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Research Results of Fine-Grained Soil Stabilization Using Fly Ash from Serbian Electric Power Plants

Les résultats de recherche de la stabilisation des sols de grains fins en utilisant les cendres volantes des centrales électriques serbes

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ABSTRACT: This paper presents the results of laboratory research of fly-ash soil stabilization. Tests were conducted on mixtures with two types of fine-grained soils and fly ash sampled in Serbian electric power plant Kolubara. Used types of soils are low plasticity silty clay and very expansive, medium to high plasticity clay. Effects of fly ash on physical and mechanical properties of soil (grain size distribution, Atterberg limits, unconfined compression strength, moisture-density relationship, swell potential, CBR) were evaluated. Test mixtures were prepared at optimum water content from standard Proctor compaction test. Results of the research indicate that fly ash can effectively improve some engineering properties of soil.

RÉSUMÉ : Ce document présente les résultats de recherche en laboratoire de la stabilisation des cendres volantes. Les analyses effectuées concernent les mélanges avec deux types de sols de grains fins et de la cendre volante récupérée de la centrale électrique serbe « Kolubara ». Les types de sols utilisés sont de l'argile silteuse d'une plasticité faible et de l'argile très gonflante d'une plasticité moyenne à forte. Les effets des cendres volantes sur les propriétés physiques et mécaniques du sol (la distribution de la grosseur des grains, les limites d'Atterberg, la résistance à la compression uniaxiale, la relation entre la densité et l'humidité, les possibilités de gonflement, l'indice portant californien – CBR) ont été évalués. Les mélanges d'essai ont été préparés à teneur en eau optimale selon l'essai Proctor normal. Les résultats de la recherche signalent que les cendres volantes peuvent améliorer de manière efficace certaines propriétés techniques du sol.

KEYWORDS: soil stabilization, fly ash, fine-grained soil

1 INTRODUCTION

Fly ash makes the most of the combustion-by-products during the production of electricity in thermal power plants. A very small amount can be recycled, while significant amounts are disposed in landfills. The use of fly ash for soil stabilization can bring multiple benefits – protection of the environment, financial savings and it can also make the poorly-graded types of soils usable.

In Serbia, approximately 7 million tons of fly ash and slag are produced every year, of which only 3% is used in cement industry. The remaining products (about 300 million tons so far), are disposed on landfills, taking up the area of approximately 1600 hectares (Cmiljanić 2008, Cmiljanić 2010).

In Serbia, fly ash soil stabilization research was conducted for the first time during the preliminary design of the Serbian regional waste management center “Kalenic” (Report FCE Belgrade 2011). This research was performed by the authors during 2011. Waste management center “Kalenic” is located at open pit near thermal power plant “Kolubara”. Disposal area of the “Kalenic” landfill is being formed by construction of the outer embankment, instead of soil excavation, which is the usual way. The construction of the embankment needs more than 1.5 million m³ of material and costs are about 33% of total investment. Therefore, the possibility of using existing material from the site was analyzed in Laboratory for Soil Mechanics at Faculty of Civil Engineering in Belgrade. Results have shown that tested material is not appropriate for construction of the embankment. Because of this, the possibility of using fly ash from thermal power plant “Kolubara” for soil stabilization were considered.

This paper presents the results of fly ash soil stabilization laboratory research performed during 2011-2012, as the part of the research project funded by Electric Power Industry of Serbia.

2 MATERIALS

Materials used for the experimental research program include: fly ash from thermal power plant “Kolubara” (KFA) and silty clays from project “Kalenic” (Soil A) and from wind park project “Kosava” (Soil B).

2.1 Fly ash

Chemical composition of KFA was determined at the Faculty for Physical Chemistry in Belgrade and the results are shown in Table 1.

Table 1. Chemical composition of fly ash [%]

SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	CaO	MgO
50.21	23.83	9.89	4.79	3.12
K ₂ O	Na ₂ O	TiO ₂	SO ₃	P ₂ O ₅
0.44	0.35	0.54	5.24	0.06

Because of the high percentage of SiO₂ and Al₂O₃, according to ASTM C 618, KFA belongs to Class F silica mineral ashes, with pozzolanic properties. Class C fly ash is not available in Serbia (Cmiljanic et al. 2010).

2.2 Soils

The soils used for this study are predominantly silty clays.

Soil A: Mineral composition consists of quartz, muscovite and soft minerals of montmorillonite (testing performed at Faculty for Physical Chemistry, Belgrade). According to USCS, this soil, known as alevrite, is medium to high plasticity clay (CI/CH), with swell potential.

Soil B: Material was collected at the site of wind park near Vrsac, Vojvodina. Terrain at the site consists of Quaternary loess sediments. According to USCS, this soil is low plasticity

clay (CL). Grain size distribution curves for used materials are given in Figure 1.

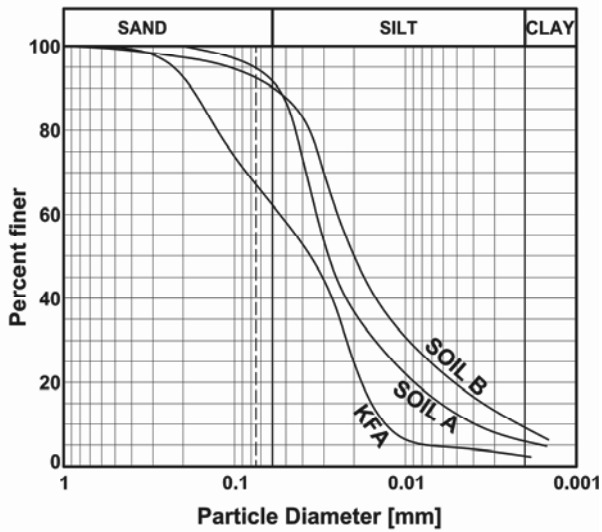


Figure 1. Grain size distribution curves

3 LABORATORY TESTING

Laboratory testing was conducted in the Laboratory for soil mechanics at Faculty of Civil Engineering in Belgrade. Testing samples were prepared by compaction, with moisture content equal to optimum moisture content from standard Proctor compaction test.

Fly ash soil mixtures were prepared at three fly ash-soil ratios (10, 15, 20% fly ash content by dry weight). After addition of water, mixtures were compacted without delay. According to (Terrel et al. 1979, Ferguson and Leveson 1999) compaction should start immediately after the mixing process and finish within a maximum of 2 hours. Samples were tested immediately after compaction ($t=0$), as well as after 7, 14, 28 and 60 days. Following engineering properties were determined: unconfined compression strength (UCS), California bearing ratio (CBR), effective shear strength parameters (c' , ϕ') and compressibility modulus (M_v). All tests were performed according to SRPS Standards.

4 RESULTS AND DISCUSSION

4.1 Soil plasticity

In case of medium to high plasticity soil (soil A), it is observed that increasing of KFA percentage results in decreases in the liquid limit and plasticity index, which is not the case for low plasticity soil (soil B), as shown in Fig. 2.

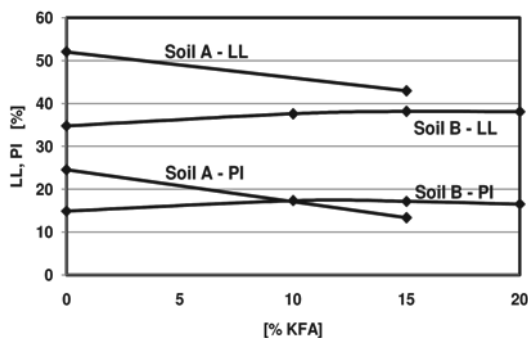


Figure 2. Variation in Atterberg limits for mixtures at $t=0$

4.2 Compaction

The results (Fig. 3) indicate that maximum dry density decreases and optimum moisture content increases as the fly ash content increases (for both soil types). The decrease in maximum dry density is associated with the fact that used fly ash has much lower weight than soil. Results are in line with Santos et al. 2011 and Sharma 2012, while opposite trend can be found for Class C fly ash stabilization (White et al. 2005 and Ramadas and Kumar 2012).

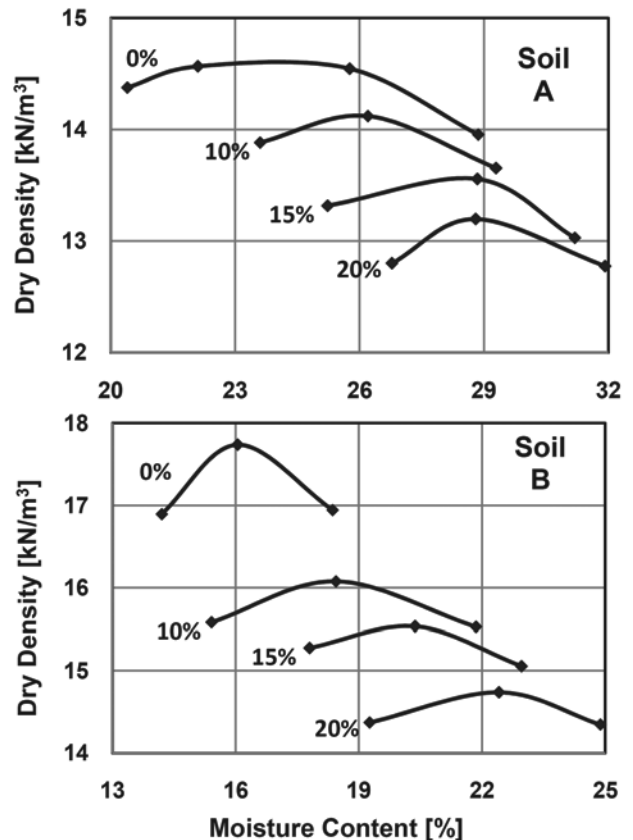


Figure 3. Moisture-density relationship of fly ash-soil mixtures

4.3 Unconfined Compressive Strength (UCS)

Increased soil strength is the main indicator of the successful soil stabilization. In previous studies (Ferguson and Leveson 1999, Ferguson 1993, Parsons 2002, Edil et al. 2006) strength of soil is usually determined by uniaxial compression test or bearing ratio test. The results of UCS tests shown in Fig. 4 indicate that maximum strength gain for soil A is obtained for mixture with 15% KFA. Soil UCS is increased by 15-25%, dependent of elapsed time.

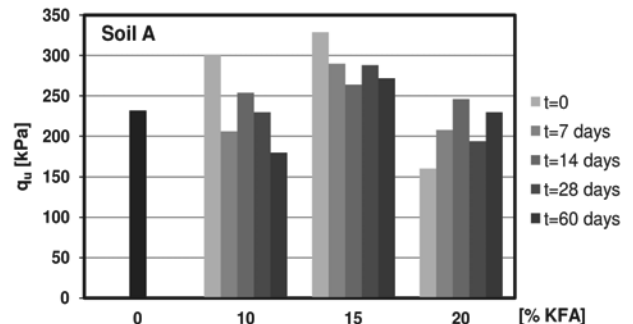


Figure 4. Strength gain of soil A for different percentages of KFA

UCS for soil B without stabilizer was around 400 kPa and addition of fly ash didn't result in strength gain.

4.4 Effective shear strength parameters

Effective shear strength parameters have been determined by using direct shear test. Obtained results (Fig. 5) show that long term friction angle doesn't substantially change with addition of fly ash, for both soil types. On the other side, cohesion significantly increases with time for all tested mixtures. This is associated with pozzolanic properties of used fly ash.

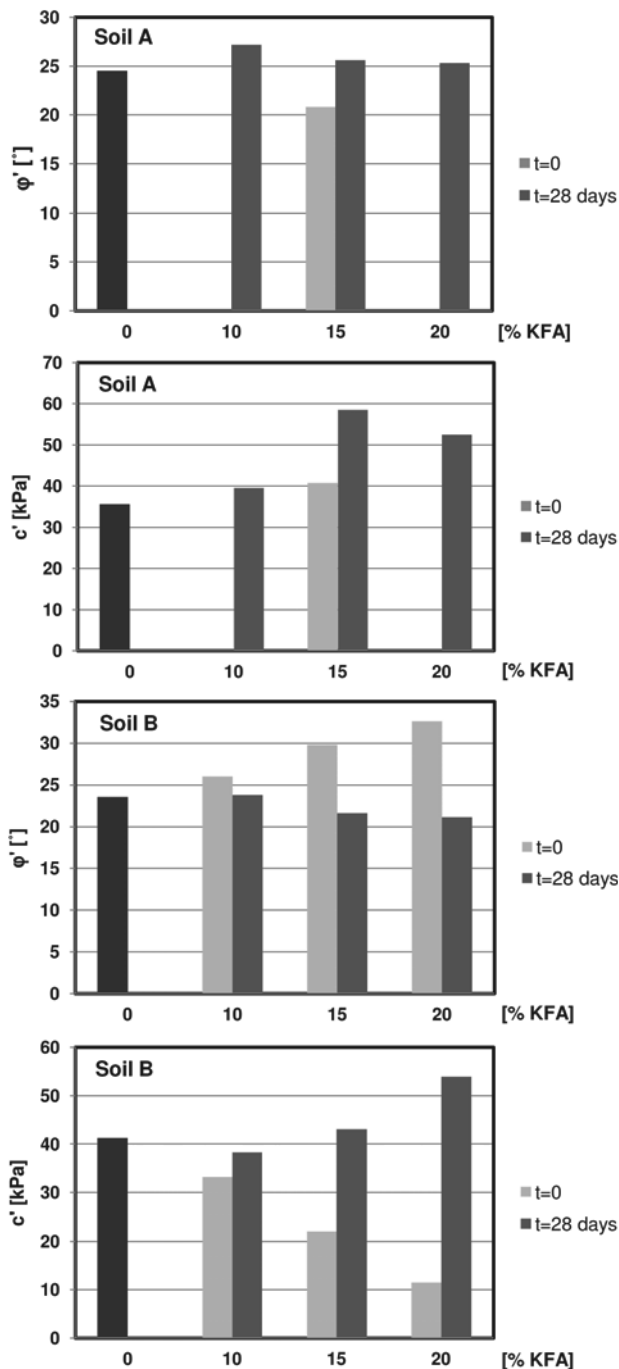


Figure 5. Variation in effective shear strength parameters

4.5 California Bearing Ratio (CBR)

For both soil types, California bearing ratio tests have been done on mixtures with 15% KFA, which is adopted as optimum. Compared with CBR values for base soils A and B, obtained results showed significant gain. In the case of soil A, CBR value

increased nearly 300%, and 260-380% in the case of soil B (dependent on elapsed time). This is especially important for soil A, because it makes it usable for road construction (CBR value was increased from 2.1 to 5.8). CBR values are shown in Fig. 6, and are in line with Mackiewicz and Ferguson 2005, White et al. 2005 and Edil et al. 2006.

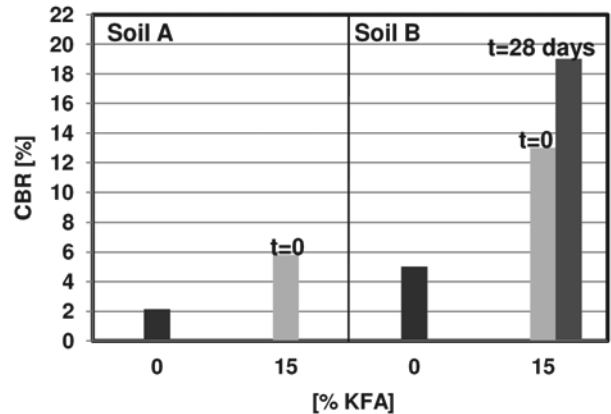


Figure 6. CBR values

4.6 Deformation parameters

Compressibility modulus (Fig. 7) for both soil types increase with addition of fly ash. Influence of time in this case was not significant. Overall modulus increase is around 15-35% for soil A and around 15% for soil B.

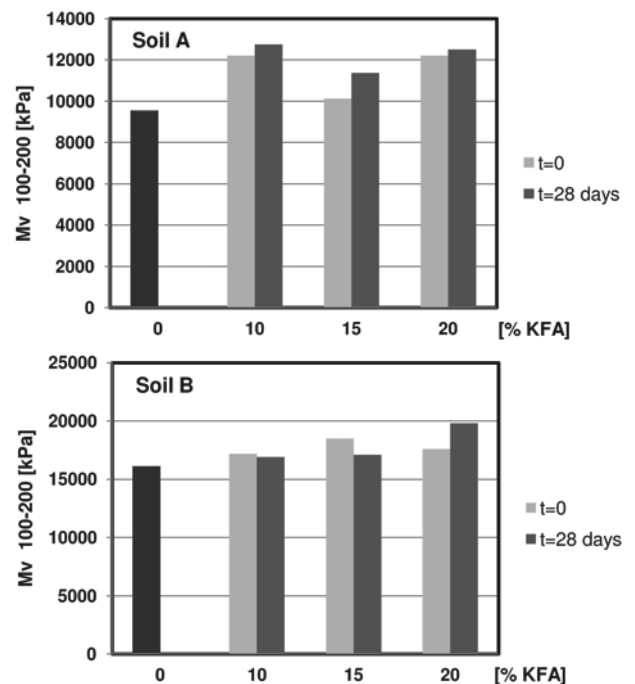


Figure 7. Compressibility modulus

4.7 Swell potential

Although strength and deformation parameters of soil A can be considered acceptable, this soil showed significant swell potential, which makes it unusable for most engineering purposes. This property is associated with the presence of expansive mineral montmorillonite. Addition of 15% of fly ash, which is determined as optimum, resulted in significant decrease of swell deformation, from $\epsilon=8.6\%$ to $\epsilon=1.8-3.1\%$. This results are in accordance with results of other authors

(Ferguson 1993, Zia and Fox 2000, Çokça 2001, Nalbantoglu and Gucbilmez 2002, Ramadas and Kumar 2012).

5 CONCLUSIONS

Although many scientific results show that Class F fly ash cannot be used for soil stabilization without addition of cement or lime, laboratory tests performed in this research have shown that fly ash from thermal power plant "Kolubara" is effective material for soil stabilization. Main conclusions of this research are as follows:

Addition of KFA decreases the plasticity index of medium and high plasticity soils (type A).

KFA impacts moisture-density relation of tested soils – optimum moisture content increases and maximum dry density decreases.

For soil A, based on UCS gain, amount of 15% KFA is identified as optimum. Strength gain was approximately 20%. There wasn't UCS gain for low plasticity soil B.

For both soil types, long term friction angle almost doesn't change with addition of KFA, while effective cohesion significantly increases with time for all tested mixtures.

CBR values increased around 260-380% for mixtures with 15% of KFA, which is adopted as optimum. This is main stabilization effect for soil B and very important effect for soil A.

Compressibility modulus for both soil types increase with addition of fly ash, without influence of time. Overall increase is around 15-35%.

Swell potential of very expansive soil A reduced with addition of 15% KFA. Swell deformation decreased from $\epsilon=8.6\%$ to $\epsilon=1.8-3.1\%$.

Despite shown positive effects, the universal principle of soil stabilization using fly ash cannot be easily defined. It is necessary to perform detailed laboratory investigations, with certain types of ash and soil. It is the only possible way to precisely determine the optimal percentage of ash to be added, to determine strength gain and define the technology operations. The presented results of laboratory tests have confirmed the need to develop a research program in this field for Serbia, bearing in mind that the average annual production of fly ash that will be disposed on landfills is around 7 million tons.

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