material rebound. Variations in spray conditions had a higher effect. Fiber rebound also was found to increase with higher aggregate to cement ratio and the addition of very fine microsilica lead to less rebound. Steel fiber rebound did not appear to be related to fiber geometry in a wet-process [4].

Polymer fibers in wet-mix shotcrete application have grown significantly worldwide since their introduction in the late 1990's. As opposed to the stiffer steel fibers to be used at relatively short length (30-35mm) to reduce lime blockage, the more flexible macro-synthetic fibers can typically be used at larger length (40-60mm) without significantly reducing the pumpability and shootability of the mixture. Furthermore an increased layer built-up thickness was observed for this fiber type [5]. Polypropylene fibers were found to lead to a reduction of fiber loss due to rebound [6].

Modern fiber technologies nowadays allow the production of bi-component fibers which possess a sheath and a core which may consist of different polyolefin polymers [7]. The sheath is optimizes regarding adhesion and bonding, while the core delivers high adequate mechanical properties. The rebound behaviour of such fiber type was studied here in detail.

Limitations of the application may arise from the fact that polymeric fibers may creep. However, Gossla [8] found limited creep for plastic fibers in prism creep tests for load levels lower than about 50%.

## 2. Materials and methods

### 2.1 Spray test and rebound

Concrete (CEM I 42.5 N: 450 kg/m$^3$, Sand 0..1 mm: 116 kg/m$^3$, sand 0..4 mm: 958 kg/m$^3$, gravel 4..8 mm: 578 kg/m$^3$, superplasticizer: 2.7 kg/m$^3$ viscocrete SC-305 (0.6% of cement), stabilizer: 0.45 kg/m$^3$ delvo crete stabilizer (0.1 % v. Z), w/c=0.45) was premixed for 2 minutes and then the fibers were added. Two differently structured polyolefin based bi-component (Concrix 1/2, diameter 0.5 mm, cut length 50 mm) fibers and one hooked-end steel fiber (Dramix 65/35, diameter 0.54 mm, length 35 mm) were used. The surface profile of the Concrix 2 fibers had a higher depth than Concrix 1 (rougher surface) so that a better bonding to the cementitious matrix results, but was otherwise identical. Additionally the effect of the addition of a small quantity of a much finer polyolefin fiber (Fibrofor HG 190, thickness 0.08 mm, length 19 mm).

The fresh concrete then was transported (5 minutes way) to the spray equipment (Meyco suprema) and sprayed onto specially designed identical concrete panels (3.5x1.39 m$^2$). These concrete walls were previously produced using special casings (artificial stone profile Cheyenne_2_121G, Reckli AG, Switzerland) so that the panel surfaces assumed well-defined identical artificial rock structure (Fig. 1).

The first cubic meter was sprayed onto a tunnel wall without special considerations in order to adjust spray settings like air pressure and accelerator dosage (accelerator: Sigunit L 53 AF, 27 kg/m$^3$ = 6% of cement). The spray parameters were kept widely constant for all mixtures. Then concrete was sprayed during a fixed time onto the artificial rock wall. The rebound on the floor was collected by means of a large plastic foil. The material uptake onto the artificial rock wall was determined by weighing them before and after the spray concrete application.

About 10 kg of freshly applied concrete was collected from the walls in order to determine the fiber (washing out of the fibers) and the content of the grains larger than 4 mm. Both values also were determined from the collected rebound lying on the floor.

Furthermore, square panels of 600x600 mm$^2$ with a thickness of about 200 mm were produced (sprayed). After hardening (covered with plastic sheets in tunnel environment at about 15°C), at an age of about 7 days, these panels were transported to the laboratory. There the front and backside were partly removed and polished (<1/10 mm), so that both sides achieved smooth and parallel faces. In that way the square panels (two of each mixture) obtained dimensions of 600x600x100 mm$^3$. The panels then were stored at 20°C/90%RH (up to an age of 28 days) and finally tested according to Swiss standard 162/6 (Testing of steel fiber concrete (1999)), which actually is very similar to the EFNARC square panel test. Specimens were loaded at their centre by means of a 100x100 mm$^2$ steel plate. The square panel was supported on a steel frame (500x500 mm$^2$, width 5 mm). The steel frame was polished to achieve a flat surface in order to prevent friction. The displacement w, increased at a constant rate of 0.025 mm/sec, and the resulting load F was measured. The energy absorption for a deflection until 25 mm according EFNARC guidelines (1996) was determined by integration of the load-deflection curve.

Fig. 1 Artificial rock wall before (left) and after spraying of concrete (right).

## 2.2 Square panel bending creep test

Macro-synthetic plastic fibers may bear the risk of high creep under tension. However, novel fiber technologies allowing the production of polyolefin based fibers with higher elastic modulus, the application of special fiber additives and structuring of the surface can significantly reduce bending creep in fiber reinforced concrete. Creep of bi-component (Concrix) fibers in the post-peak state (pre-cracked) was studied on square panels. The test equipment is widely identical to the set-up of the square panel test (central load 100x100 $mm^2$, square support 500x500$mm^2$) with the difference that the applied load is kept constant. The panels had a dimension of 600x600x100 $mm^3$. The deformation was measured by periodically (once per week) measuring the distance between two extension points (see Fig. 2) by means of a dilatometer at four different positions.

The square panels were pre-cracked prior to creep testing in a standard square panel test (SIA 162/6) until a deflection of 2 mm and then discharged. After that they were mounted in the creep frame and reloaded up to a certain percentage (48% resp. 62%) of the load reached before (at the deflection of 2 mm). The concrete used in these tests had the same composition (without stabilizer and accelerator) as the one used in the spray rebound tests. Casting was not by spraying for creep tests, but conventionally filling the fresh concrete into casings. Compaction was achieved by bar vibration.

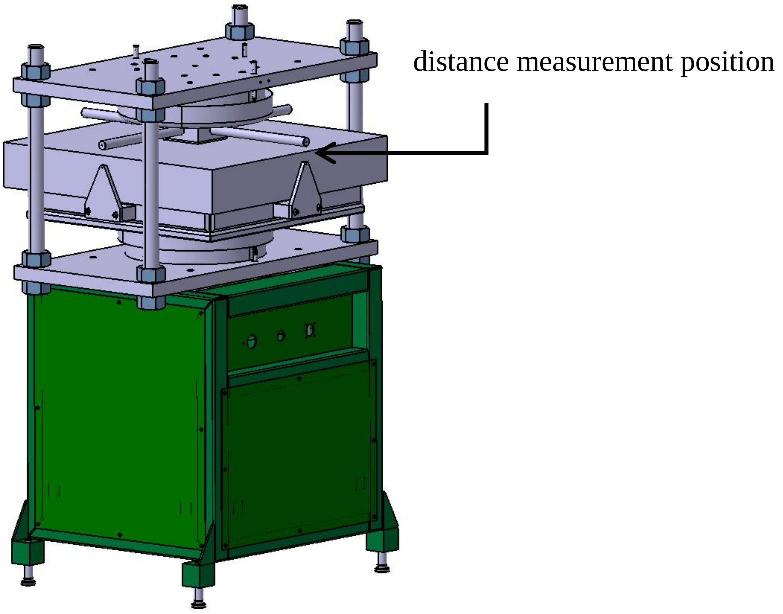

Fig. 2 Test arrangement for bending creep tests.

## 3. Results

### 3.1 Field spray tests

The mixture design and the fresh concrete parameters as derived directly after mixing of the concrete used in spray tests as well as some spray parameters are provided in table 1. Within the limitations of a field test, the important concrete parameters were successfully kept widely constant for each fiber variation. The achieved fresh concrete properties led to excellent spray conditions.

In table 2 the material rebound as collected on the tunnel floor compared to the mass remaining on the artificial rock wall and the relative amount of large grains (> 4 mm) is plotted. As can be seen, there a relatively small material rebound was collected. There seems to be a higher material rebound for the mixture with the higher fiber dosage (mixture 2) and for steel fibers (mixture 5). The application of a fine fiber (mixture 4) or a different surface (mixture 1 compared with mixture 3) resulted in similar material (concrete) rebound. The rebound of large grains seems to be relatively higher than the material rebound.

Tab. 1 Mixture design and fresh concrete properties of sprayed concrete

| | mixture 1 | mixture 2 | mixture 3 | mixture 4 | mixture 5 |
|---|---|---|---|---|---|
| **fiber parameter** | | | | | |
| fiber type | Concrix 1 | Concrix 1 | Concrix 2 | Concrix 1<br>+ HG 190 | Dramix 65/35 |
| fiber length [mm] | 45 | 45 | 45 | 45 // 19 | 35 |
| dosage [kg/m$^3$] | 4.55 | 9.1 | 4.55 | 4.55 // 0.5 | 30 |
| **fresh concrete properties** | | | | | |
| slump flow [mm]*) | 490 | 500 | 520 | 460 | 540 |
| density [kg/m$^3$]**) | 2346 | 2322 | 2311 | 2296 | 2359 |
| air content [%]***) | 2.4 | 2.6 | 2.8 | 3 | 2.2 |
| water content [kg/m$^3$] | 207 | 209 | 198 | 204 | 204 |
| w/c | 0.46 | 0.47 | 0.44 | 0.45 | 0.45 |
| **Application parameters** | | | | | |
| pump pressure | 50 | 50 | 50 | 50 | 45 |
| air pressure nozzle | 3 | 4 | 3 | 2.5 | 4 |

*)EN12350-5 **)EN12350-6 ***)EN12350-7

Regarding the rebound of fibers, the fiber content in the sprayed concrete that remained on the artificial rock wall was significantly lower than the one of the original dosage. A clear positive effect was observed when applying a fiber hybrid composition containing a fine fiber (mixture 3). The fiber dosage had no significant influence on the fiber rebound (mixture 2 compared to mixture 1) which underlines also the good dispersion properties of the Concrix fibers which are applied in bundles enwrapped in a water soluble foil. The rougher surface of one of the bi-component fibers led to a relatively high measured fiber rebound (mixture 3), but this result may be somewhat erroneous as small cement lime particles could not be removed completely from the fibers by the washing-out. A significantly higher fiber rebound was observed for the steel fibers (mixture 5).

Interesting is the thickness growth rate determined by weighing the artificial rock walls before and after spraying during an equal time for all mixtures. At the same spray duration, the concrete containing Concrix fibers (mixtures 1-3) led to a significantly higher mass uptake and larger wall thickness than the steel fiber reinforced concrete mixture (mixture 5). A significant cost reduction when applying plastic fibers instead of steel fibers hence may result. The hybrid fiber mixture (mixture 4) also showed lower mass uptake which might be related to the lower air pressure at the nozzle. The longer the fibers, the better were the results.

Tab. 2 Rebound properties and wall thickness growth

| | mixture 1 | mixture 2 | mixture 3 | mixture 4 | mixture 5 |
|---|---|---|---|---|---|
| **material rebound** | | | | | |
| grains > 4mm on wall [% of material] | 28 | 24 | 29 | 28 | 27 |
| grains > 4mm rebound [% of material] | 35 | 37 | 43 | 46 | 35 |
| material rebound [% of material] | 9.1 | 12.0 | 10.6 | 9.8 | 11.6 |
| **fiber rebound** | | | | | |
| from artificial wall [% of dosage] | 31 | 25 | 39*) | 10 | 44 |
| **thickness growth** | | | | | |
| material on wall [kg] | 1300 | 1216 | 1434 | 983 | 942 |

Fiber orientation in the concrete sprayed onto the artificial rock wall was determined by X-ray computer tomography. Fiber extraction of the plastic fibers resulted to be rather difficult and was only possible by adapted thresholding and morphological data analysis. One result of mixture 2 shows preferred fiber orientation along the rock wall. Similar result also was found for the steel fiber reinforced mixture.

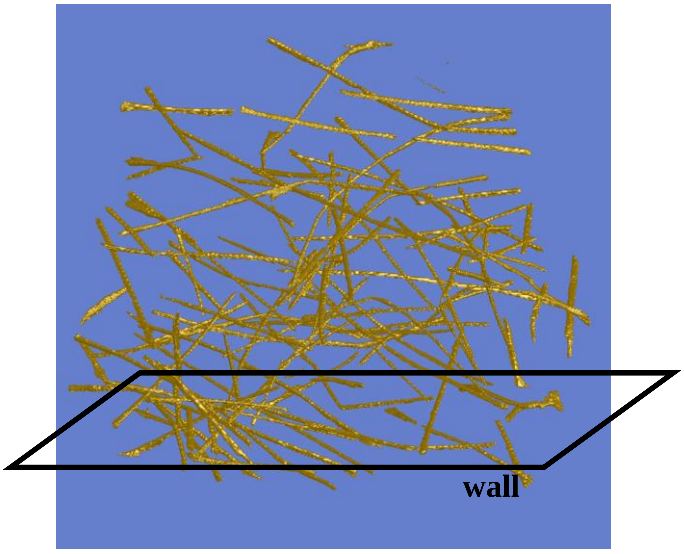

Fig. 3 Fiber orientation along artificial rock wall (X-Ray computer tomography image of plastic fibers in a drill core (Ø = 70 mm, height =50 mm)

Mechanical testing of the sprayed square panels revealed a high energy absorption capacity for almost all mixtures. Typical load-deflection curves are shown in figure 4 and characteristic values are provided in table 3. With 4.55 kg/m$^3$ of polyolefin Concrix fibers a similar result as with 30 kg/m$^3$ of steel fibers could be achieved. Mixture 3 containing the fibers with a deeper surface structured performed worse. One explanation may be related to the excellent bonding of the fibers to the cementitious matrix, which in this case was even too strong so that fiber rupture might have occurred. The broken fibers then certainly could not contribute to the energy absorption any more.

Tab. 3 Results of square panel test results.

| | density [kg/m$^3$] | peak load [kN] | number of cracks | $E_{EFNARC, 25mm}$ [J] |
|---|---|---|---|---|
| mixture 1 | 2269 | 59.1 ± 1.2 | 4 | 637 ± 1 |
| mixture 2 | 2254 | 69.2 ± 5.2 | 5 | 1122 ± 19 |
| mixture 3 | 2271 | 65.7 ± 8.4 | 4 | 454 ± 29 |
| mixture 4 | 2267 | 62.9 ± 2.7 | 5 | 729 ± 54 |
| mixture 5 | 2306 | 62.9 ± 5.9 | 4 | 729 ± 30 |

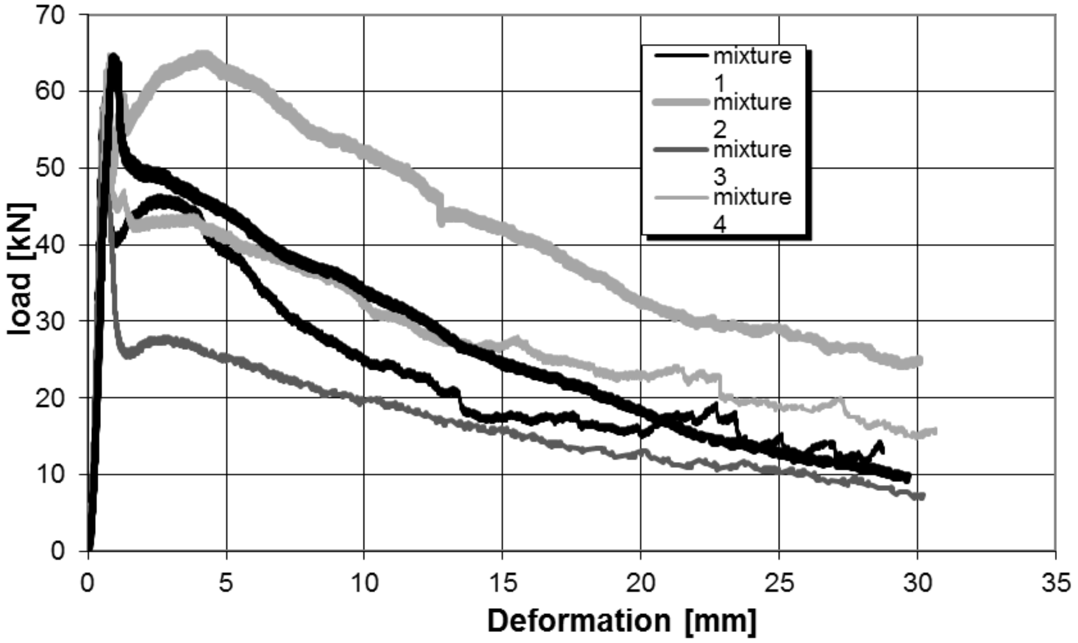

Fig. 4 Load-deflection curves as obtained from square panel tests (SIA 162/6).

## 3.2 Creep of square slab panels

The mean deflection (mean of 4 measurement positions) of two different square panels with constant centric load in function of time is plotted in figure 5. Initially both samples had been loaded at much higher load levels, which explains the strong increase of the deflection until 5 days. The loads were then reduced to the indicated values and the deflection then stabilized with slight increase only. The small increase at 150 days can be attributed to a slight readjustment of the load, which was controlled weekly. The stable creep load levels of 62 % (40 kN) resp. 48% (20 kN) are high regarding all the safety reductions of the mechanical properties which have to be taken into account for the assessment of a construction [8]. Creep hence seems not to be a limiting application factor for these macro-synthetic fibers.

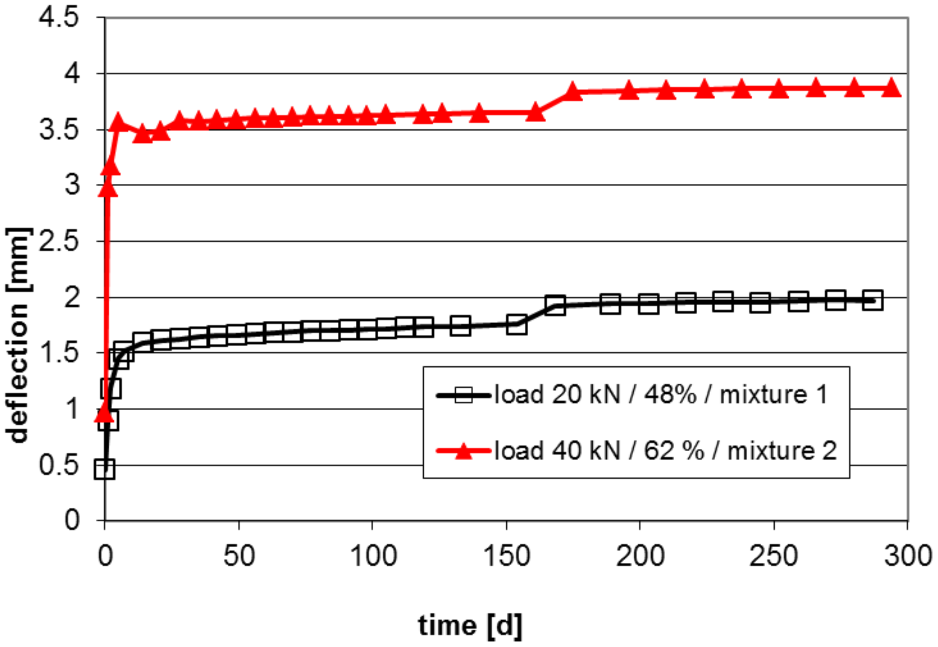

Fig. 5 Creep behaviour of polymer fiber reinforced concrete square panels.

## 4. Conclusions

The fiber and material rebound of sprayed fiber reinforced concrete was studied in field application tests on well-defined artificial stone reliefs. The rebound of larger grains and especially of fibers was significantly more important than the concrete rebound.

Plastic macro-synthetic fibers were found to have less rebound than steel fibers. A higher fiber dosage did not lead to a higher rebound. Fibers were observed by computer tomography to be oriented along the rock wall.

Furthermore, the fiber type seems to influence the thickness growth on the wall. Bi-component (Concrix) fibers were found to lead to a significantly faster concrete deposit on the walls than steel fibers.

Creep seems not to be a limiting application factor for these macro-synthetic fibers. In square panel bending creep tests, for bi-component fiber reinforced concrete stable deformation was observed for load levels up to more than 62 % (40 kN).

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