CAPILLARY BARRIER SYSTEMS FROM CONSTRUCTION WASTES TO COVER RED MUD RESERVOIRS

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ABSTRACT

Covering and revegetation of red mud disposal sites is a complex engineering task due to the special conditions, such as the high pH and the high exchangeable sodium content of red mud. The capillary barrier system introduced in this paper consists of two layers: 1. the capillary block layer consists of a coarse material that prevents upward capillary transport of the highly alkaline and Na^+ containing liquor from the red mud, 2. the capillary layer comprises fine material that withholds and stores the infiltrating water from precipitation.

The function and capacity of the capillary barrier system was tested and monitored in scaled-up experimental series. We characterized the waste materials of the capillary system by the integrated application of physico-chemical analyses and environmental toxicity testing.

Chemical analysis showed that the applied waste materials do not contain mobile metals that might pose additional risk. The environmental toxicity tests proved that the applied materials are non-toxic. The results of the microcosm studies showed that crushed concrete of 30−50 mm particle size can be used as capillary block layer, while both the 0−20 mm particle size crushed concrete and the 0−6 mm particle size crushed brick can be used as capillary layer.

INTRODUCTION

Red mud is the by-product of the Bayer process in which aluminium is produced from bauxite. Wet lagooning is the simplest way of disposal, but its high risk was tragically demonstrated by the Ajka, Hungary dam failure in October 2010. Revegetation of red mud may be problematic due to its high pH (pH>10) and high exchangeable sodium concentration (>70%). One solution can be the use of capillary barrier systems as cover. Capillary barriers typically consist of two layers of differently grained cohesionless material. The upper layer, called the capillary layer, is constructed of fine material which can be characterized as a compromise between strong capillarity and high hydraulic conductivity, whereas the lower layer, the capillary block layer, is made of coarse material with weak capillarity.

So far mainly natural materials such as sand and gravel have been used in capillary barrier systems. However, a more sustainable solution is the use of waste material, such as recycled building material or waste rock as constituents. In our experiment the construction wastes in the capillary system were crushed brick and concrete. As top layer waste soil characterized as kiscelli loam from the construction of the metro line No. 4 in Budapest was used. The red mud originated from Almásfüzitő, Hungary.

CHARACTERISTICS OF WASTE MATERIALS

METAL CONTENT, EC AND PH

The total metal contents of the waste soils and construction wastes measured in aqua regia extract were under the Hungarian quality criteria for soil, except for As in the grey soil (16.9 mg/kg, HQC=15 mg/kg). The EC and pH of the wastes (in ponding water) is shown in Table 1.

Table 1. Electrical conductivity and pH of the wastes

Waste / parameter	Red mud	Concrete		Brick	
Particle size (mm)		**0–20**	**20–50**	**0–6**	**16–50**
EC (µS)[1]	1090	1280	289	1350	2050
pH[1]	9.0	7.9	8.1	7.8	8.0

[1] In model precipitation (0.16 mM $CaCl_2(aq)$) ponding on the top of the wastes (waste–water ratio: 1:2)

TOXICITY

The exotoxicological test results proved that the waste soils and construction wastes are non-toxic to the selected testorganisms (Table 2).

Table 2. Ecotoxicity of the wastes

Waste / Testorganism	Red mud	Grey soil	Yellow soil	Concrete (<1 mm)	Brick (<1 mm)
	Inhibition (%)				
Vibrio fischeri[1]	92%	6%	14%	14%	4%
Sinapis alba root[2]	41%	-20%	-7%	-34%	-44%
Sinapis alba shoot[2]	32%	-14%	-4%	-53%	-73%
Folsomia candida[3]	54%	11%	20%	0%	8%

[1] Inhibition compared to 2% $NaCl_{(aq)}$ [2] Inhibition compared to distilled water. [3] Inhibition compared to OECD control soil.

MODEL EXPERIMENTS AND RESULTS

CAPILLARY BLOCK LAYER

In used PET bottles we measured the water suction of the crushed concrete and brick layer placed on top of the red mud (Figure 1). Both concrete and brick can be characterised by low capillarity (Table 3).

Figure 1: Red mud + concrete (20–30 mm fraction) in PET bottles

Table 3: Water suction from red by large particle size fractions of crushed concrete and brick

Waste material as capillary block	Particle size (mm)	Fringe height from original wet red mud after 1 day (mm)	Fringe height from red mud + 17 mm precipitation after 1 day (mm)
Concrete	10–20	35	80
	20–30	30	85
	30–50	25	85
Brick	20–30	20	90
	30–50	25	95

At larger scale in a 10×30×50 cm plastic vessel the larger fraction (30−50 mm) of the waste materials was placed on the top of the red mud. 45 mm (1.2 l) model precipitation was added (pessimistic scenario modeling an extreme high rain event, 6.7% of one year precipitation) and the upward capillary suction of the water has been followed.

After one week the water suction of concrete was 125 mm (Figure 2), and the water suction of brick was 185 mm (Figure 3). Recommended minimum height of capillary block layer from concrete is 150 mm and from brick is 250 mm.

Figure 2: Water suction from red mud + 45 mm precipitation by coarse concrete (30–50 mm) after 1 week

Figure 3: Water suction from red mud + 45 mm precipitation by coarse brick (30–50 mm) after 1 week

CAPILLARY LAYER

In case of the capillary layer and the top soil cover it is important that the applied materials have active capillarity and optimal water retention. The measured capillary head values indicate that small particle size brick (<1 mm) has stronger potential for the suction of water than the other tested materials, and the capillary forces are stronger in case of the brick (Table 4). According to Harder and Martin (2001) at least 200 mm capillary head is needed for an ideal material used in the capillary layer, which was fulfilled by nearly all materials.

Table 4: Physical characteristics of the wastes

Waste material / Measured parameter	Concrete				Brick			Grey soil	Yellow soil
Particle size (mm)	**<1**	**0–4**	**0–20**	**20–50**	**<1**	**0–6**	**16–50**	**<1**	**<1**
Particles <0.02 mm (%)	-	-	11.5	-	-	11.9	-	36.2	32.8
Total porosity (V%)	-	-	51.8	-	-	54.2	-	54.7	53.6
WHC (%)	31.4	-	24.0	2.6	32.3	31.5	13.4	45.5	36.8
Capillary head[1] (mm)	230	162	-	-	342	230	-	200	260

[1] Measured after 5 hours. -: Not measured

In used PET bottles we modeled the wetting and desiccation of the wastes to see the capillary motions of water in the materials (Figure 4). After 4 days we wetted the microcosms up to their maximum water holding capacity. The result showed that brick can hold the largest amount of water, which is ~50% of the total weight of the microcosms (Table 5). There were no differences in the desiccation of the wastes.

Figure 4: Wastes in PET bottles: measurement of infiltration

Table 5: Wetting and desiccation of wastes in microcosms

Process	Time	Unit	Concrete (<1 mm)	Brick (<1 mm)	Concrete: brick = 1:1	Grey soil	Yellow soil
Infiltration[1]	Day 1	mm	40	50	52	40	35
	Day 4	mm	180	195	205	210	185
Water holding[2]	Max.	ml	685	745	685	625	625
Desiccation[3]	Day 15	%	94.2	93.9	94.2	93.9	93.5
	Day 37	%	88.4	88.5	88.4	89.0	88.0

[1] Wetting front. Wetted with 62 ml (11 mm) model precipitation per day (a total of 44 mm, modelling a long lasting large rain event).
[2] Maximum amount of water that can be hold by 1.5 kg waste material. [3] At room temperature. % of the maximum water.

At larger scale we followed the infiltration (11 mm model precipitation per day) for 8 days into 50 cm top layer and 50 cm capillary layer (Figure 5). The water front reached 36.2 cm from the top by day 8. This validated under the modelled weather conditions that 50 cm should be enough for the top layer.

Figure 5: Water infiltration into the top (grey soil) layer (25 cm) after 5 days. Bottom layer: 25 cm brick.

CONCLUSIONS

The results showed that the applied materials do not contain toxic metals above the quality criteria and they are non-toxic. It was shown that both coarse concrete and brick can be used in capillary block layers. We recommend a minimum of 15 cm layer in case of concrete and 25 cm in case of brick, however, thicker layer might be necessary at field conditions. Both crushed concrete (0−20 mm) and crushed brick (0−6 mm) can be used as capillary layers, having high water retention and capillary activity. As the next step of the experiments we assess the technological parameters under field conditions in 1.5 tonnes lysimeters with built in sensors for continuous monitoring of water fronts and the electrical conductivity of the water.

Reference: Harder, H. & Martin, H. (2001) Recycled building materials as components for capillary barriers, In: The exploitation of natural resources and the consequences (Eds. Sarsby, R.W. & Meggyes, T.), Thomas Telford, London, pp. 163–169

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