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Study of compressive strength evolution in soil cement samples with fly-ash admixtures

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Abstract. Improving a soil is a process of increasing its physical/mechanical properties without changing its natural structure. Improvement is reached by means of the knitted materials, or other methods when strong connection between soil particles is established. The main reason of designing cement-soil columns is to improve properties of local soils (such as strength and stiffness) by mixing them with various cementing materials. Cement and calcium are the most commonly used binders. However, new research undertaken worldwide proves that apart from these materials, also gypsum or fly ashes can also be successfully implemented. As the Deep Soil Mixing is still being under development, anticipating mechanical properties of columns in particular soils and the usage of cementing materials in formed columns is very difficult and often inappropriate to predict. That is why a research is carried out in order to find out what binders and mixing technology should be used. The paper presents several results of the testing procedures related to soil-cement quality and internal capacity of Deep Soil Mixing columns. Presented results concerning capacity testing of laboratory samples and laboratory procedures on various categories of samples were picked from R&D and consulting works offered by Wroclaw University of Science and Technology (WrUST). The work contains two independent groups of analyses. The first one comprises results coming from the previous laboratory research undertaken at the University. This is just a small part of huge investigation which is aimed at boosting the knowledge of possible implementation of fly ashes into the DSM columns. The second part contains results of specimen prepared by the author for the purpose of MSc Diploma Work.

1. Aim and scope

The primary aim of this work is to investigate the influence of an implementation of fly ashes on soil-cement materials. In order to achieve the aforesaid goal the following study is divided into parts. The first section contains theoretical aspects of the topic under study. The subsequent part consists of laboratory tests of soil mixed with slurry comprising cement and fly ashes, which is a good example of utilizing such material and analysis of obtained results.

1.1. Characterization of fly ashes

According to the data published by GUS (Central Statistical Office in Poland) in June 2017: over 70% of primary energy produced in Poland comes from hard-coal-fired power stations. It is also the main source of energy all over Europe. In order to produce energy, coal needs to be burnt. During the combustion flammable matter burns off and that generates energy.

At the same time all the non-flammable impurities (such as alumina, quartz, silica, calcium) fuse and are transported by flue gas until it reaches low temperatures zone where these small fragments solidify into spherical particles. These products are called fly ashes. Most commonly used

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classification of fly ashes was defined in the United States by ASTM - an international standards organization.
It differentiates two groups of fly ashes based on physical and chemical properties:

- class C: produced from burning lignite or sub-bituminous coal. The total sum of silicon, alumina and iron oscillates between 50% and 70%. This kind of fly ash has pozzolanic properties (reacts with calcium hydroxide). It may contain serious amount of lime (more than 10%),
- class F: produced from combustion of anthracite or bituminous coal. The total sum of silicon, alumina and iron is greater than 70%. This kind of fly ash has pozzolanic properties. And moreover, consisting of aluminous and siliceous material it does not possess cementitious features but due to presence of moisture it reacts in normal temperature with calcium hydroxide and forms a material with cementitious properties.

Figure 1. Fly ash

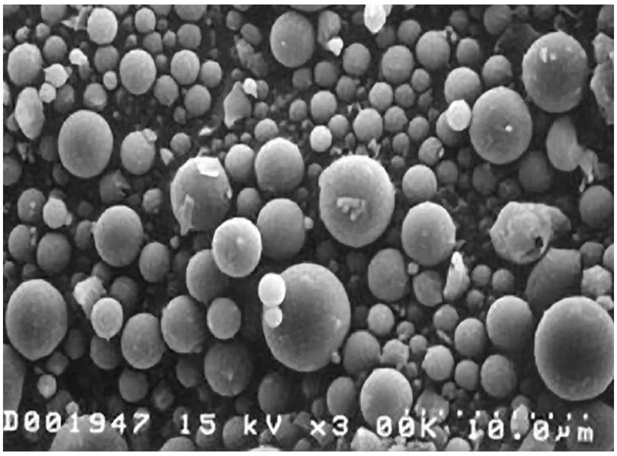

Figure 2. Structure of fly ash,
source: http://www.concreteconstruction.net

1.2. Advantages of utilizing this material in construction industry

Because of its structure consisting of very small spherical particles, smaller than the cement ones, fly ash fills voids and capillaries in concrete and cement-soils very well. It causes an increment of weathertightness, durability, resistance to environmental exposure (like, for example, sulphate, acids or salt attack) and finally it is able to protect the reinforcement (in concrete) against the effect of corrosion. Its spherical shape also improves both the pump-ability of the concrete mixture (by decreasing the friction between pump line and concrete) and the workability of the mixture without increasing the ratio between water and binder (the portions of fly ash act like ball-shaped bearings). It means that one can reduce the quantity of – water in use, however this benefit was not included in the present study.

The increment of strength in the mixture varies significantly depending on the type of ash but one can generalize that the presence of fly ash in the concrete or soil-cement slows down chemical reactions in the mixture and the hardening process is extended in time. This fact can be considered both as favourable and unfavourable. Furthermore, using fly ashes is economically justified due to the fact that this material is significantly cheaper than cement, therefore, partial replacement of cement with fly ashes can bring serious savings in production. Finally, it is necessary to mention the benefits to the environment. Nowadays more and more attention is paid to environment pollution, especially when it comes to big industries, where a substantial amount of waste is produced. That is why governments of many countries try to implement sustainable materials wherever possible.

One of the ways to accomplish it is to transform waste into a resource. This means that primary and secondary products should be produced rather than products and wastes. Since this material turns out to have many favourable properties, one can support the philosophy of sustainability by using fly ash directly in mass stabilization of soils and/or as an addition to cement slurries mixed with mineral soils.. A wide range of Deep Soil Mixing design issues are presented in works [1-4]. Selected applications are given in references of Topolnicki [5-7]. Another example of a by-products application may be recycled concrete from demolition works, which can be used for decorative concrete [8] (thin particles) and widely (all range of grain sizes) in road construction [9], geotechnical and marine engineering, as presented in reference [10].

Because combustion by-products (like fly ash) are considered harmful to people and natural environment, it is crucial to utilize them reasonably. As fly ash consists of very small and light elements, it must not be stored outside due to the danger of being blown away by the wind. Such situation is dangerous, since fly-ash can affect living beings badly when inhaled. That is why utilizing it by mixing with soil prevents it from spreading in an uncontrolled way and reduces the risk of its unhealthy influence to zero. Various applications of those hazardous materials are presented in works [11-13].

As it was mentioned before, because we use fly ashs in concrete or soil-cement materials, we can consider it rather a product than a waste. Also, thanks to fly-ash the need for cement production is reduced. When we replace some portion of cement with a certain amount of fly ash, we attain not only the reduction of "greenhouse gas" emission but we also lower the energy usage. It appears to be crucial after facing targets that were outlined by European Union leaders in legislation in 2009. The set of binding legislation is collected in "2020 =Climate and Energy Package". One of the main targets of this package is to reduce greenhouse gas emissions in the European Union by 20% compared to the data from 1990. What is more, 20% energy efficiency improvement is also required. It is important to realize that the production of cement is responsible for more or less 7% of carbon dioxide emission caused by human, while fly ash is treated as zero-emission material (the emission of CO_2 that appears during formation of fly-ash is a result of producing energy in hard-coal-fired power stations, so the ash is actually a "waste" in this process).

All the above-mentioned factors lead to the conclusion that using fly-ashes may:

- increase weathertightness
- extend durability
- increase resistance to environmental exposure
- contribute to protection against corrosion
- improve mixture pump-ability
- lead to water savings
- extend the process of hardening
- reduce costs
- contribute to reduction of greenhouse gas emission and pollution
- lead to decrease of energy usage
- reduces of carbon dioxide emission

Therefore, the material under study is used in forming DSM columns:

- as an admixture to concrete
- as an asphalt filler and subbase stabilizer
- as a light weight aggregate
- in constructing embankments [13] etc.

On the other hand, one has to remember that there is a limitation concerning the quantity of fly ash in cement slurry due to the fact that inter alia it can gain strength both too slow and insufficiently, or decrease the air content in concrete, which lowers its resistance to freeze/thaw cycles and increases probability of reinforcement corrosion.

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2. Analysing properties of soil-cement materials

The main purpose of this survey is to examine the compression strength and the modulus of elasticity (using stress-strain diagrams which represent behaviour of the material while loading) of cement-fly ash-soil mixtures. In order to draw reliable conclusions, we rely not only on the results from previous researches but also the ones that were conducted especially for this study.

The most reliable results are obtained by taking the samples on the building site while forming columns. A sample is made by collecting the material from the column right after its making, using a scoop for this purpose. However, this way of testing requires the forming of an actual column. In order to avoid that and examine the soil and composition of slurry one can use the method of cement-soil mixing in laboratory conditions. In this way, a more homogenous structure of the samples is obtained. Therefore, the results received for all the examined samples can differ from the ones obtained later in reality.

2.1. Preparation of samples

The specimens under scrutiny are typical: these are cubic samples of 15x15x15cm (Figure 3). The area that is under compression is 225 cm^2. They are small enough to be easily transported,but on the other hand, they are big enough to give reliable results concerning the largest grain sizes of the soil.

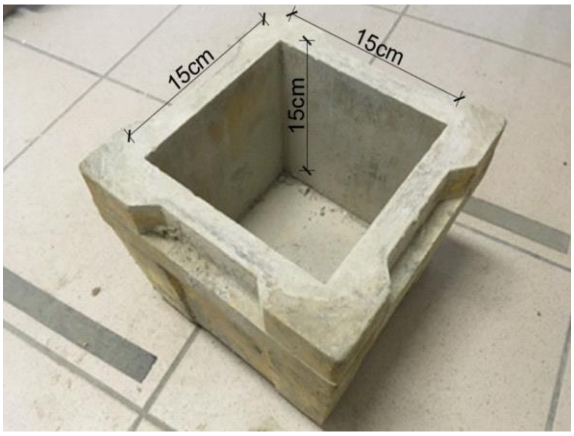

Figure 3. Cubic mould for concrete/soil-cement sample

Figure 4. Preparation of samples

The process of sampling starts with the preparation of cubic forms. At first, the moulds need to be checked if they are clean. Then, the interior walls of the forms have to be lightly oiled to facilitate the removing of the ready samples. After that, preparation of the material can be started. Firstly, cement and fly ash (or cement without addition of fly ash) must be precisely scaled and put into a bucket; after adding a particular dose of water, all the components are mixed until the mixture is uniform. Then, the cement-fly ash slurry can be added to previously scaled soil.

Afterwards, the mixing process goes on and lasts for about five to ten minutes, until the structure of the material is homogenous. The next step is putting the material into the prepared moulds and levelling the material so as to obtain a flat and straight surface of all sides of prepared cubes. It is crucial to remember that the whole procedure should not exceed 30 minutes in order to prevent the mixture to harden too much (Figure 4).

After all the samples are prepared, they are numbered and identified and subsequently placed where they are about to be stored. Our samples were stored in specific conditions at certain humidity and temperature. Two days later they were ready to be unformed and stocked in containers providing constant temperature and humidity (Figure 5).

Figure 5. Samples after unforming

Figure 7. Example of samples destroyed (tested) one week after preparation

2.2. Uniaxial compressive test

The DSM columns in reality are more often put under compression rather than tension or bending. Because of that, the perfect way to test the obtained product is to conduct uniaxial compressive test using Compression Testing Machine (Figure 6). The method of uniaxial compressive test was chosen due to the fact that this test has less optimistic results and lower strength than in case of triaxial compressive tests. That guaranties a certain margin of safety. Such method consists of few steps. At first, one has to place the previously prepared specimen on the flat surface of a circular pad. Then the upper pad is lowered until it reaches the upper surface of the specimen. Subsequently the sample is being pressed with constantly incrementing force up to the moment of destruction of the cube under examination. It is the time when we cannot only observe cracks on the samples under test, but we also see that the deformation of the sample rises without the further increase of the force acting on the sample.

Figure 6. Compression Testing Machine (PROETI)

The machine is connected to the computer during the whole process and automatically saves all the information about the conducted tests, such as the input force and strain. Dividing applied force by compressed area (0.15×0.15=0.225 m^2) results in a chart of stress σ=F/A [kPa=kN/m^2] as a function of strain ε.

Since 2015, the laboratory tests at Wrocław University of Science and Technology aimed at establishing the compression strength and the modulus of volume elasticity, assessed on the basis of the uniaxial compression of cubic 15×15×15 cm samples, for various amount of selected binders (cement, cement mixtures), differing times since their forming. The subject of tests was also material stiffness (the modulus at different stages of loading) and the tensile strength. Interesting results of microscale analysis of soil cement-materials were juxtaposed in work of Piasecki and Stefaniuk [14].

The tests reported in works [15, 16] based on the dissertation by Zajączkowski, carried out on the samples of cement-soil with the admixtures of fly ashes, confirm large parameter variability of samples taken *in situ* in comparison with a large homogeneity of the parameters of similar mixtures composed in laboratory room. More than 100 compression tests and many tension tests have been conducted. Current research programme focused on soil cement mixtures with relatively high substitution of cement by active fly ashes.

3. Laboratory test methodology

All the tests, starting from sample preparation till the end of compression tests were performed in accordance with the methodology proposed by Kanty et al. [17]. Consequently, the results are presented in similar form as in work [17]. This conformity made it possible to juxtapose and compare the present results with the archival ones.

3.1. Basic parameters of cement and soil

The hydraulic binder for the making of the cement-soil samples was cement type: CEM II B-S 32.5 R – NA. The cement compressive strength reaches 50 MPa achievable after 28 days. CEM II B-S cement reaches the strength of about 18.5 MPa already after 2 days [18]. The authors' previous experience from the testing of cement-soil pointed to a usefulness of CEM II B-S for the forming of the DSM material in mineral soils (sands, dusts, clays). The cubic samples of cement-soil, with the dimensions of 15×15×15 cm, were prepared by mixing the mineral soil together with the slurry, the density of which equalled 1.5 g/cm^3. The cement was applied in doses of pre-defined values so that the final outcome gave 200, 180 or 140 kg/m^3 of cement-soil. It must be highlighted that such an amount of cement is relatively small as for deep mixing – most often the amount of cement applied *in situ* equals 200-250 kg/m^3. For the 180 and 140 kg/m^3 samples, the cement was substitutes with a triple portion of fly ash. The soil used in the test was mineral medium sand (MSa) with admixtures of silty clay (siCl). The soil was stored in plastic bags to keep the original humidity and mixed mechanically (of all bags) before preparing the samples to guarantee its homogeneity.

3.2. Evaluation of compressive strength, elastic modulus and tensile strength

Similarly to the tests described in work [17], the tests were conducted for a constant displacement rate with the velocity of 0.01 mm/s, in controlled temperature of 20°C ± 3°C. The uniaxial compression strength of the cubic cement-soil samples were carried out as outlined in the Code of Practice [19] and method [20], in the PROETI mechanic press, synchronized with a computer recording: time elapsed since the beginning of the test, axial force loading the sample, axial displacement of press piston (reduction of the sample's length in the axial direction). The data were sent on the ongoing basis to the PC equipped with software for automatic recording of tests. The modulus of volume elasticity E_1 (Figure 8), was determined as the mean modulus for an approximately rectilinear fragment of a tension-deformation curve by a linear interpolation for various ranges of that curve. The linear interpolation was made by means of the least squares method in Microsoft EXCELL software.

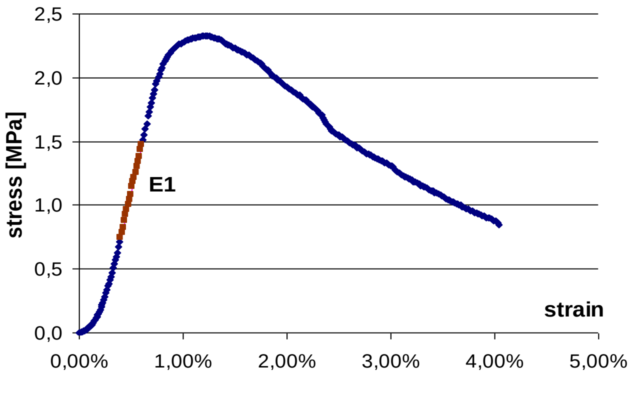

Figure 8. Marking of the modulus E1 determined for rectilinear fragment of a strain-stress curve at 50% of compression strength f_c

The tests for tension strength during the crushing of the samples of cement-soil were carried out in a way similar to compression tests – on tubular samples with the dimensions of d=10 cm and L=9 cm, where d – diameter and L – sample height. The value of the tensile strength while crushed (f_t) was obtained from the formula (1):

$$f_t = \frac{2 \cdot F_{max}}{\pi \cdot L \cdot d} \tag{1}$$

where F_{max} is the maximum loading.

4. Research test results

For the current research: 18 compressions and 5 of tension tests have been carried out altogether. Samples, prepared (2017-10-16) were waiting for failure test for 7, 14, 28, 56 and 84 days. Tests have made it possible to take into consideration various interdependencies, three of which have been presented in this work to enable for the comparison with former tests [15-17]: the increments of compression strength, the stiffness of soil-cement in relation to strength and the tensile strength.

4.1. Increments of compressive strength in time

Presented results are given for:

- soil-cement mix A(200) with cement amount 200 kg/m^3; without fly ash admixtures
- soil-cement mix B(180) with cement amount 180 kg/m^3; with 60 kg of fly ash per m^3
- soil-cement mix C(160) with cement amount 160 kg/m^3; with 120 kg of fly ash per m^3
- soil-cement mix D(140)with cement amount 140 kg/m^3; with 180 kg of fly ash per m^3

Series C(160) was taken from previous testing in 2016. In accordance with the Code of Practice [19] and the work [17], the exponential formula may be used in order to estimate strength in time:

$$f_{cm}(t,s) := f_{cm1} \cdot \exp\left[s \cdot \left[1 - \left(\frac{28 \cdot \text{day}}{t} \right)^{0.5} \right] \right], \tag{2}$$

Where: t is time, f_{cm1} is the strength of concrete after 28 days of its curing, whereas s is the coefficient dependent on the cement type and the rate of its setting (for concrete 0.20 – 0.38). In the case of soil-cement mixing, due to longer time of setting, it is highly recommended to use the reference value of f_{cm1} measured after 56 or even 84 days of its curing. Surely, such procedure is more demanding because of longer time needed for preliminary testing. Figure 9 shows value f_c of particular series for different point in time.

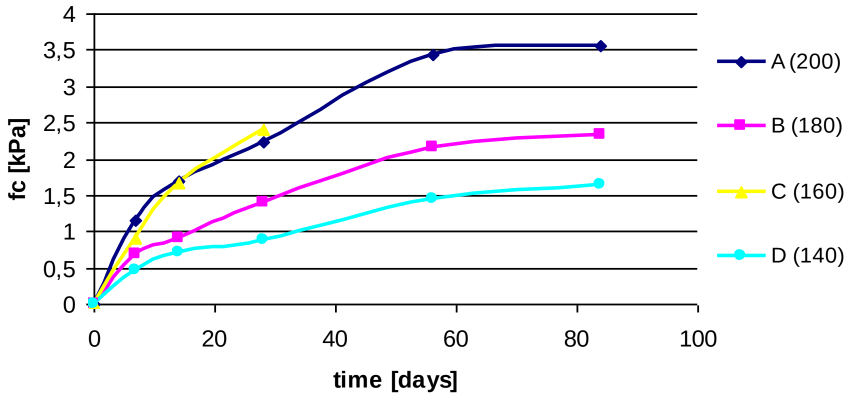

Figure 9. The increment of uniaxial compression strength in time for series A(200), B(180), C(160) and D(140) with various cement content

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4.2. Elastic modulus and stiffness vs. strength of soil-cement

The modulus of volume elasticity (*E*) was determined as a mean from the modulus E_1. Its value for a given series and particular point in time are presented in Figure 10 and Figure 11 in relation to the uniaxial compression strength.

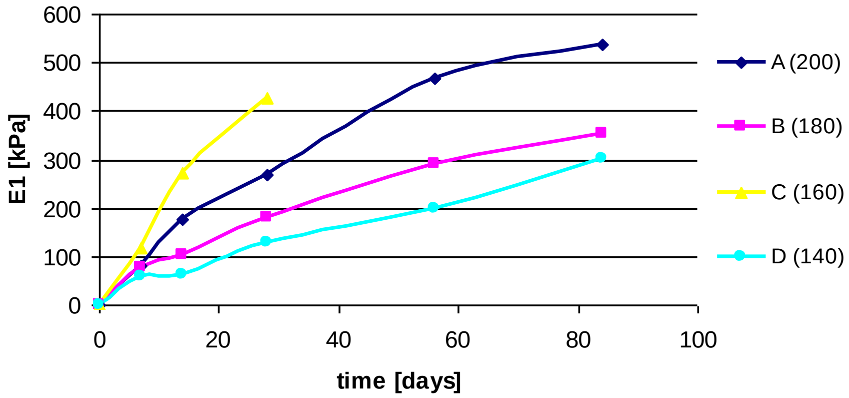

Figure 10. The increment of modulus of volume elasticity in time for series A(200), B(180), C(160) and D(140) with various cement content

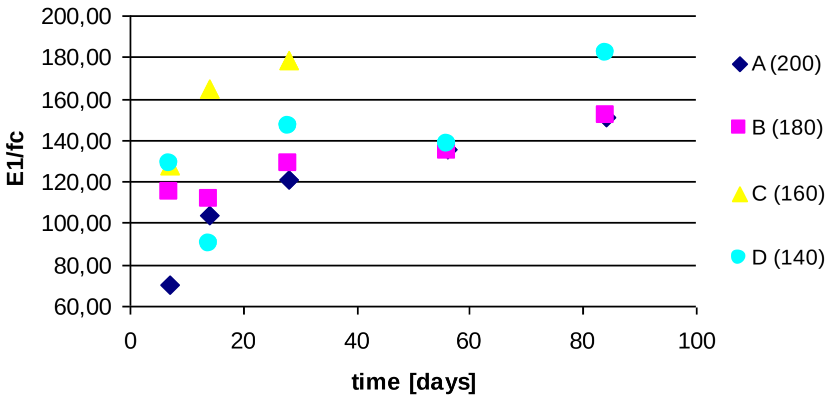

Figure 11. The dependence of E_1 modulus on f_c for the soil-cement samples under test

It is clearly visible on Figure 11 that this dependence increases and it depends on curing time of the test sample and the amount of cement used for mixing. The obtained dependence of compression strength and the mean modulus of volume elasticity on time may be also approximated by a straight line, however this is not a constant value as assumed in work [17], where the dependence between the f_{c}, vs. *E,* was formulated as follows (3):

$$E \approx 120 \cdot f_c\,[MPa] \tag{3}$$

It is necessary to remember that this given formula was only true for the tested group of organic soil and selected cement types. Generally, it may give the idea of the rank of the values of these moduli in the cases when the organic soil admixtures are considered. It is worth to notice that the relation (3) is significantly different in other type of soils. So in non-organic and organic soils not only the level of f_c and *E* is different but also the relation between them. The relation does not need to be constant.

4.3. Tensile strength vs. compression strength

Tensile strength was determined for series D(140) and for the whole range of curing time, i.e. for 7-84 days. The obtained results were as follows in Table 1. The course of testing do not present a considerable amount of trials in the tension test so the clear conclusions cannot be drawn. Despite that, the value of the obtained f_t/f_c relations is surprisingly consistent with previous experience in the tests of cement-organic soil samples. By way of generalization, it is possible to assume that the tensile strength of soil-cement f_t equals approximately 10% of the compression strength f_c.

Table 1. Results of tensile strength testing vs. compression strength

time [days]	f_c [MPa]	f_t [MPa]	f_t/f_c
7	0.45	0.05	11.4%
14	0.71	0.11	15.0%
28	0.88	0.09	10.4%
56	1.44	0.10	6.7%
84	1.66	0.16	9.5%

5. Summary and conclusions

All the results of series C(160) seem to be quite confusing as relatively small amount of cement provides best results of strength and stiffness. This confusion may be explained by so-called “bag dependency” of sample quality. The material used for preparing C(160) samples (in 2016), marked as the same geological layer, was taken from other bags and had much more of gravel fractions.

Of course, it must be also remembered that soil-cement mix – especially the one obtained in situ – will never be as homogeneous and resistant as the mix prepared in laboratory conditions. As recommended in work [17], some consolation may be offered by the fact that in the DSM columns with large diameters one can count on the averaging of the values of strength parameters on the possible failure surfaces. In order to confirm that intuition, though, large-scale tests on core samples would be necessary. The representativeness of samples and their quality in terms of extraction, treatment and transport should be however provided by independent geotechnical supervisor [21,22]. It is extremely important because the procedures doesn’t have to comply with standard procedures applied for construction concrete samples. The maximum values of strength were obtained after 84 days, however the increase in the third month is not very significant for all groups of samples.

The application of fly ashes postpones the setting process in mixed soil. To some extent, fly ashes may however substitute energy consuming cement as binder in large earthworks.

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References

[1] Topolnicki M 2006 Soil mixing - challenges of applications ranging from ground improvement to structural elements, *XIII. Danube-European Conference on Geotechnical Engineering, Ljubljana, 29-31.05.2006*, pp 1-6

[2] Leśniewska A 2007 Strength and technological issues of soil improvement by means of Deep Soil Mixing Wet technology. *Doctor’s Thesis*, Gdańsk University of Science and Technology (in Polish)

[3] Topolnicki M 2009 Design and execution practice of wet Soil Mixing in Poland, *International Symposium on Deep Mixing & Admixture Stabilization, Okinawa, 19-21 May*, pp 195-202

IOP Conf. Series: Materials Science and Engineering **365** (2018) 032049 doi:10.1088/1757-899X/365/3/032049

[4] Bruce M E C, Berg R R, Collin J G, Filz G M, Terashi M, Yang D S 2013 Federal Highway Administration Design Manual: Deep Mixing for Embankment and Foundation Support, Publication No. FHWA-HRT-13-046

[5] Topolnicki M, Sołtys G 2012 Novel application of wet deep soil mixing for foundation of modern wind turbines, Geotechnical Special Publication, (228 GSP), pp 533-42

[6] Topolnicki M 2015 Geotechnical design and performance of road and railway viaducts supported on DSM columns – a summary of practice, *International Conference on Deep Mixing, June 2-5, 2015, San Francisco*, pp 1-20

[7] Topolnicki M 2016 General overview and advances in Deep Soil Mixing”, *XXIV Geotechnical Conference of Torino Design, Construction and Controls of Soil Improvement Systems*, Torino, 25-26.02.2016, pp 1-30

[8] Pilipenko A, Bazhenova S 2017 Usage of crushed concrete fines in decorative concrete, *IOP Conference Series - Materials Science and Engineering*, vol. **245** (2), art. 032082

[9] Remišová E, Decký M, Mikolaš M, Hájek M, Kovalčík L, Mečár M 2016 Design of road pavement using recycled aggregate. *IOP Conference Series - Earth and Environmental Science*, vol. **44** (2), art. 022016

[10] Kawalec J, Kwiecień S, Pilipenko A and Rybak J 2017 Application of crushed concrete in geotechnical engineering - selected issues, *IOP Conference Series - Earth and Environmental Science*, vol. **95** (2), art. 022057

[11] Zabielska-Adamska K 2008 Laboratory compaction of fly ash and fly ash with cement additions, *Journal of Hazardous Materials*, **151** pp 481–89,

[12] Balachowski L, Sikora Z 2013 Mechanical Properties Of Bottom Ash – Dredged Material Mixtures In Laboratory Tests, *Studia Geotechnica et Mechanica*. vol. **35** (3), pp 3-11

[13] Duszyński R, Duszyńska A and Cantré S 2017 New experiences in dike construction with soil-ash composites and fine-grained dredged materials, *Studia Geotechnica et Mechanica*, vol. **39** (4), pp 17-24

[14] Piasecki D, Stefaniuk D 2016 Micro-scale laboratory investigation of cement-soils composite, *Stroitel'stvo-formirovanie sredy žiznedeâtel'nosti, Moskva, 27-29 aprilâ 2016. Moskv*a : NIU MGSU, pp 1061-65

[15] Stefaniuk D, Zajączkowski P and Rybak J 2016 Methodology of axial testing of cement-fly ash-soil samples. *Stroitel'stvo-formirovanie sredy žiznedeâtel'nosti. Moskva, 27-29 aprilâ 2016,* Moskva : NIU MGSU, pp 1091-94

[16] Egorova A A, Rybak J, Stefaniuk D and Zajączkowski P 2017 Basic aspects of deep soil mixing technology control, *IOP Conference Series - Materials Science and Engineering*, vol. **245** (2), art. 022019

[17] Kanty P, Rybak J and Stefaniuk D 2017 Some remarks on practical aspects of laboratory testing of deep soil mixing composites achieved in organic soils”, *IOP Conference Series - Materials Science and Engineering*, vol. **245** (2), art. 022018

[18] Declarations of Cement Utility Performance: Górażdze Cement S.A. CEM II/B-S 32.5R-NA 07.2016.

[19] ASTM (D 3148-02) Standard Test Method for Elastic Moduli of Intact Rock Core Specimens in Uniaxial Compression.

[20] The Complete ISRM Suggested Method for Rock Characterization, Testing and Monitoring: 1974-2006, Edited by R. Ulusay and J. A. Hudson.

[21] Sobala D, Rybak J 2017 Role to be played by independent geotechnical supervision in the foundation for bridge construction, *IOP Conference Series - Materials Science and Engineering*, vol. **245** (2), art. 022073

[22] Drusa M, Vlcek J 2016 Importance of Results Obtained from Geotechnical Monitoring for Evaluation of Reinforced Soil Structure – Case Study, *Journal of Applied Engineering Sciences*, De Gruyter Open, vol **6** (1), DOI: 10.1515/jaes-2016-0002