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USAGE OF WOOD ASH IN STABILIZATION OF UNBOUND PAVEMENT LAYERS

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Abstract

Unbound base layers are an important part of the pavement, which consume a considerable amount of granular stone material. Favorable grain size distribution of materials, necessary for the construction of unbound base layers, is achieved by selecting a suitable material from nature or favorable material composition is achieved through mechanical stabilization. The basic principle of mechanical material stabilization is the addition of finer or larger granular material to the material of unfavorable, uniform granulometric composition, which is inherently unstable. In designing economical pavement structures, the availability of local materials of natural or industrial origin is of great importance.
From natural local materials for the road construction in the area of Slavonia and Baranja, the Drava sand, a material of uniform granulometric composition of medium grain size D_{50} = 0.3 mm, is interesting and often in use. With the increasing number of biomass power plants in eastern Croatia, waste local material, wood ash, is also being created. Wood biomass ash, which is generated as a residue of biomass burning for electricity and heat production, is one of the newer and less explored alternative materials, which finds its application in construction as evidenced by the results of previous foreign studies. One possibility of using wood bio ashes in mixtures for unbound base layers is to modify / repair the granulometric composition of the base material. By combining the aforementioned local materials, that is, by designing a mixture of Drava sand and wood ash in appropriate proportions, it would be possible to obtain a mechanically stable mixture of increased load-bearing capacity for construction of unbound base layers.
In this paper testing of mixtures composed from different proportions of Drava sand and wood ash for unbound base layers is described with the purpose of proving the stabilizing effect of wood ash.

Keywords: unbound base layer; stabilizing effect; wood ash; Drava sand

1 Introduction

Unbound base layers are an important part of the pavement, which consume a considerable amount of granular stone material. They have a role to take static and dynamic traffic loads and transfer them to the lower structure of the road, without exceeding the bearing capacity and without causing harmful deformations of subgrade. These layers with their mechanical properties must respond to the stresses from traffic load and meet all the durability requirements during the design period of the pavement structure, while also possibly serving as a temporary pavement on the construction site before the completion of the upper layers of the structure.

In this regard, the granulometric composition of the granular material, which must meet certain requirements and its compaction, is particularly important. In conditions in which granular materials are compacted (optimal moisture content), a certain compaction is achieved, and depending on the thickness of the layer and the quality of the subgrade, a certain bearing capacity of the unbound base course. A favourable granulometric composition is achieved by choosing the right material in nature or by designing a granular material composition for optimal mechanical stability. The basic principle of mechanical stabilization of granular material is adding smaller or larger granular material to the one with an unfavourable, uniform granulometric composition.

When designing the pavement structure and selecting materials for construction, in addition to their mechanical properties, economy, sustainability and environmental impact should be taken into account. Availability of local materials of natural or industrial origin plays a big role in the sustainable and economical design of pavement constructions [1].

The area of Eastern Croatia lacks gravel and stone materials needed for road construction [2]. Because of that, and the need for more rational pavement constructions, large amounts of local materials like river and dug sand are used in road constructions. Sand from local rivers of Drava, Sava and Dunav, and sand dug from the surroundings of Valpovo, Đakovo and Slatina is used for the completion of unbound and bound base layers of pavement constructions. Encouragement of more rational road constructions in this area began in the 1980s, and many pavement constructions which contain sand proved that it is of quality and a favorable local material fit for use in their construction [3].

Of all the mentioned sands in the area of eastern Croatia, the Drava sand is especially often used in the construction of bearing layers of different traffic areas. Experiences from previous applications of Drava sand as a mechanically compacted and cement-stabilized material are good, and this is also the reason why Drava sand was chosen as the basic granular material in this research.

With the increase in the number of biomass power plants in eastern Croatia, the local waste material, wood ash, is being accumulated. Ash from wood biomass, which is formed as a residue from the combustion of biomass for the production of electricity and heat, is one of the newer and less researched alternative materials, and it can find application in construction as confirmed by previous research [4], [5]. One of the possible uses of wood bioash is in modification of granulometric composition of basic granular material, which results in a mechanically stabilized mixture used for the production of base layers [6], [7], [8]. In continuation of this paper, the examination of mixtures composed of Drava sand and wood bioash in different percentages will be described. The goal is to determine the stabilizing effect of wood ash.

2 Experimental part

2.1 Materials

2.1.1 Drava sand

Drava sand is a material of grayish-brown colour, a uniform granulometric composition with the medium grain size D_{50} = 0.3 mm. The degree of Drava sand unevenness totals is . Usually, the degree of unevenness represents a measure of good workability of a material, which is considered good for construction if U›5 [9].

The determination of Drava sand's granulometric composition was conducted on 500 g samples according to the norm HRN EN ISO 17892-4 [10], on a mechanical vibratory table with a set of sieves with openings ranging from 31,5 to 0,063 mm. The granulometric composition of Drava sand (mix 1) is visible on figure 1.

2.1.2 Wood ash

Wood ash is a complex mixture of organic and inorganic structure. It contains a large number of compounds whose composition can significantly vary. The amounts, quality and physical and chemical properties of wood ash depend on the type of burned biomass part, mineral impurity content, location of biomass growth, way of its collection and processing and the technology and temperature of burning. Wood ash in mixtures can be used in two ways: (1) as a binding component, when with its addition certain chemical reactions are initiated as a result of pozzolanic activity (indirect way of ash application) (2) as a filler, when it is necessary to improve the physical properties of mixtures by increasing the percentage of finer particles (direct way of ash application). The chemical composition of wood ash is important for initiating chemical reactions in a mixture, while its granulometric composition is important for the improvement of physical properties in mixtures. The elementary composition of wood ash depends on the type of biomass and part that is being burned, ground type, climate and anorganic composition. The mineral structure depends on the method of combustion [4].

During the combustion of wood biomass, three different fractions of ash are formed: bottom ash, cyclonic fly ash and electrostatic fly ash. For the purposes of this test, wood bottom ash was collected, which is collected under the boiler of grate furnace in the bioenergy plant "Strizivojna Hrast d.o.o." Strizivojna. „Strizivojna Hrast d.o.o." is a company located in Eastern Croatia which processes wood and produces hardwood floors and other wood products. The aforementioned company is the first one in Croatia that operated a cogeneration plant in 2011 for the production of electrical and thermal energy based on wood biomass combustion [4]. Particle size analysis of wood ash was conducted according to the norm EN 933-10 [11] used for particle size determination of filler aggregate by air jet sieving.

Chemical composition of the wood ash is shown by mass portion of individual components (mass. %): MgO=2.645, Al_2O_3=0.828, SiO_2=3.486, P_2O_5=2.346, SO_3=1.408, K_2O=7.134, CaO=43.7, Fe_2O_3=0,685. The analysis of x-ray diffraction showed that the main components of ash are calcite, quartz, CaO and, in a smaller amount, portlandite ($Ca(OH)_2$) [12].

2.2 Mixture composition and process of making

For the needs of this research, mixtures of Drava sand and wood ash of different composition were assembled. Their granulometric graphs are shown on figure 1.

- Mixture 1 (control): 100 % sand
- Mixture 2: 90 % sand and 10 % wood ash
- Mixture 3: 80 % sand and 20 % wood ash
- Mixture 4: 70 % sand and 30 % wood ash
- Mixture 5: 50 % sand and 50 % wood ash
- Mixture 6: 25 % sand and 75 % wood ash

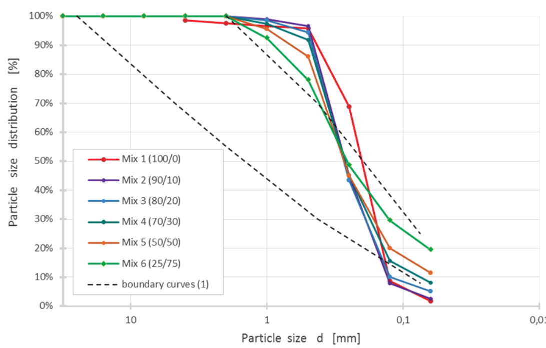

Figure 1 Particle size distribution for all mixes

From the granulometric curves it can be seen that the appearance of the curve changes significantly with the addition of a higher proportion of wood ash (especially mixture 6), the curve becomes “flatter” and approaches the limit curves [1] defined for mechanically stabilized mixtures for unbound base courses.
According to the research plan for each mixture an optimal water content and maximum dry density were determined by modified Proctor test for every mixture in order to prepare the samples for California bearing ratio (CBR) test.
The modified Proctor experiment was conducted according to the norm HRN EN 13286–2 [13]. For the purpose of the research, a Proctor’s cylindrical mold A with a 100 mm diameter and 120 mm height was used. Five layers of samples were compacted with the appropriate energy (2,7 MJ/m^3) in automatic Proctor device.
Table 1. shows the result values of Proctor’s elements (optimal water content w and maximum dry density g_d). These were used to create samples for the research of California bearing ratio CBR.

Table 1 Proctor’s elements for sample preparation

Mix No.	g_d [g/cm³]	w [%]	Mix No.	g_d [g/cm³]	w [%]
1	1.648	14.20	4	1.706	13.81
2	1.661	14.20	5	1.675	13.56
3	1.690	14.18	6	1.674	14.16

2.3 Determination of California bearing ratio (CBR)

California bearing ratio (CBR) is a measure of bearing capacity of a certain mixture or material. It is determined immediately after compaction or after a certain period of curing. The determination of CBR on sand - wood ash mixtures was conducted according to the norm 13286-47 [14] and three samples were used for every mixture. The samples were prepared in Proctor’s cylindrical mold B with a 150 mm diameter and 120 mm height. The samples were submerged under water with a surcharge of 4,5 kg during a period of 4 days, during which swelling was periodically recorded in order to determine increase in linear swelling. The CBR index was then determined on the samples using a Mathest CBR device (figure 2).

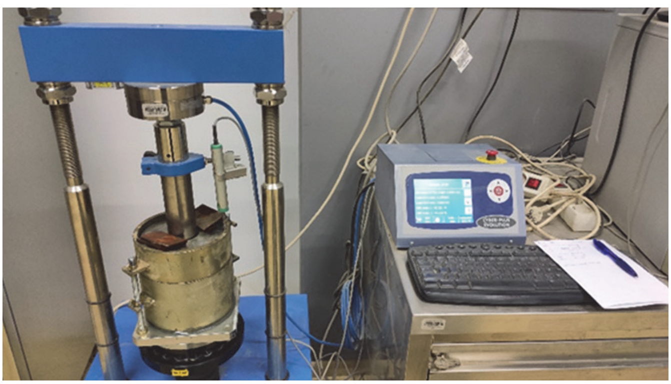

Figure 2 Examination of California bearing ratio CBR [15]

During the test, the force of piston penetration on a certain depth of the sample in the mold was measured, while it's penetration speed was 1,27 mm/min. During the test, the ratio of force and penetration was recorded, and based on the obtained diagram, the penetration force of 2.5 mm and 5 mm was read. The measured forces were then put into relation with reference forces measured at the same penetration into standardized material – crushed stone, which amount to 13,2 kN and 20 kN. The CBR index was expressed as the greater of two calculated values of the percentage of measured force in relation to the corresponding reference force. Table 2 shows the results of the bearing capacity test expressed as CBR index and linear swelling.

Table 2 Results of CBR index examination and linear swelling

Test		Mix No.				
		1	2	3	4	5
CBR 1	%	27.44	50.00	43.76	52.35	26.03
CBR 2	%	18.96	0.00	41.16	50.83	29.88
Linear swelling	%	0.02	0.53	2.14	2.33	5.11

2.4 Results commentary

Research results show that the maximum dry density increases with the increase of wood ash ratio in a mixture up to 30 %, while the optimum water content decreases. The highest value of maximum dry density of all examined mixtures (which had a value of 1,706 g/cm^3) was achieved in mixture 4, which contained 30 % wood ash. The lowest value of maximum dry density was achieved in 100 % sand (mixture 1) g_d = 1.648 g/cm^3.
The results of determining Californian bearing ratio (CBR) shown in table 2 and diagram on figure 3 show that the wood ash ratio has a direct effect on the increase of mixture bearing capacity. The control mixture of Drava sand (mixture 1) has a CBR index which is 27.44 %. Just by adding 10 % of wood ash into the sand, the bearing ration increased to 50.00 % (mixture 2). Mixture 3 (80 % sand / 20 % wood ash) had a slightly lower index of 43.76 %. The CBR was measured on mixture 4, which had 30 % wood ash and resulted in a value of 52.35 %. However, mixture 5 had a significant drop in CBR index, with a result of 29.88 %. Due to the fact that the value of CBR index in mixture 5 (50 % wood ash) was lower than those in the other mixtures and given the drop in compactness recorded by lowering of maximum dry density, the testing of mixture 6 with 75 % wood ash was not consider.

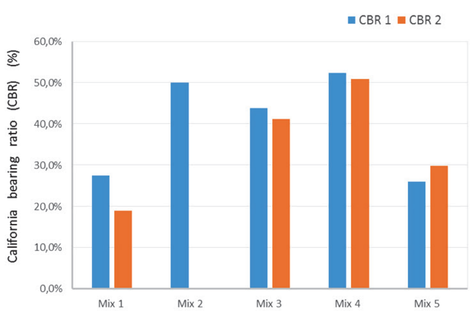

Figure 3 California bearing ratio (CBR) of all mixtures

Results of linear swelling shown in table 2 were as expected. The linear swelling increased with the increase of wood ash percentage in a mixture. For the control mixture (mixture 1), the swelling was negligible and equals 0.02 %. Swelling in mixture 2 was 0.53 %, in mixture 3 it significantly increases and was 2.14 %, while for mixture 4 it was 2.33 %. Mixture 5 with 50 % wood ash had the largest swelling which averaged at 5.11 %, making it unsuitable for base course construction.

3 Conclusion

The research on mixtures composed of Drava sand and wood ash in different ratios, shown in this paper, have proven the stabilizing properties of used wood ash. In this work, the described research of Drava sand and wood ash from biomass in different ratios has confirmed the existence of a stabilization effect in wood ash. The Californian bearing ratio (CBR) significantly increases with the increase of wood ash proportion (10 %, 20 %, 30 %) in mixtures. The highest bearing capacity was achieved in mixtures with 30 % of wood ash (Mixture 4) and amounted to CBR of 52.35 %, which is almost twice the CBR that was measured on sand (27.44 %). Also, the linear swelling of mixture 4 shows that it is suitable for base layer use in pavement constructions. These first encouraging results indicate to the possibility of applying a mixture of wood ash and sand (both local materials) in the base courses of the pavement structure of both public and commercial roads (agricultural and forest roads).

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