

STABILIZATION OF CLAY POWDER WITH MINERAL WOOL FLY ASH

Mindaugas ZAKARKA , Rimantas MACKEVIČIUS , Šarūnas SKUODIS *,
Danutė SLIŽYTĖ , Andrius KUDŽMA 

Faculty of Civil Engineering, Vilnius Gediminas Technical University, Vilnius, Lithuania

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Abstract. The aim of this article – to determine short term and long term strengthening of clay soil, by strengthening it with fly ash obtained during the production of mineral wool. This article introduces research which is used to determine the optimal ratio of fly ash in cement suspension for strengthening of clay soil. Samples which were investigated in this research work prepared by mixing Portland cement, mineral wool fly ash, clay powder, sand and water. All investigated samples compressive strength after 6 months exceeded 1.7 MPa. It is enough of such strength in geotechnics to conduct strengthening of soil and it is possible to argue that soil is strengthened.

Keywords: clay, soil stabilization, fly ash, soil improvement, mineral wool, comprehensive strength.

Introduction

When the level of economy and consumerism rises, the problem of waste treatment is becoming more and more apparent. In Europe there are approximately 16 tonnes of waste per capita during the year, and approximately 6 tonnes are recycled (European Commission, 2010). One of methods to treat waste is incineration, during which the by-products are obtained – bottom ash and fly ash (FA). The ash is obtained during waste incineration, bio-fuel burning, mineral wool production, etc. Bottom ash may be used in construction (Zabihi-Samani et al., 2018), especially in the roads (Vaitkus et al., 2017), included into the production process or disposed in mines. FA utilization problem is more complicate, because FA accounts for 15% of total ash (Pundinaitė-Barsteigienė et al., 2017). Not all FA may be used because of poor quality (Giergiczny et al., 2019). Collection, transportation and work with FA is more complicate than with bottom ash because of fine particles (Supancic & Obernberger, 2011). FA may change the fine particles of other materials and has binding properties (Rutkauskas, 2018).

One of methods to use FA in geotechnics is to change a part of cement into FA and to apply such mix in order to strengthen weak soil (Pentti, 2001), by using jet grouting. During jet grouting, into cement suspension a certain part of cement is being changed into FA. Depending on type

and ratio of FA different short term and long term values of strength are obtained (Essler & Yoshida, 2004; Hemalatha & Ramaswamy, 2017). It is important, that it is possible to strengthen clay soils with FA high in calcium as well (Kolias et al., 2004). Another possibility is to refuse using cement and use only FA (Cristelo et al., 2013). The results of this test are very advantageous, but the effect which is obtained differs from jet grouting with cement suspension. By using cement suspension, 80–85% of grouted concrete strength value is reached during 28 days (Sližytė et al., 2010). When a binder is FA, values of strength constantly grow and strengthening does not stop during the one year period (Cristelo et al., 2011; Marinković & Dragaš, 2018).

Another method to strengthen soils is relevant in road construction, in order to install strong soil layer (Turner, 1997; Zokaitė, 2015). Strong soil layer allows to reduce the thickness of the asphalt layer (Parsons & Kneebone, 2005). It is possible to strengthen soil with FA without cement admixture (Mishra & Rath, 2011; Supancic & Obernberger, 2011). This method solves the problem of FA utilisation, but it is possible to apply it only to low intensity roads. Another problem appears due to rising dust during work. Also it is possible to mix the layer of weak soil with cement or with cement and FA. The advantage of this method is that clay soils can be mixed with cement as well.

*Corresponding author. E-mail: sarunas.skuodis@vgtu.lt

One of the main problems while working with FA is that their composition is very different and it depends on incinerated materials (Vaitkus et al., 2017; Rudžionis & Ivanauskas, 2004). The properties of FA which were collected even in the same factory but in different times may differ (Rutkauskas, 2018), therefore FA collected during the production of mineral wool gain and advantage due to constant and more predictable composition. During production of mineral wool, bottom ash is returned to production process, it is possible to recycle used wool as well (Väntsi & Kärki, 2014; Balkevičius et al., 2007). Only FA stay as a by-product, it is not returned to production process due to fine particles.

Usually FA collected in thermoelectric power plant are used in tests, therefore the tests conducted using FA collected in mineral wool production is a new experience. FA from mineral wool production, in comparison with thermoelectric power plant FA, have 5% less SiO₂, 5% more Fe₂O₃, 13% less CaO, 9% more MgO, 6% more Na₂O, etc. (Česnauskas, 2018). Stabilisation of weak clay soils is a relevant problem which needs to be solved. The aim of this article – to determine short term and long term strengthening of clay soil, by strengthening it with fly ash obtained during the production of mineral wool. This article introduces research which is used to determine the optimal ratio of fly ash in cement suspension for strengthening of clay soil.

1. Testing methodology

Samples were prepared by mixing Portland cement, FA, clay powder, sand and water. FA used for tests were obtained from mineral wool production process as the waste, the chemical composition of which is presented in Table 1 (Stonys et al., 2016). Samples are produced using Portland concrete CEM I 42,5 R, which corresponds to LST EN 197-1:2013 (Lietuvos standartizacijos departamentas, 2013), clay powder, the chemical composition of which is presented in Table 2. Used sand, the grading curve of which is shown in Figure 1, coefficient of uniformity C_u = 2.77 ir coefficient of curvature C_c = 0.90. Granulometric composition was determined according to specifications of standards LST CEN ISO/TS 17892-4:2017 (Lietuvos standartizacijos departamentas, 2017) and LST CEN ISO/TS 17892-12:2018 (Lietuvos standartizacijos departamentas, 2018).

To each different composition of mixture three sets of cylindrical samples were prepared, the diameter of which 4.5 cm, height 7.0 cm. Overall 15 different compositions were investigated in tests, these compositions are presented in Table 3. At first five ratios of cement and fly ashes were prepared: 100% C with 0% FA, 90% C with 10% FA, 80% C with 20% FA, and 70% C with 30% FA. Three clay mixtures were mixed as well, which are made of 80% CP and 20% Sa, 60% CP and 40% Sa and 40% CP and 60% Sa. Plastic and liquid limits of clay soils are presented in Figure 2.

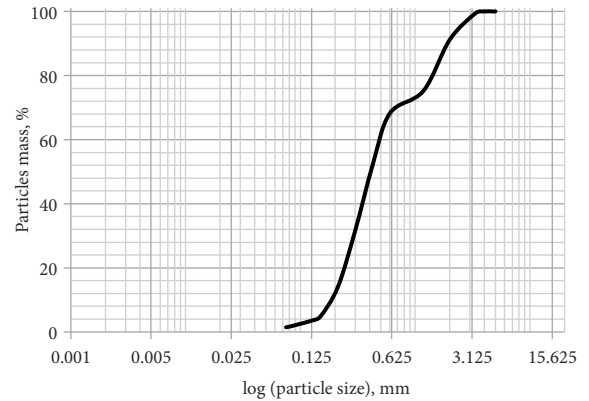


Figure 1. Granulometric composition of investigated sand

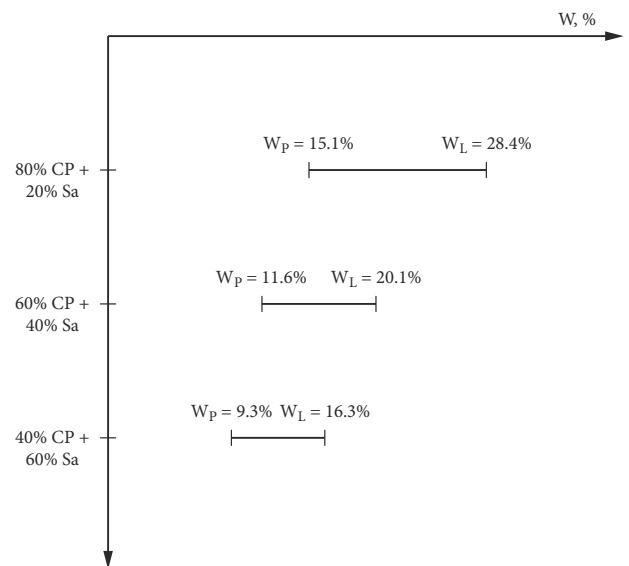


Figure 2. Plastic and liquid limits of clay mixtures

Table 1. Chemical composition of fly ash, %

SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO	Na ₂ O	K ₂ O	TiO ₂	SO ₃	Cl	other	LOI
40.6	2.14	6.91	3.52	11.1	6.71	6.34	0.23	2.41	4.58	4.67	10.79

Table 2. Chemical composition of clay powder, %

SiO ₂	Al ₂ O ₃	TiO ₂	Fe ₂ O ₃	MnO	MgO	CaO	Na ₂ O	K ₂ O	P ₂ O ₅
55.0–62.1	15.7–17.7	0.7–0.9	6.1–7.9	0.1–0.2	2.2–3.2	0.3–1.8	0.1–0.3	2.9–3.5	0.1–0.2

Table 3. Composition of samples

Sample No.	C quantity, %	FA quantity, %	W/(C+FA)	CP quantity, %	Sa quantity, %
1	100	0	1	80	20
2	100	0	1	60	40
3	100	0	1	40	60
4	90	10	1	80	20
5	90	10	1	60	40
6	90	10	1	40	60
7	80	20	1	80	20
8	80	20	1	60	40
9	80	20	1	40	60
10	70	30	1	80	20
11	70	30	1	60	40
12	70	30	1	40	60
13	60	40	1.5	80	20
14	60	40	1.5	60	40
15	60	40	1.5	40	60

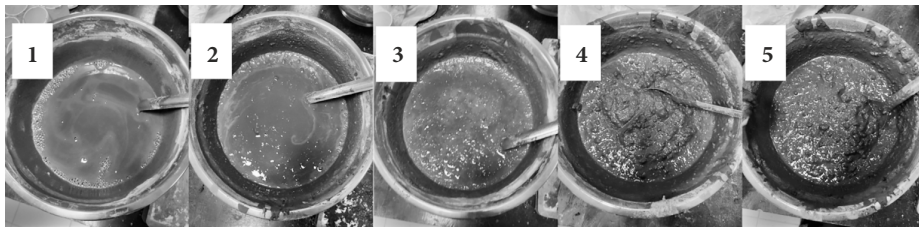


Figure 3. Cement and fly ash (C+ FA) suspension: 1 – 100% C + 0% FA; 2 – 90% C + 10% FA; 3 – 80% C + 20% FA; 4 – 70% C + 30% FA; 5 – 60% C + 40% FA

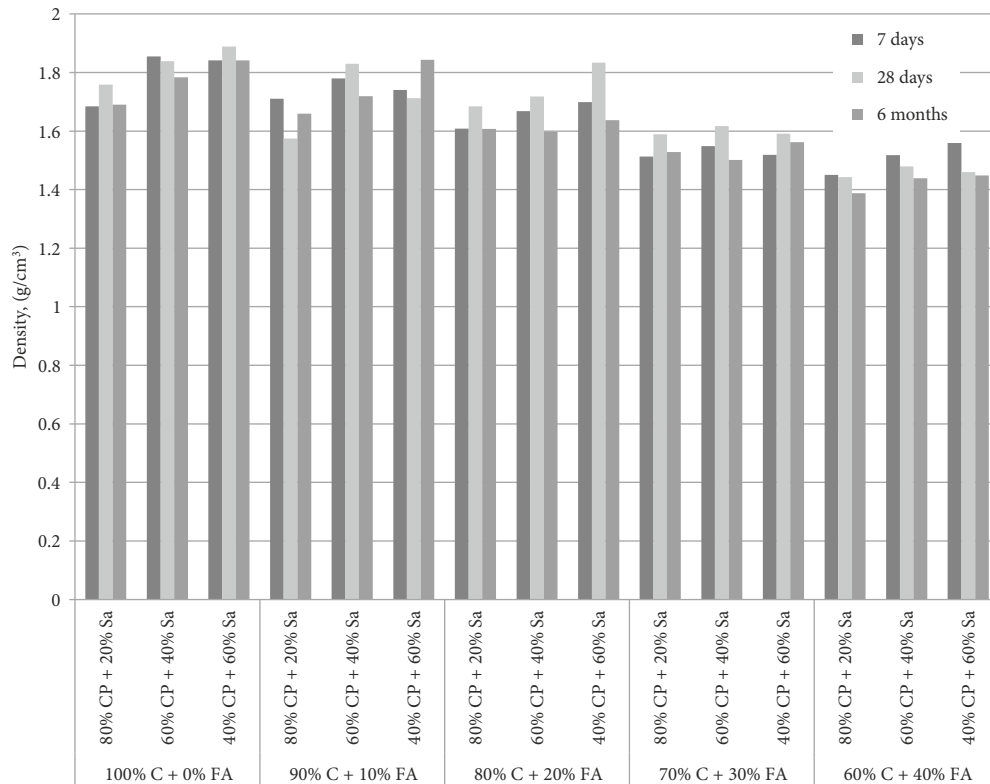


Figure 4. Density of investigated samples

Suspension of cement and fly ashes (C + FA) was mixed with water in ratio 1:1, but when the quantity of FA was increased the suspension thickened and was not suitable to work (Figure 3), i. e. at 60% C + 40% FA ratio was increased till 1:1.5. For different types of FA different water ratios are required in order to achieve maximum values of compressive strength (Fuller et al., 2018).

Samples after 24 hours were removed from forms and kept in a humid environment in exicators. After 7, 28 and 180 days density and compressive strength were determined to them.

2. Analysis of obtained results

Before determining uniaxial compressive strength the density of samples was determined (Figure 4). It was obtained by measuring dimensions of samples and by weighing them. Density of samples of the same composition which were tested after different period of time, differs in average by 3.6%, and the biggest distinction is 7.9%. The minimum density equals to 1.388 g/cm³, which was reached after 6 months for 60% C + 40% FA and 80% CP + 20% Sa. The maximum density equals to 1.889 g/cm³, which was

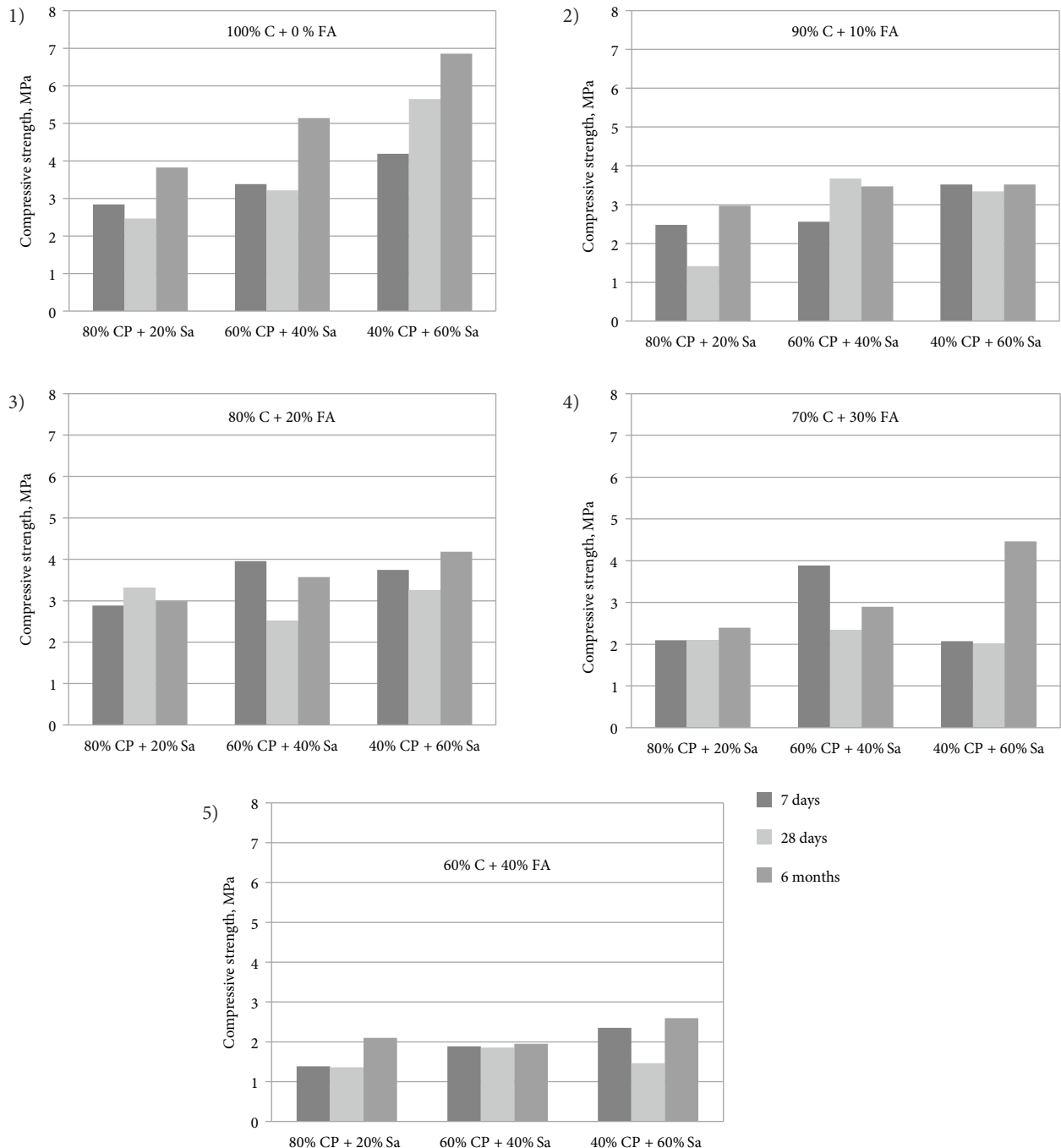


Figure 5. Compressive strength of samples: 1 – 100% C + 0% FA; 2 – 90% C + 10% FA; 3 – 80% C + 20% FA; 4 – 70% C + 30% FA; 5 – 60% C + 40% FA

reached after 28 days when there were 100% of cement and 40% CP + 60% Sa.

As standard results the data is used obtained from samples in which there is no FA. These results of uniaxial compression tests are the most clear and the most predicted (Figure 5). At 100% C + 0% FA and 40% CP + 60% Sa, values of strength increased evenly when evaluating the results during different periods of time. When 100% C samples were mixed with 80% CP + 20% Sa and 60 CP + 40% Sa, strength values after 28 days in comparison with 7 days values weakened, and after 6 months strengthened. While increasing ratio of FA from 10 to 30%, results of samples strength vary slightly and do not show big change of compressive strength.

Twelve of the fifteen mixtures had a lower strength after 28 days (in comparison with 7 days) (Figure 6). The greatest weakening was 43%. Strength of mixtures comprised from 80% C + 20% FA and 80% CP + 20% Sa; 100% C and 40% CP + 60% Sa; 90% C + 10% FA and 60% CP + 40% Sa, after 28 days in comparison with 7 days increased (the greatest strengthening 43%). After 6 months strength of thirteen of the fifteen mixtures increased, comparing to the strength after 28 days. The samples comprised of 90% C + 10% FA ir 60% CP + 40% Sa; 80% C + 20% FA

ir 80% CP + 20% Sa weakened. After 28 days the samples strengthened comparing to the results after 7 days. Strength of thirteen of fifteen mixtures increased comparing to the strengths after 7 days (increasing up to 115%). The results of samples were weaker, when the samples comprised of 70% C + 30% FA and 60% CP + 40% Sa; 80% C + 20% FA ir 60% CP + 40% Sa (the greatest weakening 38%).

The effect of sand and fly ash on samples density is shown in Figure 7. The effect of sand on density, comparing 80% CP + 20% Sa and 60% CP + 40% Sa, increased by 4.15%. Comparing 80% CP + 20% Sa and 40% CP + 60% Sa – density increased by 5.29%. The effect of fly ash on density, comparing it with samples in which there is 100% cement and 10% FA is added constantly, decreases by 3.7%; 6.9%; 13.6% and 18.5%.

Strength of samples, while comparing 80% CP + 20% Sa and 60% CP + 40% Sa, increased by 34.2%, and comparing 80% CP + 20% Sa and 40% CP + 60% Sa – 79.2% (Figure 7). Strength, when comparing with 100% C and adding 10% FA each time, decreases by 34.4%; 30.4%; 38.6% and 56.4% (Figure 7). When ratio of FA with C is between 10–30%, change of strength ranges in the interval of 5% and is not a tendency.

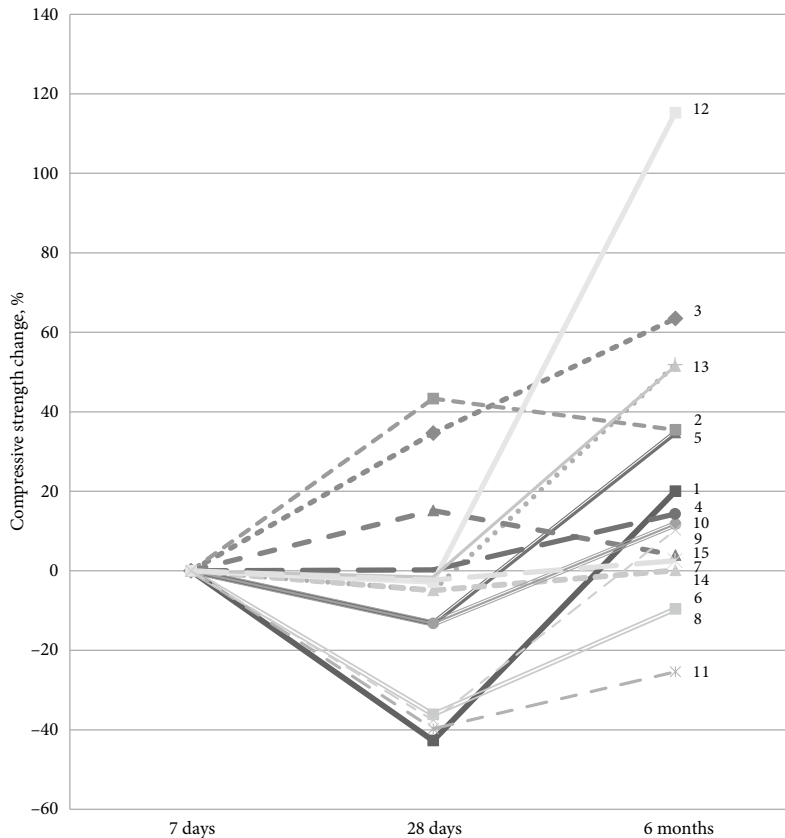


Figure 6. Relative change in strength after 28 days and 6 months in comparison with strength after 7 days: –1 – 100% C + 0% FA and 80% CP + 20% Sa; 2 – 100% C + 0% FA and 60% CP + 40% Sa; 3 – 100% C + 0% FA and 40% CP + 60% Sa; 4 – 90% C + 10% FA and 80% CP + 20% Sa; 5 – 90% C + 10% FA and 60% CP + 40% Sa; 6 – 90% C + 10% FA and 40% CP + 60% Sa; 7 – 80% C + 20% FA and 80% CP + 20% Sa; 8 – 80% C + 20% FA and 60% CP + 40% Sa; 9 – 80% C + 20% FA and 40% CP + 60% Sa; 10 – 70% C + 30% FA and 80% CP + 20% Sa; 11 – 70% C + 30% FA and 60% CP + 40% Sa; 12 – 70% C + 30% FA and 40% CP + 60% Sa; 13 – 60% C + 40% FA and 80% CP + 20% Sa; 14 – 60% C + 40% FA and 60% CP + 40% Sa; 15 – 60% C + 40% FA and 40% CP + 60% Sa

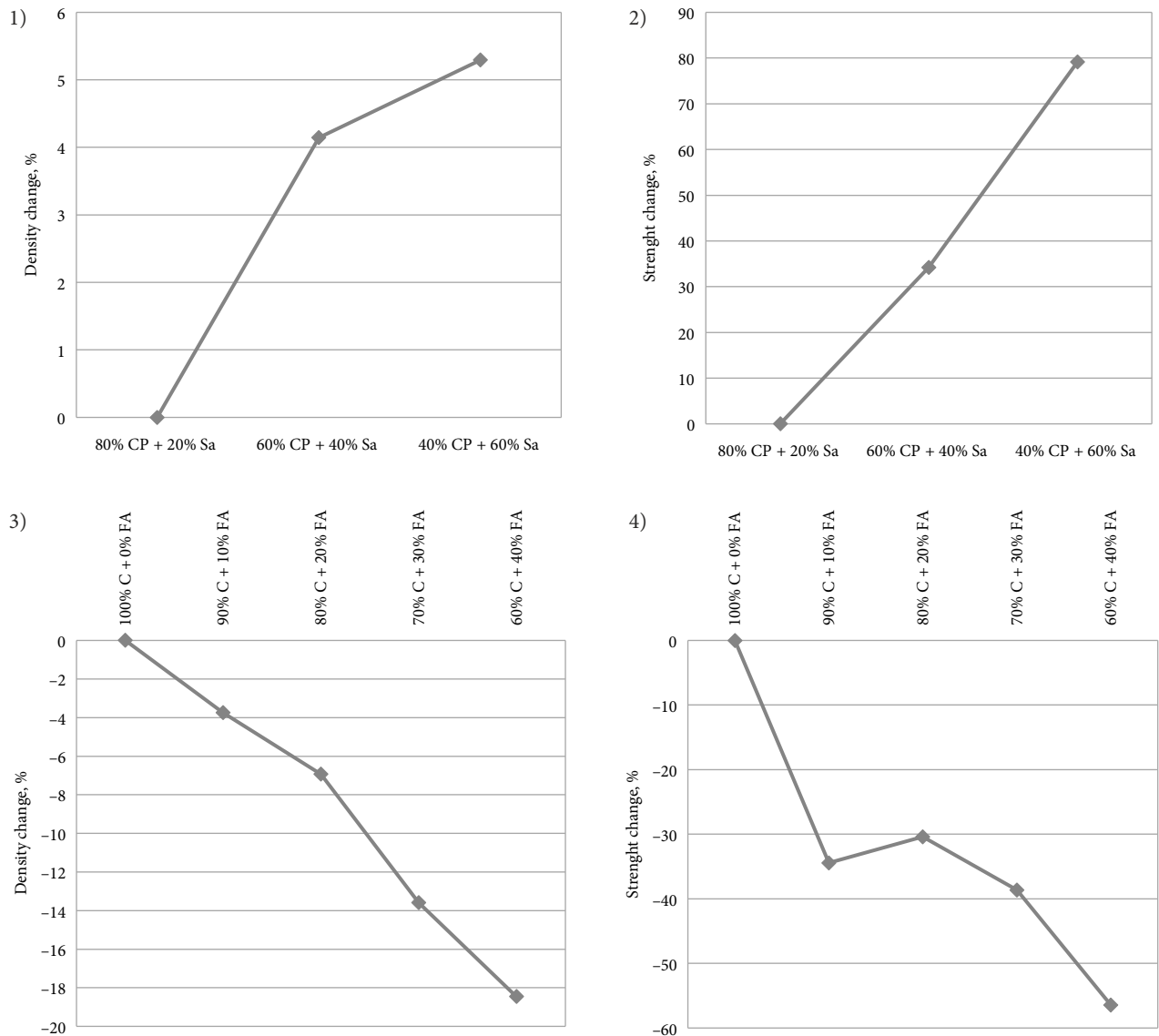


Figure 7. Effect of sand and fly ash on density and strength of samples after 6 months: 1 – Sa effect on density; 2 – Sa effect on strength; 3 – FA effect on density; 4 – FA effect on strength

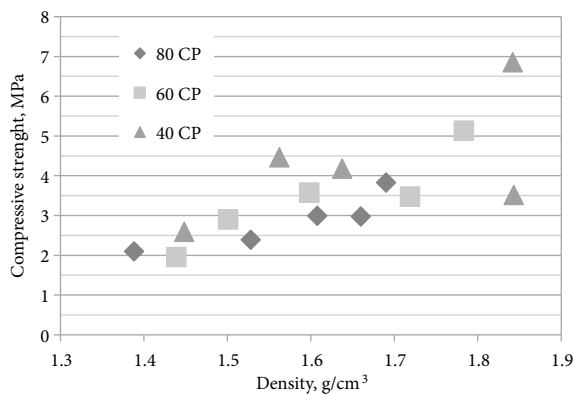


Figure 8. Density and compressive strength dependence on sand admixtures in clay

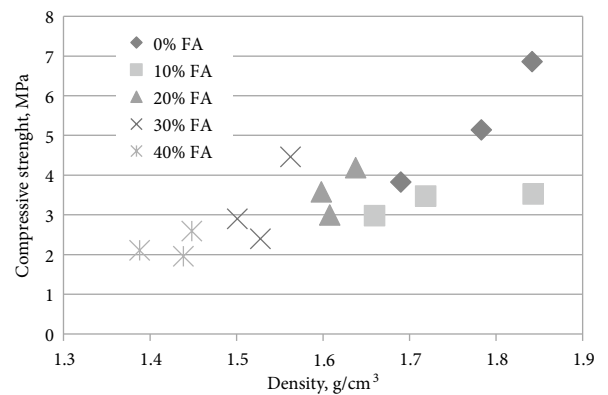


Figure 9. Density and compressive strength dependence on fly ash admixture in cement

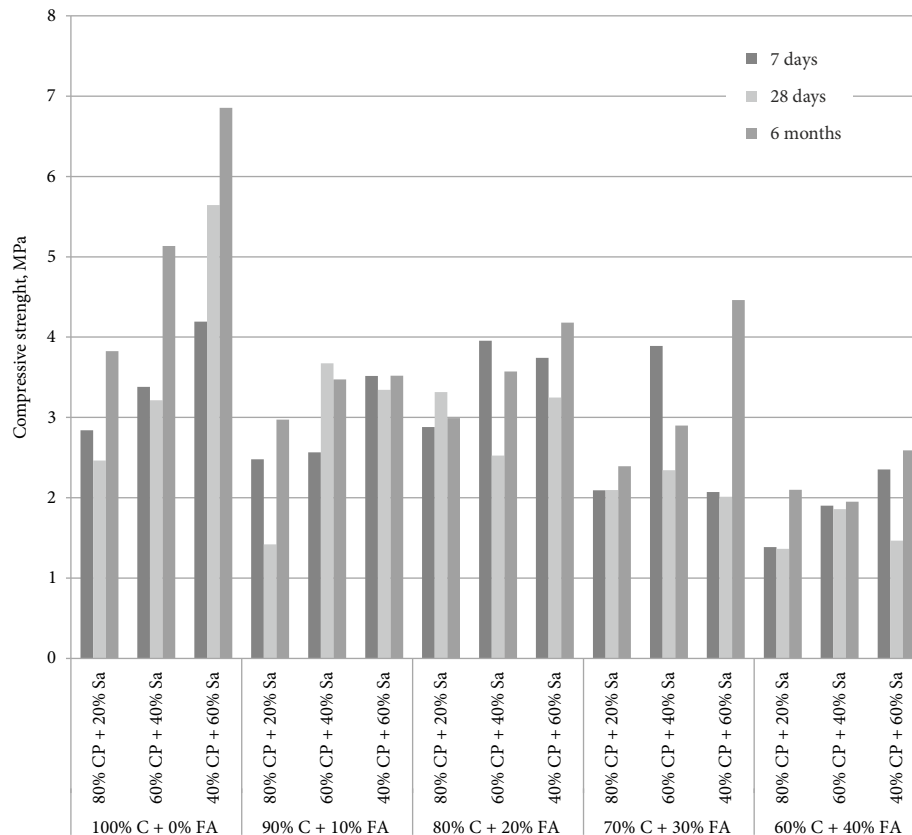


Figure 10. Compressive strength summary graph

Dependencies of density and compressive strength on sand and fly ashes are presented in Figures 8 and 9. By increasing quantity of sand in mixtures, density and strength of samples increases, and by increasing quantity of FA density decreases. When there is a 10–30% FA quantity, FA does not have effect on strength. The results of compressive strength of all tested samples are presented in Figure 10.

Notations

Abbreviations

- C – Portland cement;
- CP – Clay powder;
- FA – Fly ash;
- Sa – Sand;
- W – Water;
- W_p – Plastic water content limit;
- W_L – Liquid water content limit.

Conclusions

After the tests and analysis of tests results such conclusions can be made:

1. Increasing FA quantity in cement and FA mixture, density and strength of samples decreases;
2. Quantity of sand admixtures in clay soil has a huge effect on compressive strength of samples;

3. In suspension of cement FA ratio increased from 10 to 30% does not have clear effect on strength. An obvious decrease in results of strength occurs when fly ash ratio in cement suspension reaches 40%. According to the determined results it would be rational to limit fly ash quantity admixture in cement by 30% from mass of mixture;
4. After 28 days, while comparing with the results obtained after 7 days, compressive strength of samples decreased, and strengthening occurred after 6 months. Temporary weakening of compressive strength everywhere was no less than 1.3 MPa;
5. Even the minimal values of compressive strength after 6 months exceeded 1.7 MPa. It is enough of such strength in geotechnics to conduct strengthening of soil and it is possible to argue that soil is strengthened.

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