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Laboratory assessment of permeability of sand and biopolymer mixtures

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Abstract: *Laboratory assessment of permeability of sand and biopolymer mixtures*. This research presents a method of creating seepage barriers in a sandy soil using biopolymer additives (biosubstance), which consist of polysaccharides and water. Polysaccharides strongly interact with water to produce a viscous suspension. The paper aims to investigate the influence of a biosubstance employed in a highly permeable sandy soil. Amount of the biopolymer used in a sample were 0.5, 1.0 and 1.5%, by dry weight. The test results indicate that the hydraulic conductivity significantly decrease with the amount of biosubstance added but only slightly increase when curing time gets longer. It is thought that such application, which is a relatively new soil improvement technique, could be used as a seepage barrier installation required to protect some geotechnical works including foundation, underground structures and waste disposals.

Key words: biopolymers, permeability, seepage barrier

INTRODUCTION

Over the past years, many types of chemicals have been used for a geotechnical application. Chemical grouts are mostly toxic and hazardous for the environment. This constantly pushes researchers to find alternative eco-friendly techniques of ground improvement. It comes to light that several natural biopolymers have important characteristics, such as excellent viscosifying in high-salinity waters, pseudo plasticity, stability at large ranges of temperature and pH, jellifying agents and resistance to shear degradation.

The use of biopolymers for soil improvement is already described in readily available literature. Several studies (Feldman 1989, Li et al. 1993, Martin et al. 1996, Stewart and Fogler 2001) have investigated the application of biopolymers as plugging agents in construction of various impervious barriers. Some researchers (Karimi 1997, Momeni et al. 1999, Khachatoorian et al. 2003) demonstrated the capacity of certain biopolymers, including xanthan gum and sodium alginate to decrease the permeability and increase the shear strength, thus reduce the leaching of contaminants.

While most of the investigations focus on fine, cohesive soil, the present research analyzes the potential use of biopolymer, namely xanthan gum, to reduce hydraulic conductivity of medium grain size sand. This part of research which should be regarded as a preliminary to investigate the influence of the biopolymer content on the reduction of the soil permeability.

MATERIAL AND METHODS

The materials used in the tests described in this paper were quartz medium sand and xanthan gum. The commercially available sand was obtained from regional sources near Warsaw. The specific gravity of the grains was found to be 2.68. A gradation of the sand falling between 1.00 and 0.071 mm was artificially selected. The grain size distribution curve of medium sand taken for the investigations is presented in Figure 1, while index properties of this soil in Table 1.

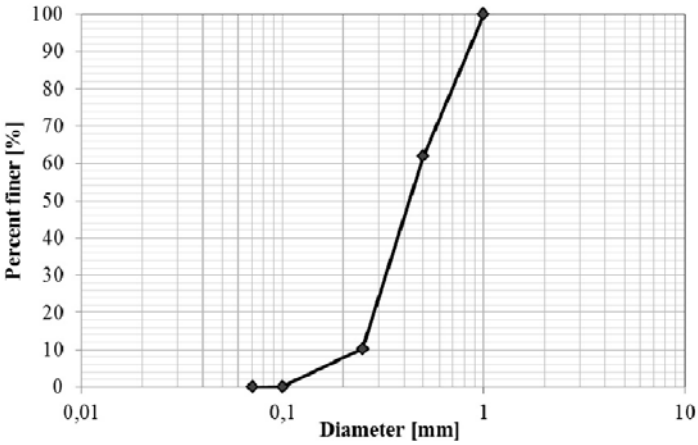

FIGURE 1. Particle size distribution curve

TABLE 1. Index properties of the sand

Property	Value
Minimum void ratio, e_{min}	0.45
Maximum void ratio, e_{max}	0.70
Relative density, R_D	45%
Uniformity coefficient, C_u	1.96
Curvature coefficient, C_c	0.84

Soil contains rectangular quartz grains with coefficient of uniformity – C_u = 1.96 and coefficient of curvature – C_c = 0.84.

The commercially available biopolymer material was obtained from a local food store in a powder form. Worldwide production of xanthan gum comes out from the bacteria *Xanthomonas campestris*. Xanthan gum is as a hydrophilic colloid to thicken and stabilize water-based suspensions. It is widely used in the drilling industry to thicken drilling fluids, and is very stable under various values of temperature and pH (Bouazza et al. 2009).

Samples were prepared by mixing sandy soil with xanthan gum by dry weight. Four different mixtures were prepared, containing respectively 0.0, 0.5, 1.0 and 1.5% of biopolymer. The required amounts of sandy soils and xanthan gum were blended together under dry conditions. Firstly sand was washed and dried in an oven at approximately 105°C. For all the tests samples were prepared at relative density 45%.

For the initial sand-xanthan gum-water specimen, the desired amount of the sand and xanthan gum were weighed, mixed, water was added, reaching 10% of each dry sample weight and then all was spooned, without vibration, into the mould (with a diameter of 69 mm, and height of 70 mm) with thin layers of sand. When the mould was completely filled, using plastic bags and foil it was tightly sealed to prevent moisture loose. Then samples were left for conditioning, respectively for 1, 3, 7, 14, and 28 days of time. Permeability apparatus with the specimen can be seen in Figures 2 and 3.

The permeability tests were conducted on clean sands and sand with xanthan gum at three different contents. A series of constant head permeability tests were performed according to ASTM D2434. Tests were conducted in a triaxial cell, where hydraulic gradient and confining pressure were controlled (Lipiński et al. 2007). All samples were made saturated from the bottom to top. Pressure at the top of each sample was set to be 0 kPa, while at the bottom applied pressure took values of 5, 10, 20, 30, 50 and 100 kPa (Head 1995). Confining pressure in the cell was set to be 50 kPa (for bottom pressure of 5, 10, 20 and 30 kPa), 100 kPa (for 50 kPa) and 200 kPa (for 100 kPa). The hydraulic conductivity of each sample was reported by the average of the last three measurements. All tests were conducted under room temperature (22°C).

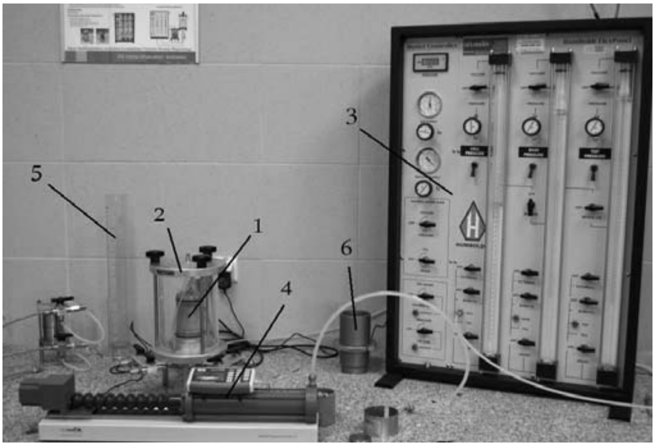

FIGURE 2. Permeability apparatus: 1 – specimen; 2 – triaxial cell, 3 – cell pressure controller; 4 – pore water controller; 5 – out-flow cylinder; 6 – sample mould

FIGURE 3. Permeability cell

RESULTS AND DISCUSSIONS

The testing results on hydraulic conductivity of biopolymer treated sand are shown in Table 2. Permeability (hydraulic conductivity) decreases when more

TABLE 2. Hydraulic conductivity of biopolymer treated sand for various curing time

Biopolymer ratio [%]	Curing time [days]	Permeability [m/s]					
		Pressure applied [kPa]					
		5	10	20	30	50	100
0.5	1	$8.65 \cdot 10^{-10}$	$9.02 \cdot 10^{-10}$	$1.13 \cdot 10^{-8}$	$8.71 \cdot 10^{-8}$	$5.25 \cdot 10^{-7}$	$1.55 \cdot 10^{-6}$
	3	$6.26 \cdot 10^{-10}$	$2.42 \cdot 10^{-9}$	$5.30 \cdot 10^{-8}$	$3.76 \cdot 10^{-7}$	$1.33 \cdot 10^{-6}$	$1.83 \cdot 10^{-6}$
	7	$4.25 \cdot 10^{-9}$	$4.42 \cdot 10^{-9}$	$9.89 \cdot 10^{-8}$	$9.75 \cdot 10^{-7}$	$1.45 \cdot 10^{-6}$	$2.14 \cdot 10^{-6}$
	14	$3.12 \cdot 10^{-9}$	$4.92 \cdot 10^{-8}$	$2.80 \cdot 10^{-7}$	$7.49 \cdot 10^{-7}$	$1.68 \cdot 10^{-6}$	$2.35 \cdot 10^{-6}$
	28	$3.14 \cdot 10^{-8}$	$2.03 \cdot 10^{-7}$	$9.02 \cdot 10^{-7}$	$1.53 \cdot 10^{-6}$	$2.67 \cdot 10^{-6}$	$2.59 \cdot 10^{-6}$
1.0	1	$1.18 \cdot 10^{-10}$	$1.24 \cdot 10^{-10}$	$4.67 \cdot 10^{-10}$	$7.23 \cdot 10^{-10}$	$7.12 \cdot 10^{-9}$	$1.98 \cdot 10^{-7}$
	3	$3.68 \cdot 10^{-10}$	$3.94 \cdot 10^{-10}$	$7.07 \cdot 10^{-10}$	$2.75 \cdot 10^{-9}$	$1.79 \cdot 10^{-8}$	$9.09 \cdot 10^{-7}$
	7	$4.98 \cdot 10^{-10}$	$5.54 \cdot 10^{-10}$	$6.74 \cdot 10^{-10}$	$3.81 \cdot 10^{-9}$	$3.75 \cdot 10^{-8}$	$1.29 \cdot 10^{-6}$
	14	$2.12 \cdot 10^{-9}$	$2.64 \cdot 10^{-9}$	$1.47 \cdot 10^{-8}$	$7.17 \cdot 10^{-8}$	$4.09 \cdot 10^{-7}$	$1.42 \cdot 10^{-6}$
	28	$2.69 \cdot 10^{-9}$	$2.50 \cdot 10^{-9}$	$5.56 \cdot 10^{-9}$	$2.00 \cdot 10^{-7}$	$3.34 \cdot 10^{-7}$	$1.03 \cdot 10^{-6}$
1.5	1	$2.84 \cdot 10^{-11}$	$7.33 \cdot 10^{-11}$	$1.28 \cdot 10^{-10}$	$2.20 \cdot 10^{-10}$	$5.08 \cdot 10^{-11}$	$9.25 \cdot 10^{-8}$
	3	$3.40 \cdot 10^{-11}$	$3.38 \cdot 10^{-11}$	$1.54 \cdot 10^{-10}$	$7.53 \cdot 10^{-11}$	$2.59 \cdot 10^{-11}$	$7.90 \cdot 10^{-8}$
	7	$4.39 \cdot 10^{-11}$	$3.90 \cdot 10^{-11}$	$7.73 \cdot 10^{-11}$	$4.91 \cdot 10^{-11}$	$3.20 \cdot 10^{-11}$	$1.41 \cdot 10^{-7}$
	14	$2.18 \cdot 10^{-11}$	$2.51 \cdot 10^{-11}$	$1.20 \cdot 10^{-10}$	$7.98 \cdot 10^{-10}$	$2.70 \cdot 10^{-10}$	$6.39 \cdot 10^{-7}$
	28	$6.84 \cdot 10^{-11}$	$5.69 \cdot 10^{-11}$	$2.80 \cdot 10^{-10}$	$7.27 \cdot 10^{-10}$	$8.66 \cdot 10^{-10}$	$1.99 \cdot 10^{-7}$

xanthan gum is added to the sample. For example, addition of just 0.5% xanthan gum to the sand decreases the permeability to almost 0.001% of the initial value. Addition of 1.5% xanthan gum changes the permeability from $8.46 \cdot 10^{-5}$ m/s to about $2.84 \cdot 10^{-11}$m/s, which is less than 1,000,000 times.

Figure 4 presents three graphs with different xanthan gum (biopolymer) content, where the changes of permeability, according to the hydraulic gradient applied for various curing time are shown. It is seen that hydraulic conductivity increases as the applied pressure increases, and as the curing time gets longer. Permeability of the specimens remains low, under greater hydraulic gradient for higher xanthan gum ratio. As presented in the graph for 1.5% biopolymer content, water flow through the sand is stable, for all the samples (different curing times) for a hydraulic gradient up to 70. In that case improved sand might be considered as impermeable, reaching values between $2.18 \cdot 10^{-11}$ and $8.66 \cdot 10^{-10}$ m/s.

Effect of time on hydraulic conductivity of the soil biopolymer mix under various pressures is shown in Figure 5. When the long-term behavior of seepage barriers is a main objective, observing short-term behavior is a good evidence of the possible technology development. A longer ageing time generally achieved a lower conductivity, but work with coarse and medium sand shows different relationship (Fig. 5). It can realized that the permeability (hydraulic conductivity) of a biopolymer treated sand increases with time, for the 0.5% mixture

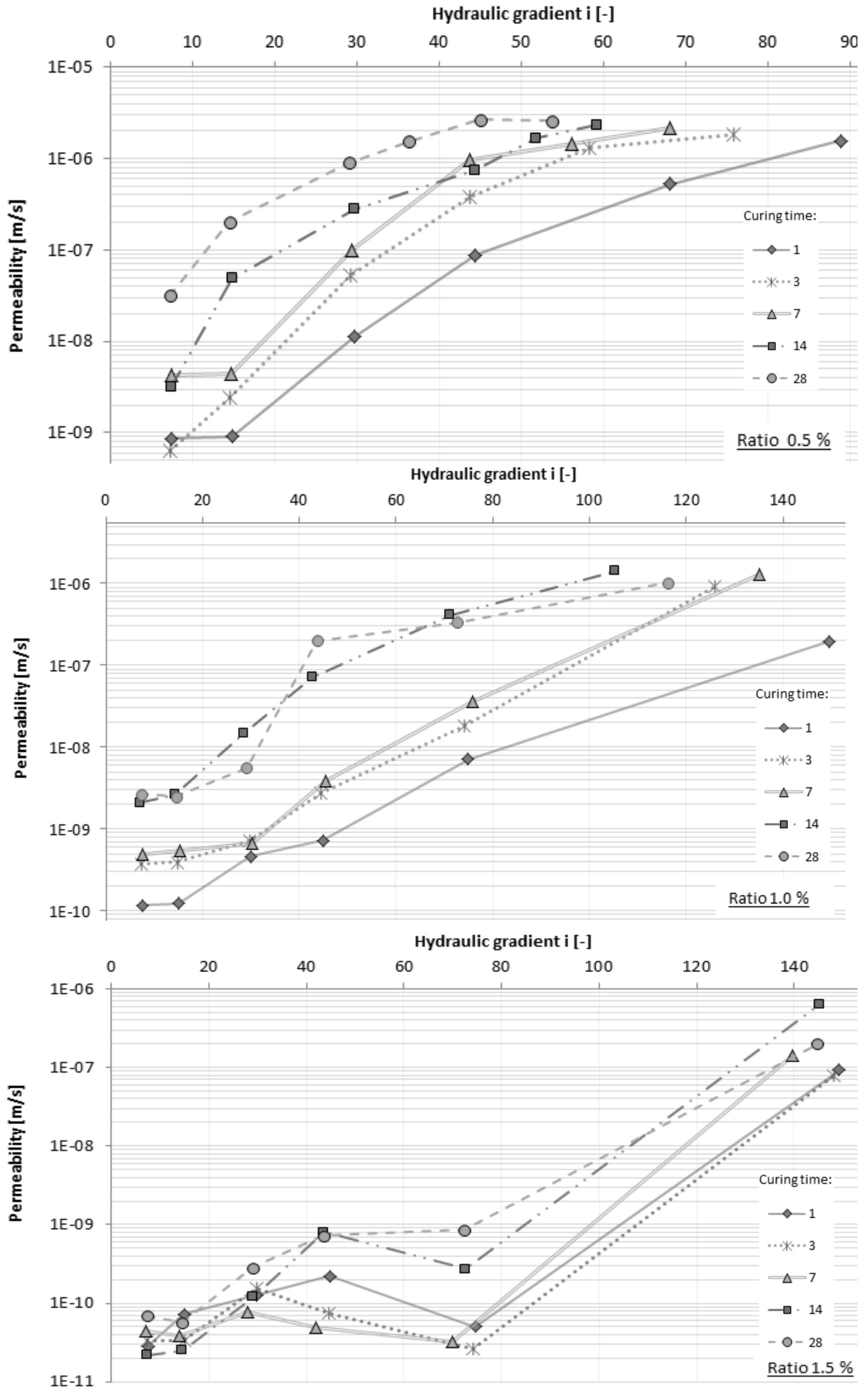

FIGURE 4. Hydraulic conductivity of a biopolymer treated sand

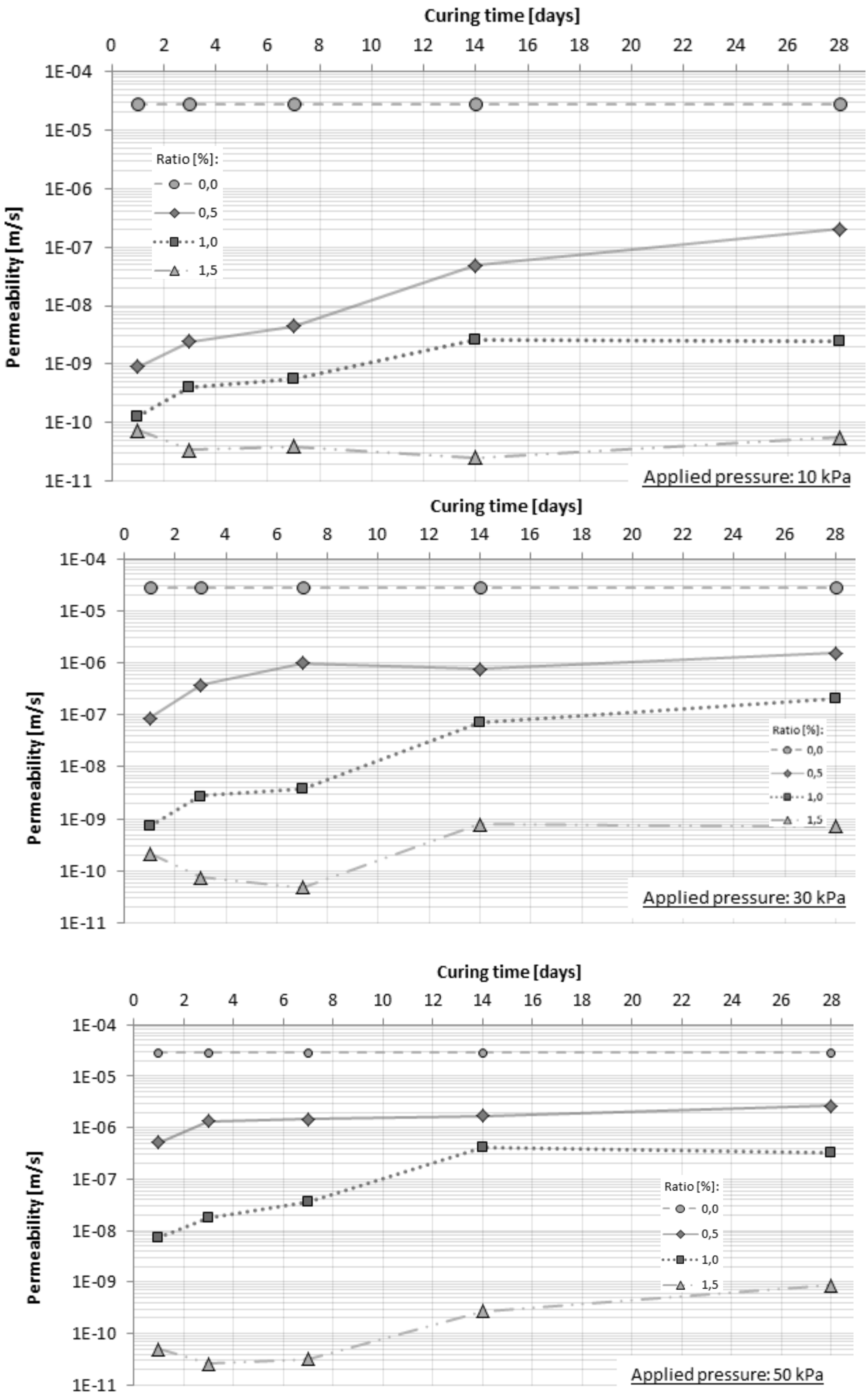

FIGURE 5. Effect of time on hydraulic conductivity of the soil biopolymer mix

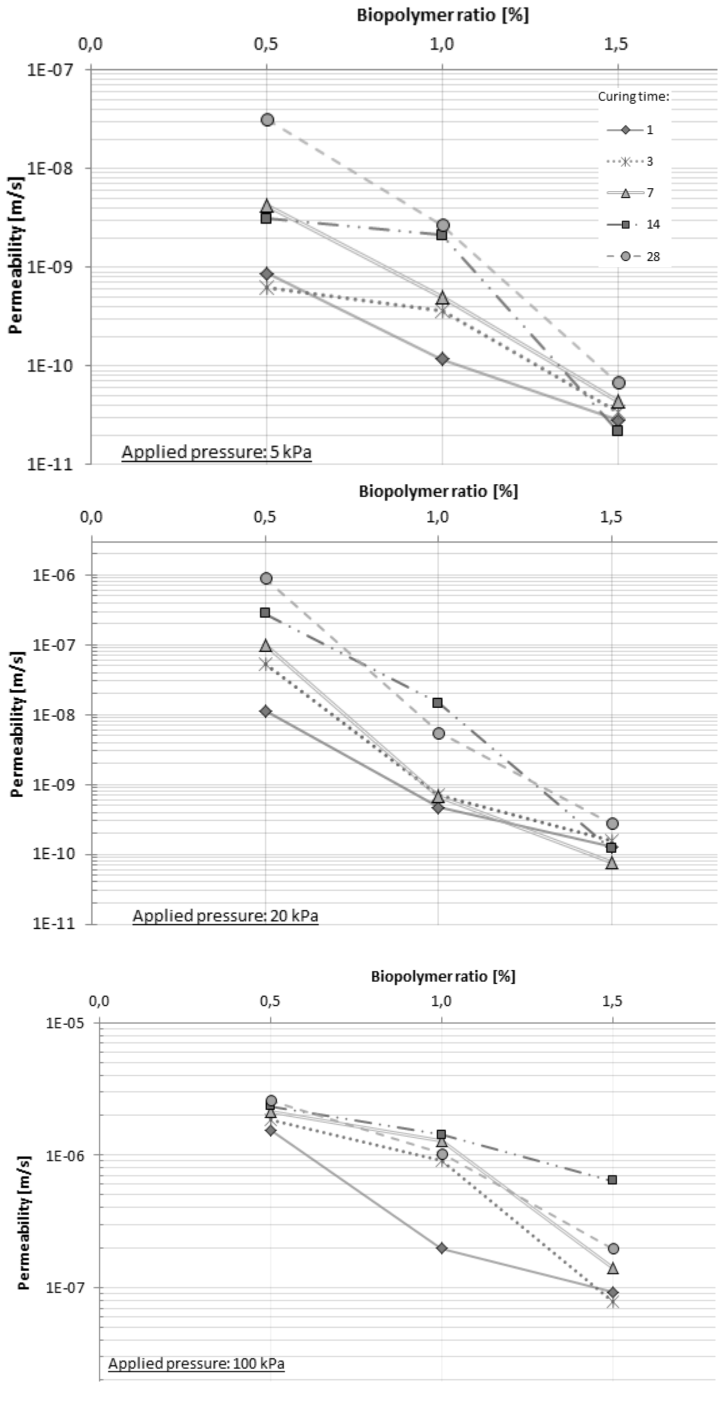

FIGURE 6. Effect of biopolymer content on hydraulic conductivity of the soil

under pressure of 30 kPa, it increases from $3.76 \cdot 10^{-7}$ m/s at 3 days to $1.53 \cdot 10^{-6}$ m/s at 28 days. The ageing influence gets lower, when the xanthan gum content increases, for 1.5% mixture under pressure of 30 kPa, it increases from $7.53 \cdot 10^{-11}$ m/s at 3 days to only $7.27 \cdot 10^{-10}$ m/s at 28 days. Permeability remains low and stable for all 28 days, up to the hydraulic gradient value of 70.

A polymerc chain is significant for permeation of the grout. When the biopolymer is placed in the soil matrix, it is desired to undergo some form of cross--linking in order to enhance strength and decrease its mobility in the ground. Cross-linking connects polymeric chains through chemical reactions, which might be initiated by temperature rise, change in pressure and pH. The process can form a comprehensive lattice in the soil matrix, which rigidifies the whole polymeric structure, enhance its mechanical strength and reduce permeability (Khatami and O'Kelly, 2012).

As the effect of the biopolymer inclusion, stable permeability decrease was observed as shown in Figure 6. When the biopolymer ratio increases permeability decreases of no account of conditioning time and pressure applied. It determines a possible usage of that chemical material to create impervious barriers in the soil.

Viscous characteristics of xanthan gum have a significant meaning for stability of the soil. As observed in Figure 7, samples mixed with the xanthan gum appeared to be much more stable. The sand grains sticked to each other, and created a linked structure. That gives another conceivable way to use of such products in the ground, for instance in slope or road embankment stability.

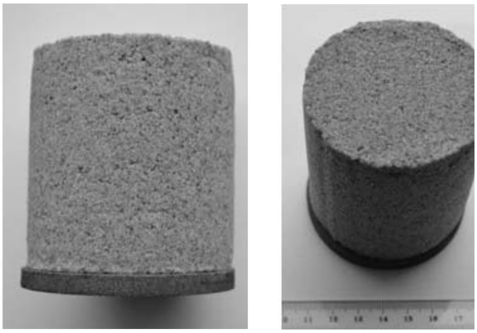

FIGURE 7. Rigid samples after testing

CONCLUSIONS

The objective of the presented study was to investigate the behavior of sandy soil and its various mixtures with xanthan gum in the terms of hydraulic conductivity. It is known that biopolymers (i.e. xanthan gum) can substantially decrease hydraulic conductivity (permeability) of soil without causing environmental toxicity.

Based on the test results which was the first part of research to investigate the influence of the biopolymer content on the reduction of the soil permeability it was proved that the permeability of medium sand treated with xanthan gum was found to be directly dependent on the biopolymer concentration.

However, on the basis of the test results the effect of curing time on changes in soil permeability cannot be fully assessed. A longer ageing time generally achieved a lower conductivity.

Also more detailed research is required to impact assessment of pore water pressure (hydraulic gradient) on hydraulic conductivity of sand-xanthan gum-water specimen.

In conclusion, biopolymer treatment occurs to be a promising technology to modify an engineering soils behavior. The eco-friendliness and cost of biopolymers also add to their attractiveness for use in engineering applications.

However, further studies are needed for better understanding of the use of different biopolymers and percentages with various types of soils. The future research will assess the sustainability of the changes in the structure of the soil, as a result of moisturizing-drying cyclicality, which seems to be crucial in the use of the method in hydro-engineering constructions. Mechanical testing of the shear strength in triaxial apparatus and oedometer compressibility tests have been started.

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Streszczenie: *Ocena przepuszczalności mieszaniny piasku i biopolimeru na podstawie badań laboratoryjnych.* Przedstawione badania dotyczą możliwości tworzenia nieprzepuszczalnych barier w przepuszczalnym podłożu gruntowym z zastosowaniem dodatków biopolimeru (biosubstancji składającej się z polisacharydów i wody) mieszanych z piaszczystym gruntem podłoża. Celem przeprowadzonych badań była ocena wpływu biopolimeru na przewodność hydrauliczną piasku średniego. Badania przeprowadzono dla zawartości biopolimeru 0,5, 1,0 i 1,5% w odniesieniu do suchej masy piasku średniego i różnych wartości gradientów hydraulicznych. Wyniki badań wskazują, że przewodność hydrauliczna znacząco zmniejsza się wraz ze wzrostem zawartości biopolimeru, jednakże nieznacznie wzrasta w miarę wydłużania się czasu kondycjonowania. Zastosowanie biopolimeru do tworzenia nieprzepuszczalnej bariery hydraulicznej jest stosunkowo nową techniką, którą można wykorzystać w niektórych pracach geotechnicznych, np. do zabezpieczania wykopów fundamentowych lub składowisk odpadów.

Słowa kluczowe: biopolimery, przepuszczalność, bariera przeciwfiltracyjna

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