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SUBBASE STABILIZATION WITH FLY ASH

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Abstract. *Due to increased activities in civil engineering, and especially in the transport infrastructure, and thus an increase in the use of additional construction materials, innovative solutions are needed in finding alternative materials for the preservation of natural resources. One of the solutions for preserving natural building materials is the application of recycled material, which will also meet the required standards in civil engineering. In the transport infrastructure, there is a great opportunity for the use of recycled material, starting from the subbase, through the embankment and all the way to the superstructure and the concrete structures. One of the recycled materials that can be used in construction is fly ash.*

Fly ash is the most promising waste material when it comes to the wide range of applications in construction. Fly ash is obtained by burning coal in thermal power plants to produce electricity.

Due to variations in the composition and characteristics of fly ash, several divisions and classifications have been created. One of the main classifications is according to the American standard ASTM C 618-05 where it is divided into class C and class F fly ash.

This research aims to investigate the application of fly ash for subgrade stabilization and to determine the difference from a financial and environmental perspective for the application of fly ash compared to natural stone aggregate.

The main research was carried out in connection with the increased use of natural stone aggregate, which appeared as a need during the rehabilitation of state road R1206, section Karpalak - Želino. Apart from the use of large quantities of stone aggregate for the stabilization of the subgrade, it also had an impact on the financial framework for the realization of the road project.

In Macedonia, an analysis of the chemical composition of 4 samples of fly ash obtained in REC Bitola was carried out. From the obtained results, it can be concluded that it belongs to the classification of F-class fly ash and with the use of an activator (lime or cement) it can be used in the stabilization of the subgrade.

Key words: *civil engineering, subbase, subgrade, fly ash, stabilization.*

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1. INTRODUCTION

In order to meet the needs of the world's population, which has been in constant growth since the 20th century, the activities in construction, especially in the transport infrastructure, are increasing. Also, existing facilities require their own maintenance and innovation. All this contributes to the increased use of construction material, and especially the depletion of large amounts of natural resources. For this purpose, it is necessary to reduce the use of natural resources and to introduce the replacement of natural materials with alternative materials, that is, solutions.

One of the solutions for preserving natural material is the application of recycled material in construction. The idea of using recycled material is with the condition that the quality of the buildings is not impaired. Due to the large amount of recycled material, there is a need for its disposal and disposal, which represents a serious environmental problem.

In the transport infrastructure, there is a great opportunity for the use of recycled material, starting from the lower structure, through the embankment, and all the way to the upper structure and the concrete structures. According to data from the European Road Infrastructure Association (2018), there are over 5 million kilometers of road network in Europe. From an economic and ecological point of view, the use of recycled material in road infrastructure should be seen as a resource, not a waste material.

Fly ash is a material that is found in large coal mines, both in Europe and in Macedonia, and it can be used as an alternative solution for replacing natural resources. Fly ash is mostly used in concrete constructions, but it is also used in subgrade stabilization, as well as a filler substitute in roadway constructions. However, the application of fly ash in road infrastructure is still low, less than 2% (ASAA 2007). In the annual report of the European Aggregate Association (2017/2018) there is information that the use of fly ash and slag is less than 2.3%.

In the last decades, the tests for the application of fly ash in the road infrastructure show positive results, such as: application of fly ash in embankments, part of the mixture for cement and concrete, stabilization of the subgrade and replacement of filler in asphalt mixtures.

In industrial practice, the term "fly ash" refers to a solid non-combustible residue that is separated during the combustion of coal.

According to the place of separation, several types of fly ash are distinguished. In thermal power plants that use a classic pulverized coal combustion system, the following are distinguished:

- slag (bottom ash), the largest non-combustible residue from combustion that separates at the bottom of the boiler;
- boiler fly ash, a large class that separates from the boiler and, together with the flue gases on the way to the electrofilters, gravitationally settles under the flue gas channel and the air heater;
- electrofilter or fly ash, the smallest class that is separated from the boiler with flue gases, and the separation from the flow of flue gases is carried out by electrostatic separation in electrofilters. The term fly ash was first used in the power generation industry in 1930, and the first use of fly ash was recorded in 1937;
- in thermal power plants where the combustion is carried out in a fluidization layer, the so-called layered ash (bed ash) which is actually a mixture of the previously mentioned types;

From the point of view of disposal, the separation of slag and fly ash is important. The fly ash is actually a combination of boiler and electrofilter ash. The slag stands out due to its specific characteristics coarseness and settling speed which are important and influence the choice of transport system.

The chemical properties of fly ash depend to a large extent on the properties of the coal and the techniques used for handling and storage. Fly ash consists of fine, powdery particles that are mostly spherical in shape, solid or hollow, and mostly glassy (amorphous). The carbonaceous material in the fly ash is composed of angular particles. The specific gravity of fly ash usually ranges from 2.1 to 3.0, while its specific surface area (measured by the air permeability method) can range from 170 to 1000 m2 / kg.

The color of the fly ash can vary from dark gray to black, depending on the amount of carbon in the ash. The lighter the color, the lower the carbon content. Ash from lignite or subbituminous coal is usually lighter in color than bituminous coal and anthracite. Bituminous coal ash is lighter shades of gray which usually indicates higher fly ash quality.

2. METHODOLOGY

The aim of this research is to improve, stabilize the subbase in the transport infrastructure using fly ash.

Professional and scientific justification of this scientific work results from the rehabilitation of the regional road R1206, section Karpalak - Želino, in the length of 12 km. The beginning of the route is at 800 m. after the exit for the village of Bojane, and ends at the exit from the village of Zelino in front of the restaurant "Dva Fazana". The object in question is an object of the 1st category.

During the construction activities on this section, due to the poor maintenance and drainage of the road section during the period of operation, there was a need to improve the existing subbase (subgrade) which did not meet the criteria for this type of building.

In the basic project for the construction of the lower structure, the following positions were foreseen:

- Mechanical excavation of an existing crushed stone in a wide trench with transport to a landfill,
- Planning and compaction the subgrade.

When starting with the construction of the subgrade of the section in question, that is, after the excavation of the existing crushed stone layer, the planning and compaction of the existing subgrade was approached. Before starting with the installation of the crushed stone layer, laboratory tests were first performed on the existing subgrade. The laboratory tests were performed by an accredited laboratory according to the technical conditions for this type of facility and the valid standards in the Republic of North Macedonia.

The following characteristics of the existing subgrade were tested by the authorized laboratory:

- Granulopetric composition of the soil (subgrade),
- Natural humidity,
- Atterberg limits,
- Proctor compactness (standard),
- California CBR Load Index,
- Content of calcium carbonate SaCO3 in soil,
- Organic and combustible substances.

Table 1 Standards according to which the existing subgrade was carried out

Experience	**Standard**
Determination of granulometric composition	MKS EN ISO 17892-4:2017
Determination of Atterberg limits (Casagrande's method)	MKS 1013:2016
Proctor Density	MKS EN 13286-2:2012
Determination of the California CBR Load Index	MKS EN 13286-47:2013

3. RESULTS

For the purposes of the project, 3 samples were taken, where they were examined in an authorized laboratory.

During the determination of Atterberg's limits (Casagrande's method), results were obtained for:

- Yield strength W_I (%),
- Limit of plasticity W_P (%),
- Plasticity index I_P (%),
- Consistency index I_C (%).

The data from the obtained results are shown in table 2 form in the following order:

Table 2 Overview of the results of geotechnical measurements of the existing subgrade, karpalak-želino section

Layer:	**Subgrade**			
Depth: 0,20-0,60 m	Trial 1 km 6+500	Trial 2 km 7+163	Trial 3 km 7+513	Criterion
Granulometric curve	Granulometric curve	Granulometric curve	Granulometric curve	/
Natural humidity	$W_{пр}$ = 12,00 %	$W_{пр}$ = 10,00 %	$W_{пр}$ = 12,00 %	/
Atterberg limits	W_P = 42,30 % I_P = 18,86 %	/	W_P = 42,30 % I_P = 18,86 %	W_P< 30,00 % I_P< 17,00 %
Proctor Compactness (standard)	P_{dmax}= 1,650 Mg/m³ W_{opt} = 21,40 %	P_{dmax}=2.,60 Mg/m³ W_{opt} = 7,60 %	P_{dmax}= 1,860 Mg/m³ W_{opt} = 13,00 %	P_{dmax}>1.750Mg/m³ W_{opt} < 20,00 %
California CBR Load Index	$CBR_{2.50}$ = 5,00 % $CBR_{5.00}$ = 5,05 %	$CBR_{2.50}$ = 63,64 % $CBR_{5.00}$ = 83,00 %	$CBR_{2.50}$ = 3,94 % $CBR_{5.00}$ = 4,00 %	min 8 %
Calcium carbonate content $CaCO_3$	/	/	7,77%	/
Organic and combustible substances	Combustible– 4,62 % Organic – 0,33 %	Combustible– 1,73 % Organic – 0,44 %	Combustible– 5,17 % Organic – 0,70 %	max 8 %

*******Note*: for sample 2, the Atterberg limits cannot be determined due to the large presence of sand, while for sample 1 and sample 2, the presence of carbonates in the soil cannot be determined due to the large reactive action that forces the liquid from the graduated tube completely.

From the obtained results in table 1, it can be noted that Tests 1 and 3 do not meet the necessary criteria according to technical conditions. Atterberg's limits for Plasticity Limit WR = 42.30%, Plasticity Index IP = 18.86% exceed the permissible limit which is for WR = 30% and IP = 17%.

The Proctor compactness for Trial 1 of the results obtained does not meet the criteria, but Trial 3 is within the range of permissible limits.

The California load index CBR value for Trial 1 and 3 does not meet the proposed technical characteristics because they are 5% and 4% which is below the limit of min 8%.

The values for organic and combustible substances in all three samples are within the permissible limit.

Only trial 2 meets the prescribed criteria. All parameters from Trial 2 satisfy the prescribed technical conditions.

Based on the laboratory report, it can be noted that the majority of the existing subgrade does not meet the required criteria for this facility.

In order to continue with the construction of the upper structure, a solution had to be found for the existing subgrade, which was in a bad condition caused by several factors, such as: inadequate maintenance of the road body during its operation, poor drainage of the existing subgrade, drainage of some sections were not resolved at all, existing channels and culverts were not maintained, etc.

Representatives from the Investor, Supervisory Authority and Contractor were involved in finding a solution for the existing subgrade. After several meetings and offered alternative solutions, it was finally decided to replace the existing mattress material with a new material and thereby achieve satisfactory results. The new material that had to be incorporated was a natural resource, that is, a material made of crushed stone.

The implementation of the new solution entailed more manufacturing positions, thereby significantly increasing the value of the project.

Fig. 1 Excavation of the existing subbase at km 11+000, karpalak - želino section

3.1 Analysis of fly ash from REK Bitola

4 samples of fly ash from the REK Bitola thermal power plant were analyzed, and the obtained results of the chemical composition of the fly ash are presented in the following table:

Table 3 Results of chemical composition of fly ash from REK Bitola, Macedonia

Trial:	1	2	3	4
SiO_2	46,83	48,61	44,85	40,49
TiO_2	0,62	0,52	0,59	0,58
Al_2O_3	25,90	24,21	23,20	24,90
CaO	6,86	8,30	11,48	13,20
Fe_2O_3	9,96	8,94	9,58	10,55
MgO	2,99	2,64	3,53	3,99
MnO	0,19	0,27	0,33	0,38
Na_2O	1,50	1,20	1,17	1,21
K_2O	2,56	2,06	1,87	1,92
P_2O_5	0.34	0,41	0,41	0,39
SiO_2+ Al_2O_3+ Fe_2O_3	82,69	81,76	77,63	75,94
Mo=CaO+MgO/SiO_2+Al_2O_3	0,13	0,15	0,22	0,23
Ms=SiO_2/Al_2O_3	1,81	2,01	1,93	1,63
K=CaO+MgO+Al_2O_3/SiO_2+MnO	0,76	0,72	0,84	1,02

According to the classification of the American standard ASTM C 618-05 and the McCarthy division, the tested samples belong to class F, because the value of SiO_2+ Al_2O_3+ Fe_2O_3 ranges from 75.94 to 82.69, CaO from 6.86 to 13.20.

On an annual level, REK Bitola produces 1.5 million. tons of fly ash. Part of the ash is purchased by the cement plant USJE - Skopje, which uses it in the production of cement, but most of it ends up in a landfill in REC Bitola. Additional financial resources are used for the disposal of fly ash.

The price of fly ash in REC Bitola is 125 den/ton for loading directly in a tank truck and 25 den/ton for loading in a tipper truck.

4. Discussion

In order to achieve successful stabilization of the subgrade with fly ash, attention must be paid to:

- Uniform distribution of fly ash,
- Proper pulverization and thorough mixing of the fly ash with the material to be stabilized,
- Moisture content control for maximum density and strength,
- Final compaction within the prescribed time frame (usually 2 hours).

Typical design specifications call for fly ash content to be 1 to 2 percent greater than the optimum content determined in the laboratory. Tankers should be used to transport fly ash to the construction site. Careful discharge of fly ash over the exposed subgrade by conveyors is the best way to obtain uniformity of application. The amount of ash can be calculated knowing the depth, width, length and projected percentage of fly ash. Uniform distribution can be achieved by means of transport metering ports or direct metering of the ash in the mixing drum of the mobile mixer.

Construction discs (cultivators) can effectively combine the ash with the soil. The depth that the disc cuts must be carefully monitored. Where higher degrees of stabilization are required, the use of a mobile mixer is required to ensure adequate pulverization and uniform distribution of fly ash and moisture. One or two passes of the mixer may be used to obtain good mixing.

Fugitive dust can be a problem, just like any other construction process. The maximum dust is generated at the moment when the ash is discharged from the cisterns onto the pad. Construction activity will generally minimize dust.

When a rotary mixer is used, water is added to the mixer, which minimizes dust. This is the most effective procedure for building good stabilized soil:

Weather conditions:

- Favorable
  – Wet or dry,
  – Little or no wind,
  – Temperature above 4,5 ˚C.
- Bad
  – Windy,
  – Temperature below 0 ˚C.

Transportation

Fly ash is transported to the construction site via:

- Tarpaulin trucks or
- Tanks with pressure pumping systems.

Method(s) of mixing

a. The trucks already eject fly ash in a uniform line (if there is no wind);

b. The planning of the fly ash over the pad is done

c. It is mixed with a recycler moving at a speed of 6 – 10 m/min or with a disc to increase the depth.

d. Add water if needed.

e. Final planning is done with construction machinery

Compaction procedures

a. Initial compaction – is done with a hedgehog roller

b. Final compaction – steel roller with wheels to ensure a smooth surface

c. Compaction control

d. Compaction must be done within two 2 hours because working the mixture after that can break up the hydration products that stabilize the soil.

Hardening of the soil-fly ash mixture: When self-cementing fly ash is mixed with water, the hydration of the material creates a gel that binds (stabilizes) the soil resulting in a stronger, more uniform material with less permeability. Hydration requires water. Therefore, the planned surface should be kept moist.

Construction dynamics: about 1 to 1.2 km of stabilized pad can be built in one day.

PRECAUTIONS:

1. Wind: be aware of winds if fly ash is placed on the pad.
2. Mixing: to mix fly ash as soon as possible
3. Mixing: to mix fly ash as soon as possible

Durability: With proper mix design and performance, the subgrade is expected to last at least 50 years.

Fig. 2 Mixing of soil and fly ash with recultivator

4. Conclusion

Although different classifications of fly ash are applied in different countries, almost all types of fly ash can be used in construction and worldwide efforts and activities are being made to exploit the use of fly ash. In the last two decades, there has been an increase in scientific research activities in the field of application of alternative materials in construction, including the application of fly ash with the intention of protecting the environment from the negative impacts of waste material, as well as saving natural resources, i.e. to the use of stone aggregate decreased.

From the research we can conclude that:

- Fly ash is a suitable and safe construction material that can be used in road infrastructure,
- The use of fly ash instead of crushed stone contributes to the preservation of natural resources in R. of North Macedonia,
- The use of fly ash reduces the amount of waste, as well as the area for its disposal,
- From an economic point of view, fly ash as a waste material not only requires large areas for depositing and construction of landfills, but also requires additional investments in protection, preservation and maintenance of landfills, i.e. waste management,
- Reduction of construction activities, by causing a reduction in the need to use construction machinery, etc.

Considering the results obtained from REC Bitola, the studied fly ash fulfills the characteristics for classification in class F. The research in this scientific work on the application of fly ash during stabilization in the subbase gave an insight that there is a big difference from a financial aspect when using this material. However, there is still an opportunity for expansion in the research of the characteristics of fly ash from other thermal power plants located in Macedonia.

Fig. 3 Storage and maintenance of fly ash in a power plant

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STABILIZACIJA PUTNE PODLOGE UPOTREBOM ELEKTROFILTERSKOG PEPELA

Zbog pojačanih aktivnosti u građevinarstvu, a posebno u saobraćajnoj infrastrukturi, a samim tim i povećanja upotrebe dodatnih građevinskih materijala, potrebna su inovativna rešenja u pronalaženju alternativnih materijala za očuvanje prirodnih resursa. Jedno od rešenja za očuvanje prirodnih građevinskih materijala je primena recikliranog materijala, koji će zadovoljiti i zahtevane standarde u građevinarstvu. U saobraćajnoj infrastrukturi postoji velika mogućnost za korišćenje recikliranog materijala, počev od podloge, preko nasipa pa sve do gornjeg stroja betonskih konstrukcija. Jedan od recikliranih materijala koji se može koristiti u građevinarstvu je elektrofilterski pepeo. Elektrofilterski pepeo je otpadni materijal koji najviše obećava kada je u pitanju širok spektar primena u građevinarstvu. Elektrofilterski pepeo se dobija sagorevanjem uglja u termoelektranama za proizvodnju električne energije. Zbog varijacija u sastavu i karakteristikama elektrofilterskog pepela, stvoreno je nekoliko podela i klasifikacija. Jedna od glavnih klasifikacija je prema američkom standardu ASTM C 618-05 gde se deli na klasu C i klasu F elektrofilterskog pepela. Ovo istraživanje ima za cilj da istraži primenu elektrofilterskog pepela za stabilizaciju podloge i da utvrdi razliku iz finansijske i ekološke perspektive za primenu elektrofilterskog pepela u poređenju sa prirodnim kamenim agregatom. Glavna istraživanja su sprovedena u vezi sa povećanom upotrebom prirodnog kamenog agregata, koji se pojavio kao potreba prilikom sanacije državnog puta R1206, deonica Karpalak – Želino. Osim upotrebe velikih količina kamenog agregata za stabilizaciju podloge, to je uticalo i na finansijski okvir za realizaciju projekta puta. U Makedoniji je urađena analiza hemijskog sastava 4 uzorka elektrofilterskog pepela dobijenog u REC Bitola. Iz dobijenih rezultata može se zaključiti da pripada klasifikaciji elektrofilterskog pepela F klase i da se uz upotrebu aktivatora (kreča ili cementa) može koristiti u stabilizaciji podloge.

Ključne reči: *građevinarstvo, posteljica, podloga, elektrofilterski pepeo, stabilizacija*