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Tensile Strength of Barrier Material

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Abstract. The most significant element of the municipal landfill construction is leak-proof assurance which reduces the negative influence of waste on the environment. Mineral liners and covers are correctly built-in cohesive soil layers, with a coefficient of permeability less than 10^{-9} m/s. Recently, researchers have conducted investigations with the possibility of utilising fly ash as a mineral barrier material. A very important part in the selection of material for the barrier is determining its ability to deformation. Its destruction is initiated by the process of the formation and propagation of cracks caused by tensile stress. Tensile strength was determined for the compacted samples of fly ash and ash with the addition of sodium bentonite which improves plasticity of the ash, as well as for compacted clay, for comparison. Laboratory tests were performed using indirect method (Brazilian test) on disc-shaped samples, using a universal testing machine with a frame load range of ± 1 kN. It was found that sodium bentonite significantly affects the tensile strength of fly ash. The obtained values of deformation and tensile strength of compacted fly ash containing up to 5% bentonite have been compared to those obtained for the clay used in mineral sealing.

Keywords: tensile strength, fly ash, bentonite, barrier deformation, Brazilian test.

Conference topic: Environmental protection.

Introduction

Embedding of mineral sealing layers under the embankments and landfills should be connected to the layer's ability to deform. Uneven ground settlement can cause damage or cracks of the sealing layer and create a privileged path of flow. Destruction of layers is initiated by the process of the formation and propagation of cracks caused by tensile stress, especially when this stress reaches or exceeds the tensile strength in the layer of soil (Fig. 1).

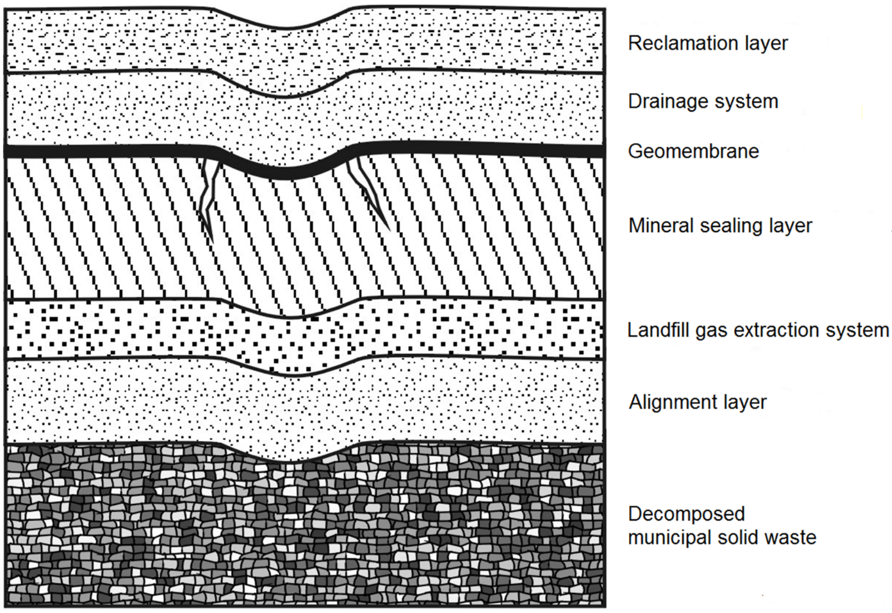

Fig. 1. Tension and cracking of mineral sealing layer in landfill cover
(source: own elaboration)

Ground's resistance to uneven settlement can be characterised by the results of the tensile or breaking strength and extension of the sample. In geotechnical practice, it is assumed that the strength of the soil stretching is negligible or equal to zero, because this is a relatively small value compared to the compressive strength of the soil. In soil mechanics, methods to assess the tensile strength of soil has not been developed, and it is necessary to adapt the methods of similar scientific disciplines and specialties. Laboratory tensile tests can be carried out using direct or indirect method. In the indirect method, the so-called Brazilian method, cylindrical or disc samples are compressed at side length (Mollamahmutoğlu, Yilmaz 2001; Wasil *et al*. 2015; Araki *et al.* 2016). In another indirect method, a supported in five points beam or rectangular samples are bent (Plé *et al.* 2012). Direct methods are used to conduct tests on extension in triaxial compression apparatus, breaking test on cylindrical samples inserted into forms (Kokowski 1994; Plé, Lê 2012; Wasil *et al.* 2015), and the sample in the shape of a dog-bone (Eisele *et al.* 2004; Araki *et al.* 2016). Direct tests are also performed in a specially designed direct tension apparatus, equipped with a different bipartite box (Tamrakar *et al.* 2005; Chakrabarti, Kodikara 2007; Stirling *et al.* 2015) and in a centrifuge (Divya *et al.* 2012).

In recent years, there has been much research on utilising fly ash for mineral barriers, in respect to its chemical, physical and mechanical properties. The hydraulic conductivity of fly ash built-in mineral liners ranges from 10^{-6} to 10^{-9} m/s, and depends, among other properties, on fly ash compaction and calcium oxide content. Fly ash retains various contaminants, including heavy metals. Its permeability decreases with time, and using waste leachate for permeability tests does not affect or slightly decreases it. In the case of unsatisfactorily low fly ash permeability coefficient, it can be improved by adding bentonite or hydraulic binding agents to obtain low hydraulic conductivity, without affecting, or even with improving fly ash mechanical properties (Zabielska-Adamska 2006, 2011).

The aim of the study is to determine the tensile strength and extension measured by the value of deformation that can be carried without cracking by the fly ash barrier. The tensile strength testing was performed using an indirect method for the compacted samples of fly ash and ash with the addition of bentonite, a material improving plasticity of ash, and which may also be used to construct the sealing layers.

Brazilian tension test

Experimental research has been performed at the Faculty of Mechanical Engineering of Bialystok University of Technology, with the application of electromechanical universal testing machine with a load range of frame during compression ± 1 kN. The samples were compressed using a force displacement controlled with the optical transducer during which the compressive force dependency on the deformation of the test zone has been recorded. The speed of displacement increment $\Delta\dot{l}$ was 1.2 mm/min = 0.02 mm/s. During the experiment compressive force and the momentary length of the specimen have been measured. These values allow the determination of the state of stress and strain in the specimen.

Tensile strength was performed using Brazilian splitting tensile strength test conducted by compressing a cylinder at side length. The dimensions of the test specimen were chosen according to ASTM D3967-08 (2008), where the preferred relation of the height of the cylinder (disc) to its diameter was specified as H/D = 0.2–0.75. The diameter of the sample should be at least 10 times greater than the largest grains in the sample. These dependencies are found in the specimens of 65 mm ID and 20 mm high, compacted in a bipartite device, which had been designed for non-cohesive soil sample forming for oedometric tests. Figure 2 shows a sample disc compression in the testing machine.

The tensile stress in Brazilian method is defined by the formula:

$$\sigma = \frac{2F}{\pi HD}, \tag{1}$$

where: F – maximal value of compression force at failure, H – height of disc sample, D – diameter of disc sample.

Deformation in Brazilian method is referred to as a vertical displacement (reduction of the diameter of the sample) or relative strain:

$$\varepsilon = \frac{H - H_0}{H_0}, \tag{2}$$

where: H − length of sample at fracture, H_0 – length of sample prior to test.

Loading of the sample perpendicularly to its axis causes fractures along the plane passing through the cylinder axis, created mainly by tensile forces, leading to splitting of the sample. In the older literature, there is a prevailing view that in accordance with the criterion of Griffith's, the destruction begins in the middle of the sample. On the other hand, more up to date literature positions state that it is the stress concentration at points of load contact that can lead to the destruction of the samples (Li, Wong 2013).

a)

b)

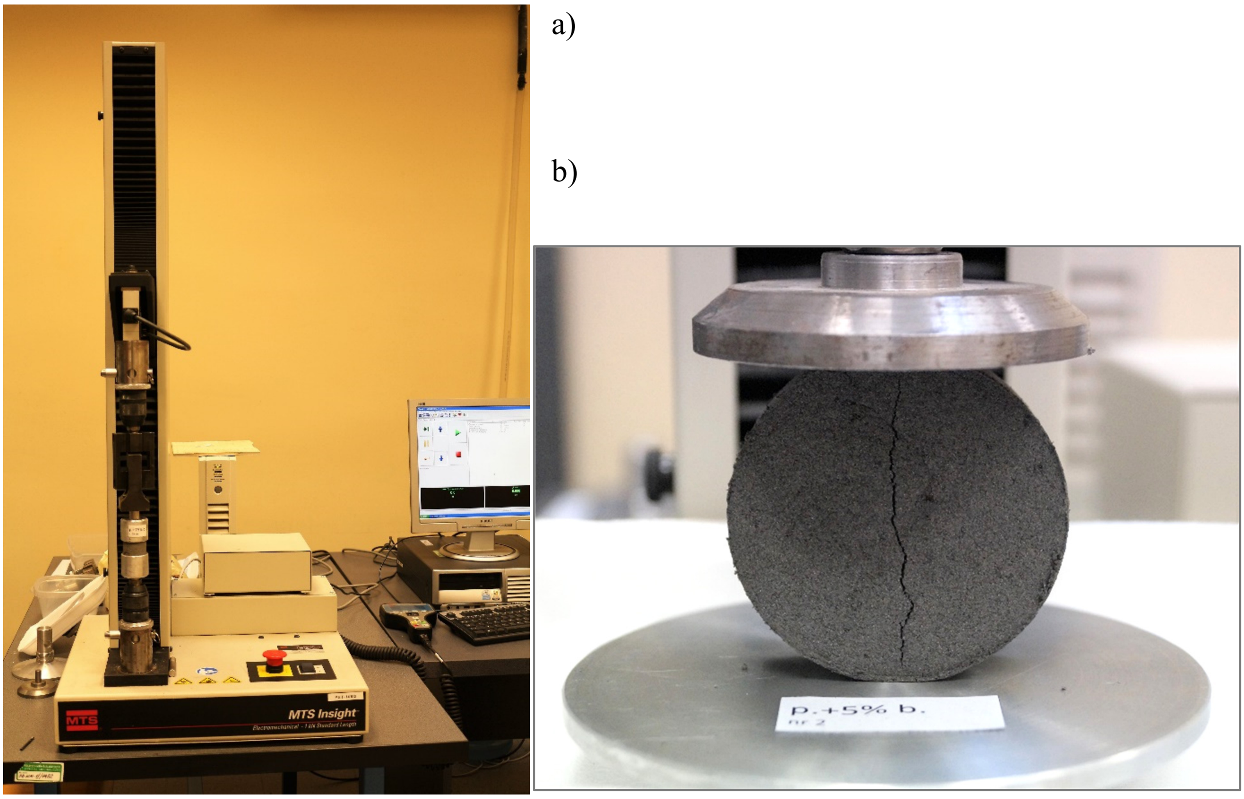

Fig. 2. Brazilian test: a) view of universal testing machine (range of load frame ±1 kN),
b) fly ash sample after splitting (source: own elaboration)

Tested materials

Granulometric composition of tested fly ash, originating from coal combustion in Thermal-Electric Power Station in Bialystok corresponds to sandy silt – saSi (EN ISO 14688-2 2004) whose effective size is $D_{50} = 0.05$ mm. Fly ash and fly ash with 5, 10 or 15% of sodium bentonite additive, calculated in weight relation to dry mass of specimens, have been compacted in bipartite moulds at the optimum water content to reach the maximum dry density obtaining with the standard Proctor method, allowing only a single compacting of the same waste sample (Zabielska-Adamska 2008). The values of specific soil density and compaction parameters of tested materials are shown in Table 1.

Table 1. Parameters of tested materials (source: own elaboration)

Tested material	ρ_s (g/cm^3)	Compaction parameters by the standard Proctor method	
		Optimum water content (%)	Maximum dry density (g/cm^3)
FA	2.18	40.0	1.073
FA + 5% B	2.18	39.0	1.100
FA + 10% B	2.22	36.3	1.118
FA + 15% B	2.24	33.0	1.134

Explanation: FA – fly ash, B – bentonite.

Bentonite was added immediately prior to compaction, and the samples were thoroughly mixed and then compacted. Specimens were tested directly after compaction and after 7 and 28 days of remaining in a humidity chamber at moisture content above 96%. Samples were tested at room temperature.

Comparative tensile test on standard compacted high plasticity soil – medium clay – MCl (EN ISO 14688-2 2004), used for the erection of mineral barriers, has been conducted.

The test has been repeated 2–4 times for each case.

Test results analysis

Figure 3 shows the tensile test results for fly ash and ash with 5, 10 or 15% addition of sodium bentonite, depending on the vertical displacement during the test. In the majority of tests a convergence of limit of tensile strength and the point that corresponds to the fracture of the specimens has been observed, which proves their high brittleness.

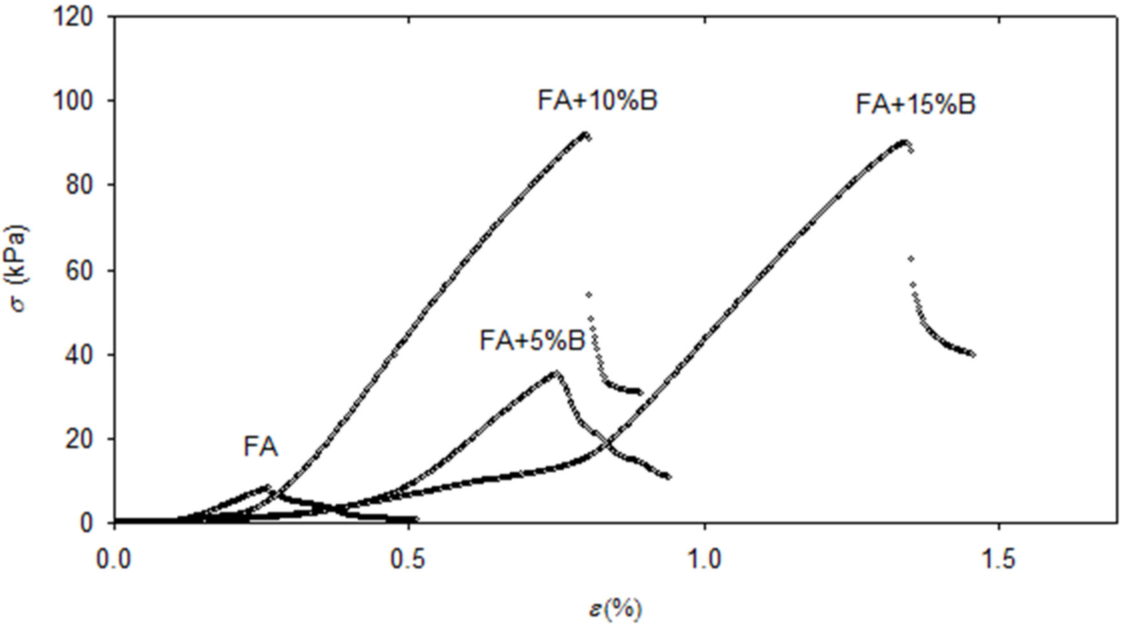

Fig. 3. Examples of relationships between tensile strength by Brazilian method and vertical displacement of ash samples with different contents of bentonite cured for 28 days (source: own elaboration)

Fly ash tensile strength, as determined by indirect method, was 6.86-7.32 kPa. The tensile strength of the specimens stabilised by the addition of 5, 10 or 15% of bentonite after 28 days of incubating amounted to, respectively: 20.67–47.63 kPa, 56.39–97.32 kPa and 64.95–90.00 kPa. Deformation grew with the plasticity of specimens and did not exceed the value of 1.4%. It should be noted here that during the Brazilian test both forms of propagation of destruction were observed – from the centre of the sample and the contact load points (Fig. 4).

a)

b)

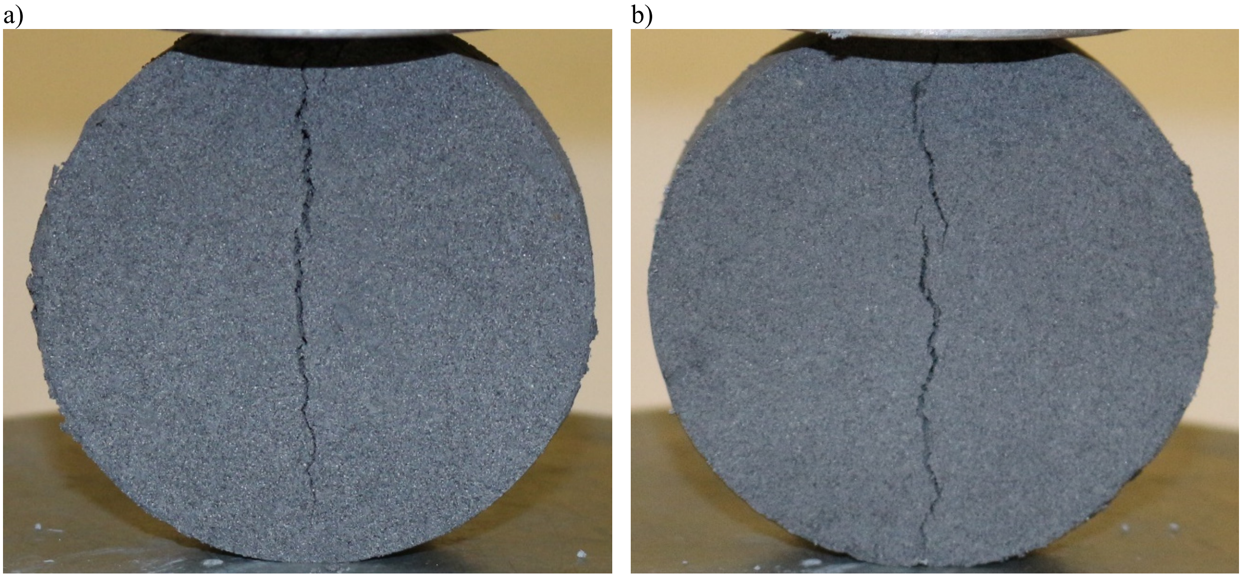

Fig. 4. Propagation of ash destruction during Brazilian test: a) from the centre of the sample, b) from contact load points (source: own elaboration)

Figure 5 shows strength test results with two dimensional regression equation plotted with 95% of confidence intervals obtained for the samples tested immediately after compaction and after 7 and 28 days of incubating, depending on the percentage content of bentonite. The biggest differences in the results obtained in tensile strength tests were found in the samples cured for 28 days, where coefficient of determination, $R^2 = 0.7524$.

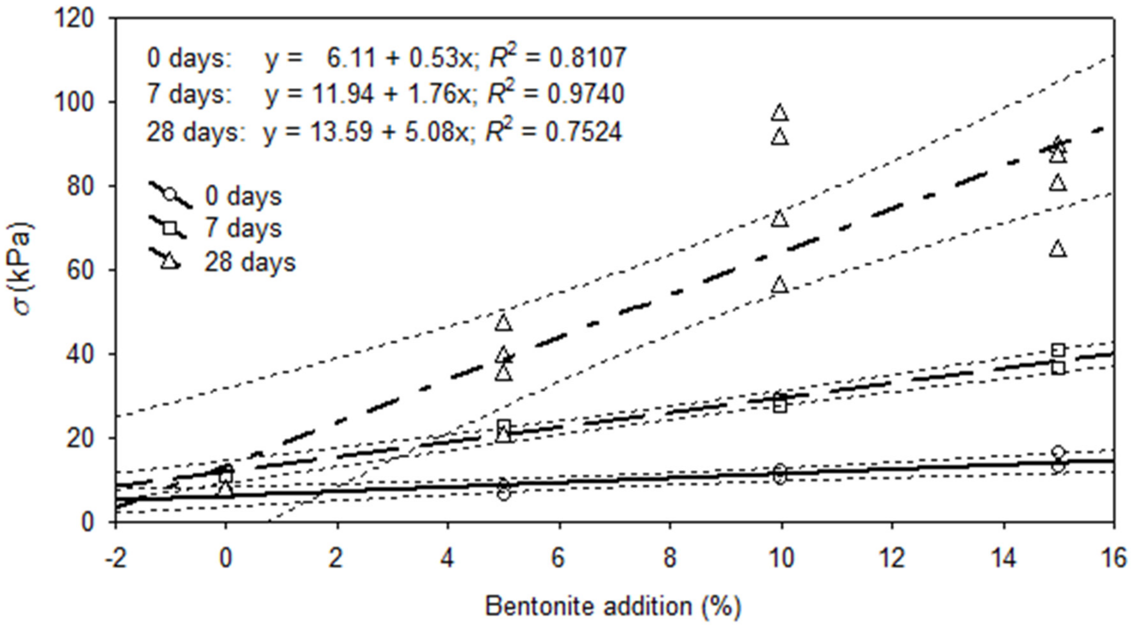

Fig. 5. Regression equations plotted with 95% of confidence intervals obtained for of ash specimens with various bentonite content immediately after compaction and cured for 7 and 28 days (source: own elaboration)

Mollamahmutoğlu and Yilmaz (2001) by applying Brazilian test obtained for unadulterated fly ash strength equal 7.8–10.9 kPa, and – compared to the results presented in this paper – received much lower strength values for ash with additives of bentonite. The level of deformation has been determined by them as 1% for all presented tests.

The mean tensile strength of medium clay – MCl, with the parameters recommended for the materials embedded into the mineral sealing, tested by the direct method by breaking specimens ranges from 24.41 to 39.60 kPa at a maximum strain of 0.36%. Medium clay was compacted at the optimum water content to maximum dry density value determined using the standard method. For comparison, Plé *et al.* (2012) obtained similar results in tensile test through bending a 5-point supported beam. The tensile strength of compacted silty clay at the optimum moisture content was about 20 kPa, at a strain of up to 0.3%.

It should be added that comparative test results obtained for medium clay by direct method can be lower because the Brazilian test overestimates the tensile strength because of biaxial stress instead of uniaxial tension condition, so it can never replace uniaxial tensile testing of rocks. Furthermore, the compressive stress concentration near the loading platen has been recognized as having a significant influence on the results of Brazilian tests (e.g. Li, Wong 2013).

Conclusions

1. Additives of 5, 10 or 15% of sodium bentonite affect the compaction characteristics of fly ash. Optimum moisture content of the mixture decreases in proportion to the percentage addition of bentonite, while the maximum dry density increases. With the addition of bentonite also specific density of mixture increases.
2. The bentonite increases the strain of specimen in proportion to the percentage of the additive. The value of strain in ash barrier during cracking, with 15% addition of bentonite, has been determined by Brazilian test as 1.4%.
3. The sodium bentonite significantly affects the tensile strength of the fly ash, as determined by the indirect method (Brazilian method). Adding 10% of bentonite increases more than 10 times tensile strength of the fly ash compacted by the standard method at optimum moisture content. Raising content of bentonite to 15% increases the strain recorded at fracture of specimen and causes slight increase in strength.
4. The obtained values of strain and tensile strength of compacted fly ash containing up to 5% of bentonite, are comparable or higher than those obtained for cohesive soil used for mineral sealing.

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Disclosure statement

Authors declare not to have any competing financial, professional, or personal interests from other parties.

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