Usage of Polyvinyl Alcohol (PVA) Fibre as Slurry Wall Reinforcement Material for the Two-Phase-Process

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ABSTRACT: Nowadays, slurry walls are used in many cases to ensure potential contaminant wells, such as landfills, refineries or other industrial facilities. In this way, it is aimed to prevent contaminated leach ate from broadening outside the encapsulation. As shown in various experiments, clay-cement bonded slurry wall materials are quite refractory. Furthermore, they are only able to absorb small amounts of tensile strengths. This material behaviour plays an important role at variations of stresses in soils. Installed in the ground, the functionality of slurry walls can be reduced significantly by fractures caused by additional tensile strengths. To address this problem, PVA fibre reinforcement was used to improve the functionality of the slurry wall. The purpose of PVA fibres is the improvement of mechanical properties, such as ductility and tensile strength of. The prevention of crack initiation and propagation was expected when PVA fibres were added. In case of a good bond between expandable PVA fibres and the cement matrix, fibres are able to absorb a significant amount of tractive forces when the cement is fractured. Since it is known that the fibre geometry influences the bond strength considerably, different fibre geometries were investigated. More over, the fibre content was varied to optimise its mechanical properties and process ability. This means that the process ability of the new fibre-slurry wall mixture compared to the process ability of the initial mixture must not be worse. Unconfined compression tests and bending traction tests were made on reinforced slurry wall material samples. Test results revealed the tendency to improved mechanical properties.

1 INTRODUCTION

Small and large scale mechanical experiments were carried out to investigate active slurry wall materials. The material that is used for the two-phase-process, was developed by the Division for Geotechnical Engineering (IGT) at the Swiss Federal Institute of Technology (ETH) in Zurich (Brinkmann 2002).

The experiments showed that the slurry wall material has a low ductility, and therefore a low tensile strength (Brinkmann et al. 1999).

Responsible for the brittle behaviour is the Calciumsilicatehydrate in the cement stone. The short fibres of this structure have an irregular meshwork, which leads to substantial resistance to compression loading. On the other hand, this material can not mobilise its full tensile strength. Under tensile stresses, the fibres are pulled out of the structure and inhibit the possible tensile strength (Wischer 1974).

Fibre reinforcement, as used in fibre concrete, was used to enhance the material properties. Polyvinyl Alcohol (PVA) fibres were chosen based on laboratory tests carried out at IGT (Brinkmann 2002).

2 THE FIBRE-MATRIX-INTERACTION

In brittle materials, crack initiation already starts at low expansions. Reinforcement is used to limit expansions as long as possible. Fibres are capable for reinforcement because of their high tensile strength and ductility. Furthermore, they can be easily distributed in the slurry wall material.

In general, they inhibit the crack initiation by spreading charging forces over a larger area. During the non-torn state, fibres take only a low ratio of tractive forces. This ratio corresponds to the ratio of their extensional stiffness to the extensional stiffness of the matrix. In case of matrix failure, the matrix breaks and generates cracks and the fibres are exposed on traction. During this stage, the tensile forces are solely compensated by the fibres.

The geometry, content, orientation, and the bracing of the fibres have an eminent influence on the composite material. These factors also influence fibre whether to be pulled out or ripped off. The material shows a ductile behaviour after the fibre failure.

The fibre fails when the loading on the fibre is higher than its tensile strength. This is valid only, when the binding forces can be mobilised over the full length of the fibre, and when the crack of the matrix takes place in the middle of the fibre. If the crack happens eccentrically, the shorter part will fail first.

The pull out of fibres should always be preferred to mobilise the fictional resistance between fibres and matrix. Even after a matrix crack, a loading increase is possible, if there are just enough force spreading fibres.

3 SLURRY WALL MATERIAL

We used a slurry wall material, which was developed by the IGT for the two-phase-process (Hermanns 1993). The second phase was used as indicated in Table 1.

The producibility of non-reinforced slurry walls based on this composition was successfully investigated in the past (Günther et al. 1995). Furthermore, the requirements on PVA fibres, e.g. the long-term resistivity against cement, were already proven (Akers et al. 1989).

Since both, dimensions and content of fibres influence significantly the mechanical behaviour of the composite material, these parameters were modified in our work. Table 2 provides an overview of all used types of fibres and their characteristics.

Table 1 Composition of slurry wall materials

Fibre content [Vol.-%]	0	0.75	1.1	1.45
Water [kg/m³]	654	644.25	639.7	635.15
Clay [kg/m³]	491	491	491	491
Fly ash [kg/m³]	123	123	123	123
Cement [kg/m³]	368	368	368	368
Fibre [kg/m³]	0	9.75	14.3	18.85
Liquefier [kg/m³]	3.68	3.68	3.68	3.68

Fibre contents of 0.75 Vol.-%, 1.1 Vol.-% and 1.45 Vol.-% were added to the composite material. The change of consistency necessitated the application of a liquefier. One mass-percent was applied to ensure a good fibre distribution. With increasing fibre content, the water content was decreased, to keep the volumetric weight on a constant level.

Table 2 Types of fibres and their characteristic values

Type of fibre	∅	Length	Density	E-Module	Tensile strength
	[µm]	[mm]	[kg/m³]	[MN/m²]	[MN/m²]
RM 128	14	6	1.3	36000	1500
		12			
REC 7	26	12	1.3	40000	1500
REC 15	40	6	1.3	40000	1500
		12			
REC 100	100	6	1.3	38000	1500
		12			
		16			
		24			

4 LABORATORY EXPERIMENTS

The hardened samples, of 14, 28 and 56 days old, had to weather through unconfined compression tests, three-point bending traction tests, and permeability tests. Unconfined compression tests and permeability tests were carried out on cylindrical samples with 100 mm in height and diameter. The samples for the three-point bending traction tests had 280 mm in length, and 70 mm height and width.

4.1 *Unconfined compression tests*

The stress-deformation curve indicates clearly the effect of the fibres. The characteristic drop down of stress after a crack, as know from non-reinforced samples, was not observed on reinforced samples.

Figure 1 shows, that partially an increase of stress can be measured in reinforced samples. The reason for this increase is that in a compression test tractive forces mainly do occur across the allocation level. When the matrix fails, these forces can be adsorbed by the fibres.

This effect was observed at the REC 100 (∅ 100 µm) fibre, even though the compressive strength of the non-reinforced sample was not reached.

The compressive strength did not diminish constantly. It showed a residual strength, because it just came down to the static friction. All samples were 28 days old, 12 mm in fibre length, and had 1.1 Vol.-% fibre content.

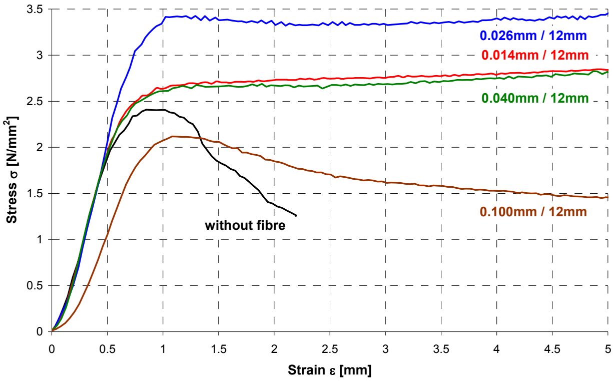

Figure 1 Unconfined compression tests with a fibre content of 1.1 Vol.-%

The largest compressive strength was found with REC 7 (∅ 26 µm) fibres. The fibres had a length of 12 mm. The fibre content had no influence in this experiment. Furthermore, the influence of the fibre content was investigated.

The influence of the fibre percent is recognisable even though it has a varying influence on fibres with different diameters. The largest compressive strength was reached for all types of fibres, except REC 15 (∅ 40 µm), at a fibre content of 0.75 Vol.-%.

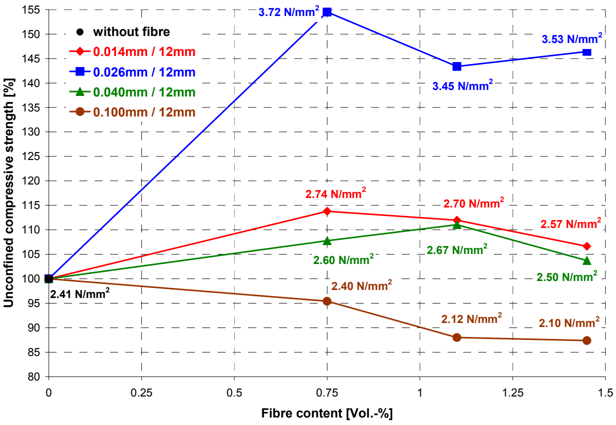

Figure 2 Fibre content dependence of the unconfined compressive strength

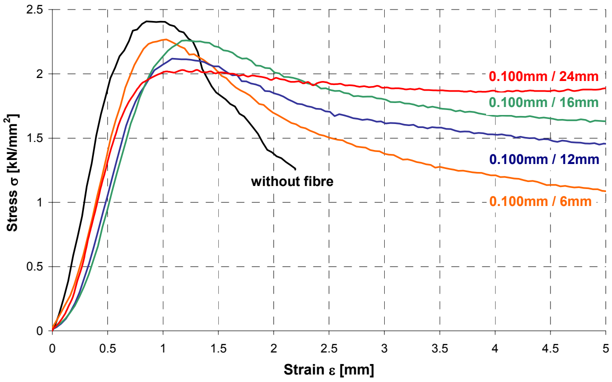

Figure 3 Fibre length dependence of the unconfined compressive strength, with a fibre content of 1.1 Vol.-%

Also, the influence of the fibre length at a constant fibre diameter was found. It became clear, that the compressive strength increased with an increase of fibre length. This correlation was investigated under fibres of the REC 100 (∅ 100 µm) type. The samples had a fibre content of

1.1 Vol.-%. Figure 3 shows that similar results could be reached with smaller fibre contents, too.

An enlargement of the fibre length to more than 24 mm could lead to the assumption, that there would be no stress drop down after the matrix failure. This behaviour was observed at REC 15 (∅ 40 µm) fibres. In this case, the stress did not drop down at a fibre length of 12 mm, while it did drop down at 6 mm fibres.

4.2 *Three-point bending traction tests*

Three-point bending traction tests were made to show the influence of the fibre reinforcement. A significant increase of the tensile strength was proved.

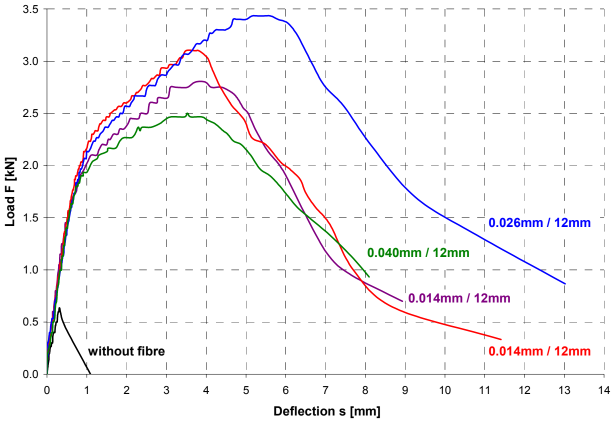

Figure 4 Three-point bending load-displacement diagrams, with a fibre content of 0.75 Vol.-%

The effect of fibre types on the material strength can be shown in a load-displacement diagram (figure 4). In the elastic area, the fibre is fully connected with the matrix and involved in the load take over. Partly, the adhesion is responsible for the load increase.

The elastic area is followed by a plastic area. In this area, first cracks occur. On the other hand, a strengthening happens which is indicated by a further load increase. When the maximum load is reached, the load falls off. At this stage, the fibres are pulled out and only hindered by the friction strength.

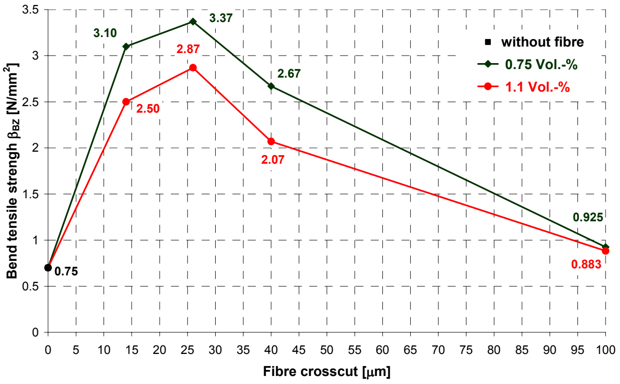

Figure 5 Three-point bending traction tests with different cross sections

By means of the reinforcement, the ductile behaviour of the slurry wall material was significantly enhanced. Furthermore, the load was increased to a multiple of the failure load. The different courses of load-displacement curves show clearly the influences of fibre content and fibre length. Type REC 7 (∅ 26 µm) fibres achieved the largest friction load at a fibre content of 0.75 Vol.-% and a fibre length of 12 mm.

Both the types RM 128 (∅ 14 µm) and REC 15 (∅ 40 µm) fibres have a smaller friction load. The maximum strength of the reinforced samples was about 4 to 5 times higher than the strength of the non-reinforced. The effects of the reinforcement on the displacement were even higher. The displacement could be enhanced up to a factor 22, as figure 5 indicates.

4.3 *Further mixing tests*

In further experiments, 10 mass-percent and 15 mass-percent of sand (0-4mm) was added to the initial composite material to reach a more homogeneous fibre distribution. Simultaneously with the addition of sand, the share of solid material was proportionally reduced. This was based on the recognition that the fibres tended to build cluster structures. The addition of sand should hinder a cluster building. New mixtures were used to do further three-point bending traction tests.

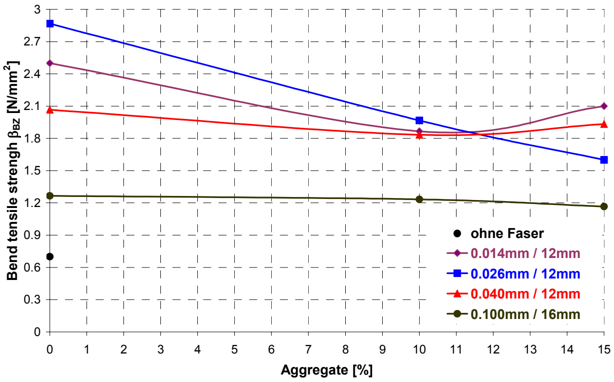

Figure 6 Bending traction tests with fibre content 1.1 Vol.-% and aggregated sand

No improvement on the bending tensile strength independently of the fibre type was reached with the addition of the sand. The results were even deteriorated as figure 6 illustrates. Among other things the reason for this behaviour are the fibre distribution and fibre orientation. These have a considerable influence on the tensile strength of the composite material.

The structure was changed with the addition of sand. Sand particles moved between the fibres. This had the effect of partial increase of the distance between fibres, while at other parts the distance decreased. Through this, the distance between fibres became irregular and the burden could not be transferred evenly. As a consequence, the bending tensile strength was reduced.

The type REC 100 (∅ 100 µm) fibres behaved differently due to the number of fibers in the sample. The number of fibers in the samples is defined by the respective fiber diameter, content, length, and density. In the fibre type REC 100 (∅ 100 µm), the distances between fibres are largest and due to the addition of sand the distance is slightly reduced. Therefore the bend tensile strength decreased in these samples (figure 6)

4.4 *Permeability tests*

Permeability experiments on non-deformed samples have shown that the fibres did not have a negative influence. The examinations were carried out in triaxial test cells. The flow through gradient in these tests was i = 30 and was increased after 50 days to i = 50.

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The samples were installed after three weeks and the test was carried out. After approx. 100 days the tests were stopped. With a increasing test duration, all samples showed a decrease of the permeability coefficient k.

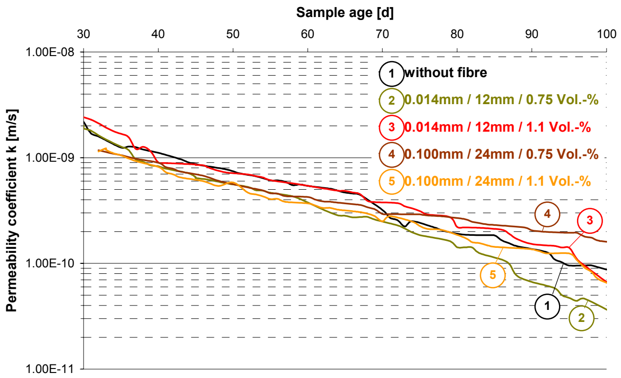

Figure 7 Permeability tests

In further tests, the permeability of deformed materials will be investigated to ensure the barrier effect even on deformations with crack formation. However, no deterioration of the permeability values was observed in the reinforced samples.

5 SUMMARY AND CONCLUSION

The experiments prove that the fibre reinforcement leads to a significant enhancement of mechanical properties, mainly the ductility of the composite material.

Type REC 100 (∅ 100 μm) fibres did not meet the expectations. They showed unpromising results in all areas like uniaxial compressive strength and bending tensile strength as well as at the deformations.

Type REC 128 (∅ 14 μm), REC 7 (∅ 26 μm), and REC 15 (∅ 40 μm) fibres had the best improvements on the material qualities at fibre lengths of 12 mm.

REC 7 (∅ 26 μm) showed the best performance in the composite material.

The addition of sand 0/4 did not cause an increase of the bending tensile strength, or rise of the ductility. In general, these characteristics were deteriorated. In this, the amount of addition did not play a role.

A negative influence of the fibres on the permeability coefficient k was not recognised. The permeability coefficient depends neither on the fibre content nor on the fibre geometry.

By means of crack formation at bending fraction tests, fibre related differences were observed. At the non-reinforced samples a continuous crack appeared. At samples, armoured by the REC 100 (∅ 100 μm) fibres with a length of 12 mm the pull out of the fibre can clearly be recognised. A gaping crack occurred and it needs to be expected that the barrier is not functional any more. In this, the fibre content did not play an essential role. With REC 7 (∅ 26 μm) fibres, the development of the crack were distributed on a bigger area of the sample, i.e. a clear multiple crack formation was reached.

In addition, no complete break of the sample arose and it can be assumed that the barrier remains in function under such conditions.

It was noticed at the examination of the surfaces of the break and the fibres in the crack area that the fibres were all pulled out.

A closer analysis of the fibre under a scanning electron microscope confirmed this behaviour and showed simultaneously that a good connection between fibres and matrix was reached.

At the moment, a large-scale experiment at a 1:1 scale is under preparation. This might prove the practical application and knowledge of the mechanical behaviour of the composite material.

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