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RESEARCH OF CEMENT ADDITIVES INFLUENCE ON THE PROPERTIES OF SOILCRETE

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Abstract. The article analyses a possibility of replacing a part of cement with fly ash in jet grouting piles, because the received strength of cement treated grout is much higher than it is necessary for these piles. The paper presents the problems of fly ash utilization, overviews experimental and theoretical works and analyses laboratory tests on the samples of cement treated grout. The conducted experiments involved manufacturing cylindrical cement treated grout samples containing different additives when the diameter of the cylinder is 35 mm, and its height is 70 mm. The experiments on the samples comprising the additives of fly ash were made in sand and clay soils. 25% to 75% of cement was replaced with fly ash in cement treated grout samples tested under compressive strength following 7 days hardening in air.

Keywords: soilcrete, fly ash, compressive strength, sand soil, clay soil, jet grouting.

Introduction

For renovating buildings, constructing additional floors, installing foundation pits adjacent to the existing buildings, eliminating excessively large and uneven deposits of the buildings erected on loose soil and constructing tunnels under severe conditions, high-pressure jet grouting is frequently applied. Cement slurry is injected into soil through an injector under the pressure of 400–600 bars (Fig. 1a). Dynamically operating cement slurry cuts and shreds soil, loses the energy and forms a mixture with the degraded soil. The hardened mixture turns into the strong cement treated grout (Fig. 1b), the compressive strength of which is received higher than required. A high content of the used cement is one of the drawbacks of the introduced technology, i.e. more than 500 kg per cubic meter of slurry can be injected (Dagys *et al.* 2010). Therefore, this is a reason why a part of cement could be effectively replaced with other material. In this case, fly ash can be accepted as one of such materials (McCarthy, Dhir 2005).

Presently, Lithuania counts 160 larger and smaller boiler-rooms fired by wood waste. Solid bio-fuel power plants burning wood pellets or the whole wood fuel, including branches, needles and stumps, extract ashes at the final level of the combustion process. Annually, more than 30 000 tons of wood ash are produced, though it is expected that the number will reach 100 000 in the future. Currently, enormous taxes are paid in Lithuania to deliver them to the landfill where they are composted or buried in the ground. Two types of ashes can be distinguished – those deposited during the combustion process and those running through the exhaust outlet of the chimney stack and deposited in the filters of the chimney. Fly ash, i.e. the one accumulated in the filters of chimneys due to silicon

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Fig. 1. Specificities of jet grouting technology: a – in the course of jet grouting, cement slurry is injected into soil through small-diameter nozzles (Jet grouting... 2016), b – cement slurry is mixed with soil, and cement treated grout columns are received

dioxide, an active element necessary for concrete hardening, is much more appropriate for concrete industry (Levickaitė, Ivanauskas 2014).

Sweden has established standards for using ashes rich in carbon and silicon in the process of manufacturing cement and concrete. The ashes resulting from the combustion of biofuels do not meet these standards, therefore the wood ash was investigated as an additive in the manufacture of concrete. The laws in Sweden prohibit the use of ashes in large amounts for producing concrete, there are high requirements for ashes. However, it is a necessity to use the fly ash as a binder in concrete because of high price of cement (Nordström, Thorsell 2003).

Investigations into the compressive strength of concrete show the strength decreases replacing a part of cement with fly ash (McCarthy, Dhir 2005; Berndt 2009). To apply such replacement to soilcrete, research on compressive strength is required. Lack of data on the percentage of replacing cement with fly ash has led to pilot experiments on two types of soil and four proportions of cement and fly ash.

Investigated mixtures of soilcrete

The composition of the investigated soilcrete includes cement, water, soil, and fly ash. The compressive strength of soilcrete depends on the relative content of every component and the type of soil (Dagys *et al.* 2010; Medzvieckas, Sližytė 2013; Gomes Correia *et al.* 2009).

Two types of soil were used. The first one is sand the granulometric composition of which was determined according to the requirements of LST EN 933-1:2002. The granulometric curve of this soil is provided in Figure 2. The second type of soil represents the above mentioned sand mixed with clay powder under laboratory conditions and which is further entitled as clay soil. The process of producing the mixture involved 10% replacement of sand with clay powder. The mixture is necessary in order to assess the possibilities of fly ash usage in clay soils.

To produce mixtures, fly ash taken from biomass boiler house was used. These ashes formed in the process of burning wood waste, including branches, needles and stumps. They are collected at the last level of the combustion process when ashes deposit in the filters of the chimney stack.

Portland-cement EN 197-1-CEM II/A-LL 42.5 N was used.

To prepare specimens, the ratio of water to cement made W/C = 0.5/1 while the ratio of sand to cement was S/C = 2, and coarse aggregate was not applied. The amount of additives of fly ash in the mixtures of soilcrete was 0%, 25%, 50%, and 75% respectively. The mixtures that do not contain fly ash were

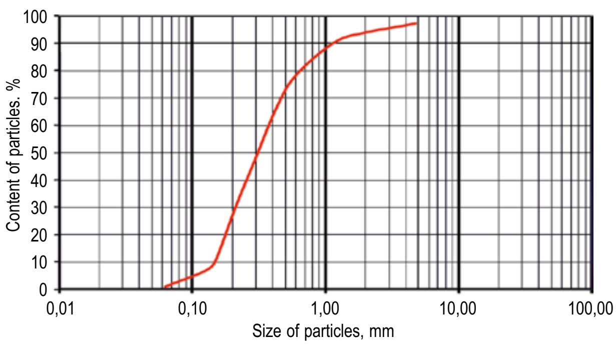

Fig. 2. A curve of the granulometric composition of sand

Table 1. Formulae of cement treated grout

	In sand				In clay soil			
Content of fly ash	0%	25%	50%	75%	0%	25%	50%	75%
Fly ashes (kg)	0	0.025	0.050	0.075	0	0.025	0.050	0.075
Water (kg)	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Cement (kg)	0.100	0.075	0.050	0.025	0.100	0.075	0.050	0.025
Sand (kg)	0.20	0.20	0.20	0.20	0.18	0.18	0.18	0.18
Clay (kg)	0	0	0	0	0.02	0.02	0.02	0.02

used as the control ones. To conduct the experiment, the specimens were produced in series of 3 items with a different content of fly ash. The formulae of the mixtures are presented in Table 1.

Preparation of soilcrete specimens

The produced soilcrete specimens were made as cylinders of 35 mm in diameter and 70 mm in height (LST EN 12716:2003). In order to manufacture these specimens, tubular PVC forms of 35 mm in diameter (Fig. 3a) were used.

The made mixture of soilcrete of the required consistency was poured into the moulds.

The three layers were made in the form and each one was thickened with the metal rod, pressing them 10 times. Surplus was removed level with the shaped edges (Fig. 3b).

After 24 hours the specimens were taken out from PVC moulds (Fig. 3c) and placed into the sealed container where they were stored in air. Compressive strength was determined after a week.

Compressive strength of soilcrete specimens

The cylindrical compressive strength of the specimens was defined using uniaxial compression machine TRIAX 50 according to the standard LST EN 12390-3:2009 *Compressive Strength of Concrete*. Loading took place at a speed of 1,0 mm/min thus determining the fracture load (ultimate load) of each sample. The compressed specimens are shown in Figure 4. Compressive strength is calculated according to formula (1):

$$f_c = \frac{F_c}{A_c}, \tag{1}$$

where F_c is compressive strength of the fracture, A_c

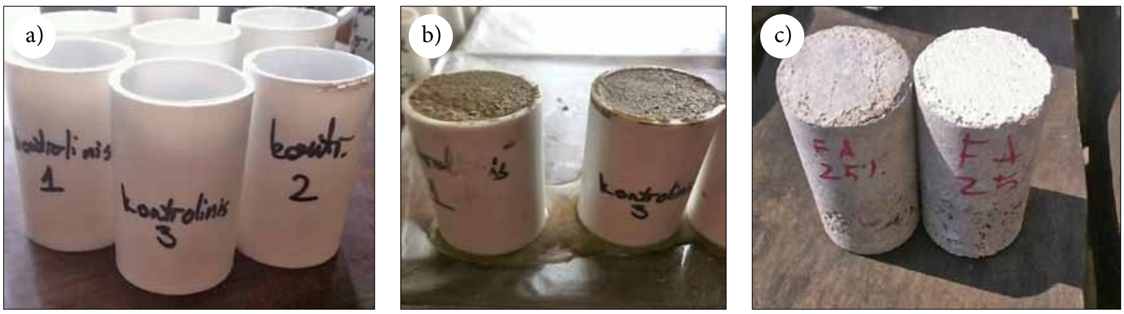

Fig. 3. Specimen preparation: a – tubular PVC; b – specimens removing surplus level with the shaped PVC edges; c – produced specimens taken out from PVC moulds

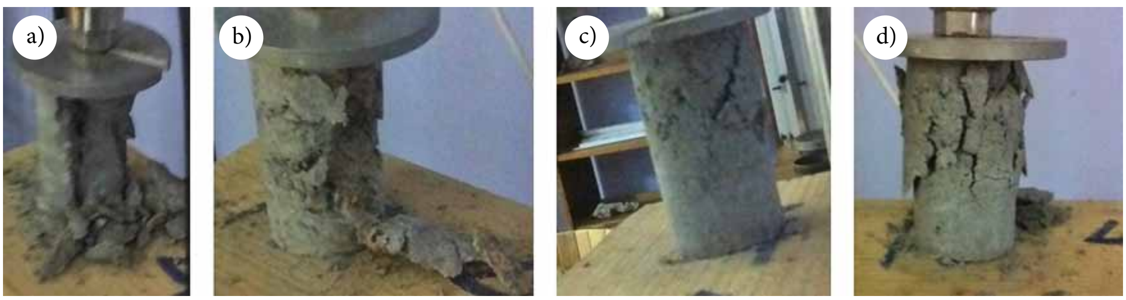

Fig. 4. Compressed specimens: a – no additives (sand soil), b – no additives (clay soil), c – containing fly ash (sand soil), d – containing fly ash (clay soil)

is cylindrical cross-sectional area (LST EN 12390-3:2009).

The defined density ρ and compressive strength f_c of soilcrete specimens with fly ash additives in sand are shown in Table 2.

The calculation of the average values of the compressive strength of each series has revealed a trend that an increase of fly ash in the composition reduces compressive strength (Fig. 5).

The specimens not containing the additives of fly ash possessed the strongest properties of compressive strength which was equal to 5.90 MPa. These are control specimens, and therefore the obtained results are compared with the properties of these samples. The compressive strength of the specimens in which 25% of cement was replaced with fly ash was equal to 4.05 MPa. Compared with control specimens their strength decreased by 31% (Fig. 6). The compressive strength of the specimens in which 50% of cement was replaced with fly ash was equal to 2.50 MPa. Compared with control specimens their strength decreased by 58%. The compressive strength of the specimens in which 75% of cement was replaced with the additives of flying ash was the lowest and reached 0.65 MPa. Compared with the specimens containing no additives, the strength decreased by 89%.

The defined density ρ and compressive strength f_c of soilcrete specimens containing the additives of flying ash in clay soil are shown in Table 3.

The calculation of the average compressive strength valuesin each series has disclosed the same tendencies as those observed in the case of different types of sand when an increase of fly ash amount in the composition reduces compressive strength (Fig. 5). The specimens that did not contain the additives of fly ash exhibited the strongest compressive properties and compressive strength which was equal to

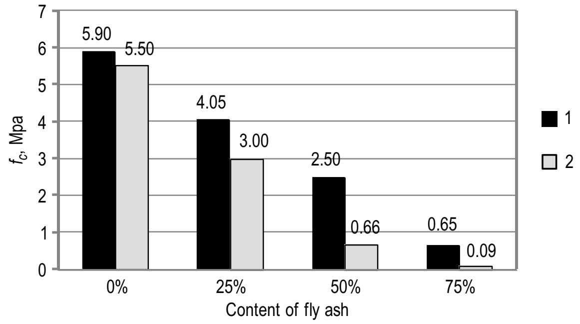

Fig. 5. The dependence of the average values of the compressive strength on the content of fly ash and the type of soil following 7 days of hardening: 1 – sand soil, 2 – clay soil

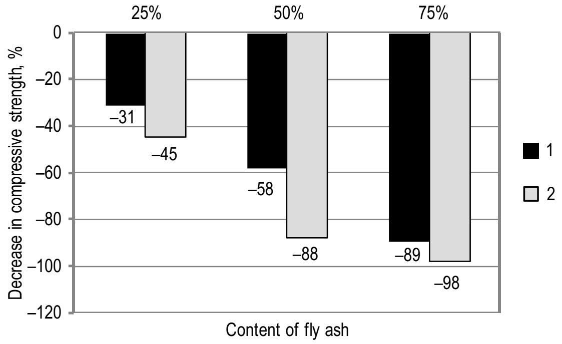

Fig. 6. Decrease in compressive strength depending on the content of flying ash and the type of soil: 1 – sand soil, 2 – clay soil

5.50 MPa. The compressive strength of the specimens in which 25% of cement was replaced with fly ash was equal to 3.00 MPa. Compared with control specimens the strength decreased by 45% (Fig. 6). The received strength of the specimens in which 50% of cement was replaced with fly ash was equal to 0.66 MPa. Compared with control specimens thestrength decreased by 88%. The compressive strength of the specimens in which 75% of cement was replaced with the additives of fly ash was the lowest and reached 0.093 MPa. Compared with the specimens containing no additives, the strength decreased by 98%.

Table 2. The results of experiments on soilcrete containing fly ash additives in clay sand following 7 days of hardening

Specimen	Specimen No 1		Specimen No 2		Specimen No 3	
	ρ, g/cm^3	f_c, MPa	ρ, g/cm^3	f_c, MPa	ρ, g/cm^3	f_c, MPa
Control specimens (sand soil)	2,09	5,83	2,14	5,90	2,15	5,95
Specimens containing ash additives replacing 25% of cement with fly ash	2,08	4,14	2,05	4,00	2,06	4,01
Specimens containing ash additives replacing 50% of cement with fly ash	2,02	2,57	2,08	2,66	2,05	2,58
Specimens containing ash additives replacing 75% of cement with fly ash	1,93	0,64	1,95	0,65	1,98	0,66

Table 3. The results of experiments on soilcrete containing the additives of fly ash in clay soil following 7 days of hardening

Specimen	Specimen No 1		Specimen No 2		Specimen No 3	
	ρ, g/cm^3	f_c, MPa	ρ, g/cm^3	f_c, MPa	ρ, g/cm^3	f_c, MPa
Control specimens (clay soil)	2.15	5.57	2.14	5.51	2.09	5.42
Specimens containing clay soil replacing 25% of cement with fly ash	2.11	3.05	2.09	2.98	2.08	2.97
Specimens containing clay soil replacing 50% of cement with fly ash	2.06	0.69	2.04	0.6	2.05	0.68
Specimens containing clay soil replacing 75% of cement with fly ash	1.84	0.09	1.93	0.098	1.89	0.091

A comparison of the specimens in which pure sand and sand containing clay was used has demonstrated that soil has a substantial impact on the strength of soilcrete. Compressive strength in clay soil specimens of concrete was significantly lower then in the sand soil ones (with the same amount of fly ash). When the 50% of cement in the clay soil was replaced with fly ash, the results showed that the compressive strength would be too low for structures. Meanwhile, when the similar amount of cement were replaced with fly ash in sand, the average compressive strength still reaches 2.5 MPa.

Conclusions

1. The conducted experiments on uniaxial compression demonstrate that when replacing up to 50% of cement into the fly ash, we get the specimens of the soilcrete of sufficient strength. The replacement of 25% cement with additives reduced the strength of the specimens by 31% (up to 4.05 MPa) while the replacement of 50% cement with additives decreased strength by 58% (up to 2.5 MPa). However, a larger 75% increase of fly ash additive in the composition of soilcrete shows that the received specimens don't have a sufficient strength which is equal to 0.65 MPa.
2. Similar experiments on the specimens containing clay have disclosed that when replacing up to 25% cement into fly ash, we get soilcrete specimens of sufficient strength. The replacement of 25% cement into the additives points to a decrease in strength by 45% (up to 3.0 MPa). When the fly ash amount in the composition of soilcrete increases up to 50% and 75%, the received specimens are of insufficient strength which is equal to 0.66 MPa and 0.1 MPa respectively.

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