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Swelling-shrinkage properties and hydraulic conductivity of a compacted coal mine tailing rock likely to be used for landfill capping

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Abstract. The capping and remediation of municipal landfills require large amounts of soil material which should fulfil definite requirements with respect to hydraulic and shrinkage properties. One of such materials, likely to be applied for landfill capping and remediation, is tailing rock from Bogdanka (Lublin Region, Poland) coal mine. The effect of bulk density (1.35, 1.45, and 1.55 Mg m^{-3}) on water permeability and on swelling/shrinkage properties of that material was studied under laboratory conditions. After the measurement of water permeability of the compacted material its pore water pressure was differentiated (-60, -300 and -500 hPa) and then it was re-saturated and again placed on tension plates of different water potential. During each test the pore water potential and the bulk density were measured. The changes of the properties of the material under investigation are discussed from the point of view of its potential application for the construction of landfill top liners.

Keywords: landfill liner, swelling, shrinkage, water permeability

INTRODUCTION

Minimisation of the environmental effects of landfills requires appropriate construction of bottom and top liners separating the waste body from the surroundings. There are two tendencies in landfill liner construction. The first one relies on application of different types of plastic (usually polyethylene) geomembranes and the second proposes the application of natural minerals containing clays.

The construction of mineral liners seems to be very promising because they can persist thousands of years, while the use of plastic geomembranes only postpones the problem in time by several decades of years (as long as the membrane is water tight) and in fact creates a chemical time bomb. The mineral material for landfill liner construction has to be characterized, according to existing legal regulations, by low water permeability *eg* TASi 1993; ITB Instruction No. 339/2003, Directive 31/1999EC and by appropriate mechanical properties (Horn and Stepniewski, 2004; Wysocka *et al*., 2004; 2006) like *eg* rigidity, resistance to suffusion and to crack formation. Low permeability materials contain clay minerals and due to this are susceptible to swelling and shrinkage, which may result in formation of cracks presenting a threat for the sealing tightness for water and gas flow (Horn and Baumgartl, 2002; Tay and Stewart, 2003; Tay *et al*., 2001). It should be stressed that long-term stability of the landfill liner properties is a prerequisite of their usefulness. Due to this a very good knowledge of the swelling and shrinkage properties of the materials, likely to be used, is needed. It should be emphasised that the process of swelling and shrinkage itself needs to be better recognised and described as well.

The capping and remediation of municipal landfills require large amounts of soil material of appropriate parameters. In this connection different waste materials of adequate properties, produced by mine activity would be a good solution.

One of such materials, likely to be applied for landfill capping and remediation, is tailing rock from the Bogdanka (Lublin Region, Poland) coal mine.

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The aim of the present study was to investigate the effect of bulk density and pore water pressure changes within 0 to -500 hPa range on the swelling and shrinking process of tailing rock from Bogdanka coal mine.

MATERIALS AND METHODS

Waste rock from Bogdanka coal mine used in the studies is a product of hard coal mining and enrichment. The physical characteristics of the material are presented in Table 1, and the chemical composition in Table 2. The material is characterized by about 80% content of clay stone which easily undergoes weathering to clay. The material, exposed for two years to weathering (storing in a pile), was preliminarily sieved through a 4 mm sieve. Particles >4 mm, which constituted 40% of the material, were separated and rejected. For this study only particles <4 mm were used.

Stainless steel cylinders 100 cm^3 in volume were filled with this material which was then compacted manually to obtain three different bulk densities: d_1=1.35, d_2=1.45, and d_3=1.55 Mg m^{-3}. The material prepared in this way was used for measurements of saturated water permeability (k_f) using the falling water head method described by Hartge and Horn (1992). The determination of k_f was done in 4 replications for each of the densities and the measurement was repeated three times for each cylinder in order to characterize the initial conditions.

The volumetric shrinkage at these 3 bulk densities was measured at pore water pressure of -60 hPa, -300 hPa and -500 hPa (using cylinders different from those for water permeability measurements, with 4 replications for each treatment). Than the material was re-saturated and put on ceramic water tension plates of pore water pressure -60 hPa. For the -500 hPa treatment an additional series of 4 cylinders was prepared which were put to the -300 hPa tension plate.

The weight and volume were measured after every saturation and dewatering of the material. The bulk densities were obtained by measuring the height of the sample with the use of an electronic slide caliper, with the accuracy of 0.01 mm, in four points at the cylinder's edge and in its centre.

RESULTS

The values of water permeability are shown in Table 3. As it could be expected the compaction caused a decrease of the saturated water conductivity. However, the values of the order of 10^{-6}-10^{-7} m s^{-1} are considered to be characteristic for semi-permeable materials which, without modification, would not be accepted for the construction of liners of municipal landfills (Directive 31/1999 EC).

Saturation with water resulted in swelling and in a decrease of bulk density by 0.12-0.16 Mg m^{-3}; the decrease being higher for higher bulk densities. During desaturation on tension plates the material started to shrink and the bulk density was increasing with the decrease of pore water pressure. At -60 hPa the bulk density was still lower by 0.04 -0.05 Mg m^{-3} than the initial value, at -300 hPa it was similar to the initial value, while at -500 hPa the menisci forces contracted the soil to a bulk density higher than the initial values by 0.04 Mg m^{-3} for the lowest bulk density to 0.08 Mg m^{-3} for the highest compaction.

Second saturation caused swelling resulting in the decrease of bulk densities dependent on the intensity of predrying. For -60 hPa the bulk density after second swelling was by 0.15-0.19 Mg m^{-3} lower than the initial value and slightly (by 0.03-0.04 Mg m^{-3}) lower than after first swelling. For –300 hPa tension b. densities after second swelling were by 0.02-0.05 Mg m^{-3} higher than those after initial swelling and were by 0.11-0.12 Mg m^{-3} lower compared to the initial values. For –500 hPa treatment the bulk densities after second swelling were higher by 0.12-0.16 Mg m^{-3} than those after initial swelling and they were identical with the initial values. Thus the contraction of the material by

Table 1. Initial particle size characteristics of the waste rock from Bogdanka (Borys *et al*., 2002)

Dimension (mm)	>75	75÷2	2÷0.05	<0.05
Content (%)	0÷5	55÷65	14÷20	18÷26

Table 2. Chemical composition of the waste rock from Bogdanka (Borys *et al*., 2002)

Component	Content (%)	Component	Content (%)
S_iO_2	48.68	MgO	1.92
T_iO_2	0.92	Na_2O	0.35
Al_2O_3	22.47	K_2O	2.61
Fe_2O_3	4.36	P_2O_5	0.11
CaO	1.43	SO_3	0.53

Table 3. Values of saturated water permeability for particular bulk densities

d (Mg m^{-3})	k_f geometrical mean (m s^{-1})
1.35	2.69 10^{-5}
1.45	8.69 10^{-6}
1.55	3.70 10^{-6}

Table 4. Bulk density values obtained during preparation and consecutive stages of saturation and desaturation (Δd) was referred

Treatment	Preparation d_0 (Mg m^{-3})	Saturation I Swelling I			Desaturation I Shrinkage I			Saturation II Swelling II			Desaturation II Shrinkage II		
		Pore water pressure (hPa)	d_1 (Mg m^{-3})	Δd (Mg m^{-3})	Pore water pressure (hPa)	d_2 (Mg m^{-3})	Δd (Mg m^{-3})	Pore water pressure (hPa)	d_3 (Mg m^{-3})	Δd (Mg m^{-3})	Pore water pressure (hPa)	d_4 (Mg m^{-3})	Δd (Mg m^{-3})
A	1.55	0	1.40	-0.15	-60	1.50	-0.05	0	1.36	-0.19	-60	1.45	-0.10
	1.45		1.32	-0.13		1.41	-0.04		1.28	-0.17		1.37	-0.08
	1.35		1.23	-0.12		1.31	-00.4		1.20	-0.15		1.26	-0.09
B	1.55	0	1.39	-0.16	-300	1.56	+0.01	0	1.44	-0.11	-60	1.53	-0.02
	1.45		1.31	-0.14		1.44	-0.01		1.34	-0.11		1.42	-0.03
	1.35		1.23	-0.12		1.40	+0.05		1.25	-012		1.30	-0.05
C	1.55	0	1.39	-0.16	-500	1.63	+0.13	0	1.55	0	-60	1.62	+0.07
	1.45		1.31	-0.14		1.50	+0.05		1.45	0		1.51	+0.06
	1.35		1.23	-0.12		1.39	+0.04		1.35	0		1.38	+0.03
D	1.55	0	1.39	-0.16	-500	1.63	+0.13	0	1.55	0	-300	1.64	+0.09
	1.45		1.31	-0.14		1.50	+0.05		1.45	0		1.54	+0.09
	1.35		1.23	-0.12		1.39	+0.04		1.35	0		1.41	+0.06

menisci forces induced by negative pore water pressure caused in this case more intense and more stable (swelling resistant) compaction of the material than the initial mechanical compaction.

The second desaturation caused shrinkage again, leading to increase of bulk densities dependent on the history of the material. In treatment A the return to the pore water pressure of -60 hPa gave bulk densities lower by 0.04-0.05 Mg m^{-3} than those after the first desaturation and by 0.08-0.10 Mg m^{-3} lower than the initial values. In the case of treatment B the final bulk densities were lower by 0.02-0.10 Mg m^{-3} than those after the first desaturation at -300 hPa and lower by 0.02-0.05 Mg m^{-3} compared to the initial values. For treatment C the final bulk densities at -60 hPa were practically identical with those after first desaturation at -500 hPa and higher by 0.03-0.07 Mg m^{-3} than the initial values. For treatment D the final bulk densities at -300 hPa were higher by 0.01-0.04 Mg m^{-3} compared to previously applied pressure of -500 hPa and by 0.06-0.09 Mg m^{-3} than the initial values. Thus the history of the material (subjecting to pore water pressures of -60, -300, and -500 hPa) affected the differentiation of the final bulk density. In treatment D, the final bulk density increased similarly to that in treatment C.

CONCLUSIONS

1. Swelling potential of the material freshly compacted by mechanical kneading increased with its bulk density.
2. Shrinkage of the soil caused by capillary forces at pore water pressure below -300 hPa was more effective than the mechanical compaction.
3. Pore water pressure of 300 hPa and 500 hPa reduced soil swelling ability.
4. Waste rock under study requires, for application to landfill liner construction, modifications reducing its water permeability.

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