



## ELASTIC MODULI OF STABILIZED MIXTURES WITH WOOD ASH

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### Abstract

Stabilized base courses are an indispensable part of today's pavement structures. Stabilized mixtures as we know them consist of high-quality crushed aggregate bound with a hydraulic binder, usually cement. Due to their composition, stabilizing mixtures increase the strength and stiffness of the pavement structure, which is expressed by modulus of elasticity, i.e., the measure of the stiffness of the pavement structure due to dynamic loading. Although classic stabilized mixtures meet the criteria of load capacity, stiffness and durability, the modern approach in road construction is changing. Namely, in order to meet requirements of sustainable development, it is necessary to use alternative, waste materials. Wood ash, a by-product of the combustion of wood biomass in the production of electricity and thermal energy, has been shown through various studies to be a potentially valuable and non-standard material that can be used in road construction. Wood ash can improve the properties of stabilizing mixtures (as strengths or modulus of elasticity) and can contribute to reducing the amount of cement required in the stabilized mixture. This paper describes the determination of the elasticity modulus on stabilized mixtures containing sand, cement and wood ash by a non-destructive ultrasonic method. The mixture of sand and ash was stabilized with different amounts of cement. The aim of the work was to determine the dependence of the modulus of elasticity value on the stabilized mixture composition. These test results show the improvement of stabilized mixtures properties as well as the importance of ultrasonic method in assessing properties and quality of stabilized mixtures.

*Keywords: elastic moduli, stabilized mixtures, wood ash, pavement, ultrasound velocity*

### 1 Introduction

Various analyses of traffic flows show a trend of continuous growth in traffic from year to year. The growth of traffic volume determines the sizing and construction of a high-quality road pavement structure. The pavement structure must ensure equally safe and efficient traffic flow for current traffic demand as well as for future demand. In cases where very heavy or heavy traffic loads are expected on the roads, stabilized bearing layers are obligatory as part of the pavement structure. Stabilized bearing layers, due to their various advantages such as favorable stress distribution to the lower layers of the pavement structure and consequently increasing the compressive and tensile strength as well as the overall rigidity of the pavement structure, contribute to extending the road's lifespan.

Stabilized layers are made from a homogeneous mixture of an optimal amount of water and granular stone aggregate bound by hydraulic binder. The hydraulic binder most used in stabilization mixes is cement.

The properties of stabilization mixes are preliminarily examined, prescribed, and monitored during and after construction [1]. The mechanical properties of stabilization mixes are expressed by compressive and tensile strength, while the elastic properties of the mixes are expressed by the modulus of elasticity  $E$  and the Poisson's ratio  $\nu$ .

The modulus of elasticity is a measure of material stiffness, determined as the ratio of stress to strain resulting from loading. The value of the modulus of elasticity can be determined by various methods, with non-destructive methods being preferred. The value of the modulus of elasticity of stabilization mixes is influenced by the binder content, quality and gradation of the granular material, as well as the compactness and length of sample curing [2]. Additionally, as reported in the Final Report of COST 333 Action [3], some researchers have considered the condition of stabilized layers caused by cracks (uncracked or post-cracked condition) and found a significant difference between  $E$ -modulus values.

Numerous studies on the properties of stabilization mixes of various compositions and materials have been conducted. For instance, authors [4] investigated the influence of different cement contents in a stabilization mix composed of gravel and slag on the value of the modulus of elasticity determined by measuring the ultrasonic pulse velocity. The conducted study showed that increasing the cement content (2%, 4%, 6%) results in an increase in the value of the modulus of elasticity of the stabilization mix. In the same study, it was found that Poisson's ratio barely influenced the modulus of elasticity determined by ultrasound pulse velocity. In the paper [5], the authors analyzed the elastic properties of stabilized mixes composed of sand, cement, and fly ash (generated from coal combustion in power plants). Non-destructive methods were used to determine the modulus of elasticity: the resonant frequency method and the ultrasonic pulse velocity method, investigating the influence of the cement and fly ash content in the mix, as well as the time and temperature of sample curing. The results showed that the values of moduli of elasticity determined by the resonant method were ~9% higher than those determined by ultrasound velocity. In their study, authors [6] examined the possibility of replacing Portland cement by adding 0%, 25%, 50%, and 75% fly ash (municipal solid waste incineration (MSWI) fly ash generated in waste incinerators) into a mix of gravel material. The obtained results showed a positive influence of fly ash on the properties of the stabilized mixture, however, with the limitation of fly ash content in the mix up to 25%.

Generally, the standard composition of stabilized mixes meets the prescribed technical requirements. However, due to the global need for environmental protection through the reduction of waste materials in landfills and the preservation of natural aggregate reserves, in line with sustainable development guidelines, the use of non-standard, waste materials in pavement structures is encouraged. Research and application of certain waste materials have already been mentioned, and due to its properties and the fact that it can indirectly and directly affect mixes, wood ash has emerged. This ash is generated as a by-product of burning wood biomass for the production of electric and thermal energy and consists of existing (part of the organic structure or mineral particles introduced into the biomass during collection and processing) and newly formed inorganic substances that arise during the combustion process, often with a smaller proportion of unburned organic matter, moisture, and gases. Wood ash can be used in its original form without any additional processing in the bearing layers of pavement structures, and numerous studies have confirmed its good properties, which have a positive effect on the bearing capacity of unbound and stabilized layers of pavement structures [7-14].

The aim of this study is to determine the impact of changes in the composition of cement-stabilized mixtures of sand and wood ash on the values of the modulus of elasticity. Non-destructive ultrasonic pulse velocity measurement method was applied to determine the modulus of elasticity.

## 2 Experimental part

In the stabilized mixes, a single-grain sand from the Drava River was used as the base material, with the addition of 30% cyclone wood ash. The mixture of sand and cyclone wood ash was stabilized with cement in proportions of 0%, 2%, and 4%, with the addition of the optimal amount of water required for compacting the mixture and cement hydration.

### 2.1 Materials, mixtures and samples preparation

The sand from the Drava River is a uniformly graded local material with a medium grain size of  $D_{50} = 0.3$  mm and a degree of uniformity  $U = d_{60}/d_{10} = 1.68$ . The uniform granulometric composition and the presence of voids hinder the compaction of the mixture, making it necessary to improve its granulometric composition.

Improvement of the granulometric composition of Drava sand in stabilized mixtures has been achieved by adding cyclone (fly) wood ash (WA) from the Strizivojna Hrast d.o.o. factory in Strizivojna. Cyclone ash is a coarser fraction of flying ash particles, ranging in size from 5 – 100  $\mu\text{m}$ , collected in a cyclone dust collector. Although the granulometric composition of wood ash is a crucial property when used as a filler in stabilization mixtures, its chemical composition also has a significant impact on improving the mixture's properties. The chemical composition of the wood ash is represented by the percentage of individual components (mass%) in Table 1. As evident from the composition, the main component is calcium oxide, suggesting that wood ash could possess hydraulic properties.

**Table 1** The chemical composition of the wood ash

Components	CaO	SiO <sub>2</sub>	MgO	P <sub>2</sub> O <sub>5</sub>	K <sub>2</sub> O	SO <sub>3</sub>	Al <sub>2</sub> O <sub>3</sub>
Mass fraction [%]	46.91	4.05	3.06	2.90	2.82	1.59	0.44

Considering the hydraulic properties of ash, the cement content in the mixtures is significantly reduced compared to the usual content of 8 to 12% cement in stabilizing pure sand. The cement used in the research is CEM II/B-M (P-S) 32.5 R, a blended Portland cement produced at the Našice cement factory in Našice. The composition of stabilized mixtures is shown in Table 2.

**Table 2** Composition of stabilization mixtures

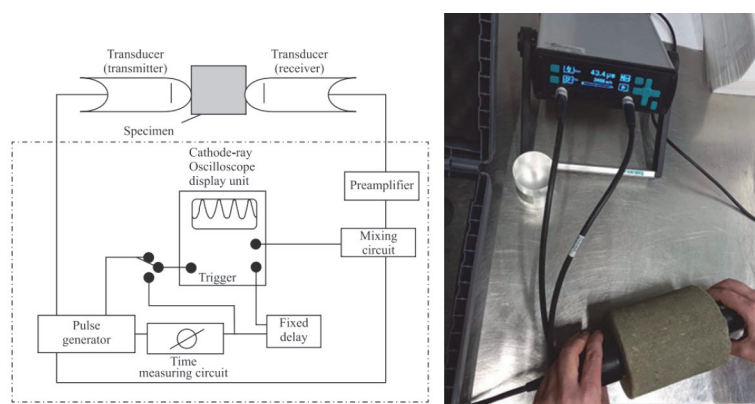
No.	Mixture composition	MDD [g/cm <sup>3</sup> ]	OWC [%]
1	(70 % sand + 30 % WA) + 0 % cem.	1.72	13.50
2	(70 % sand + 30 % WA) + 2 % cem.	1.73	12.69
3	(70 % sand + 30 % WA) + 4 % cem.	1.70	11.61

In addition to enabling savings in the amount of cement and sand compared to standard sand stabilized mixtures, locally available materials increase the economic viability of this solution. Modified Proctor experiments were conducted on stabilization mixtures according to the standard HRN EN 13286 – 2 [15], and values for optimal water content (OWC) and maximum dry density (MDD) were obtained, as shown in Table 2. Based on these values, samples were prepared for testing the ultrasonic velocity. The samples were cured for 7, 28, and 180 days, wrapped in transparent foil, placed in climate chambers at 20 °C [1], and then proceeded to measure the ultrasonic velocity.

## 2.2 Determination of ultrasonic pulse velocity

The modulus of elasticity can be determined using destructive and non-destructive methods, with non-destructive methods being advantageous as they do not cause sample failure. In this study, the modulus of elasticity of the samples was determined using the ultrasonic method according to the standard HRN EN 12504-4 [16]. The advantages of using the ultrasonic method include speed, simplicity, and the non-destructive nature of the testing.

The ultrasonic method is based on measuring the time of passage of longitudinal ultrasonic waves through the sample. The wave frequency for testing stabilization mixtures ranges from 20 to 250 kHz, depending on the sample size [17]. The device for measuring the velocity of ultrasonic waves through the sample, depicted in Figure 1.a, consists of an ultrasonic pulse generator, transmitter, receiver, electric pulse amplifier, and a timer. To ensure good contact during the transmission of pulses between the sample and the device, gel was used. The velocity measurement was performed on three samples of each stabilization mixture, and its mean value was calculated.



**Figure 1** Ultrasonic velocity measurement; a) schematic overview [17]; b) measuring equipment [1]

The ultrasonic velocity is calculated from the Eq (1) [16]:

$$v = \frac{l}{t} \text{ [km/s]} \quad (1)$$

where

$v$  – ultrasonic velocity [km/s]

$l$  – specimen length [km]

$t$  – travel time of ultrasound through the specimen [s].

Knowing the ultrasonic velocity  $v$  (m/s), the density of the stabilization mixture  $\rho$  ( $\text{kg/m}^3$ ), and adopting the value of the Poisson's ratio (0.2) based on previous tests, the modulus of elasticity is calculated from the Eq (2):

$$E = \rho v^2 \frac{(1+\nu)(1-2\nu)}{1-\nu} \quad (2)$$

where

$E$  – modulus of elasticity [ $\text{MN/m}^2$ ]

$\rho$  – sample density [ $\text{kg/m}^3$ ]

$v$  – ultrasonic pulse velocity [km/s]

$\nu$  – Poisson's ratio.

### 3 Analysis and commentary of the results

#### 3.1 Analysis of ultrasonic velocity results

Analysis of Ultrasonic Wave Passage Measurements through Stabilization Mixture Samples was conducted after sample curing periods of 7, 28, and 180 days. The results of the ultrasonic velocity testing are depicted in the diagram in Figure 2. The results lack the velocity for mixture 1 after 180 days of curing because the testing was not conducted.

From the results in the diagram in Figure 2, it is evident that increasing the amount of cement in the stabilized mixtures leads to an increase in the velocity of ultrasonic pulse passage through the samples. The highest recorded velocities of ultrasonic pulse passage were measured in samples of mixture 3 with 4% cement, while the lowest values were recorded for mixture 1, without cement. The increase in ultrasonic pulse velocity for mixture 1 after 28 days of curing compared to 7 days of curing is 20.3%, the average increase in velocity for mixture 2 is 21%, while the average increase in ultrasonic pulse velocity for mixture 3 is 10.8%. A decrease in the velocity values of stabilization mixture 2 is observed in the results after 180 days compared to the velocity after 28 days of curing, indicating a measurement or sample preparation error.

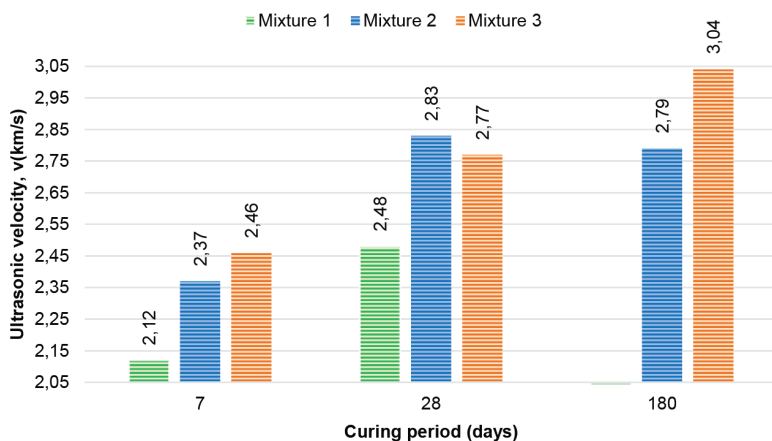


Figure 2 Relationship between ultrasonic velocity and cement content in the mixture for different curing period

Ultrasonic velocity is an indicator of mixture quality, and higher values indicate better quality stabilization mixtures, while lower ultrasonic velocities suggest the presence of certain discontinuities and sample inhomogeneity [1]. From the presented results of ultrasonic velocity, it can be concluded that the highest quality stabilization mixture is mixture no. 3, composed of 70% sand + 30% wood ash + 4% cement.

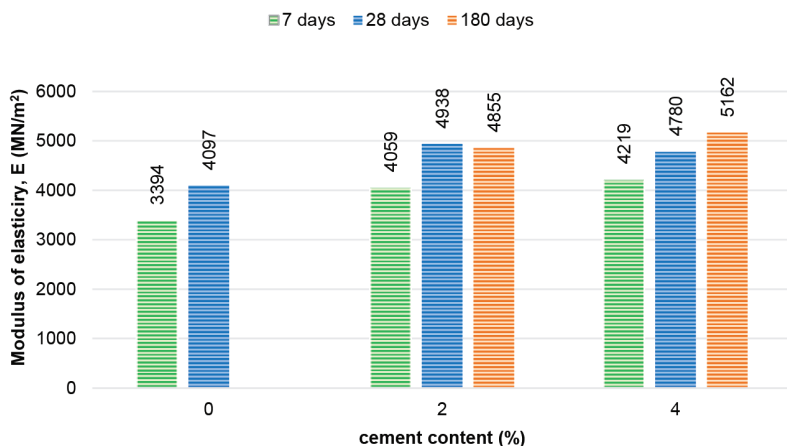
#### 3.2 Analysis of the results of modulus of elasticity

Based on the obtained ultrasonic velocities, the modulus of elasticity was calculated using Eq (2). The selected value of the Poisson's ratio for the calculation of the modulus of elasticity is  $\nu = 0,20$ .

**Table 3** Average values of density, ultrasonic velocity, and dynamic modulus of elasticity of stabilization mixtures [1]

Sample curing	7 days			28 days			180 days		
Mix No.	1	2	3	1	2	3	1	2	3
$\rho$ [kg/m <sup>3</sup> ]	1830.9	1922.7	1907.5	1838.0	1941.7	1914.7	-	1926.1	1887.1
UPV [km/s]	2.06	2.35	2.46	2.48	2.83	2.77	-	2.80	3.04
E [MN/m <sup>2</sup> ]	3394	4059	4219	4097	4938	4780	-	4855	5162

As evident from Table 3 and the diagram in Figure 3, increasing the amount of cement and longer sample curing result in an increase in the values of the modulus of elasticity. The values of the modulus of elasticity range from 3394-4097 MN/m<sup>2</sup> for mixtures without cement, from 4059 to 4938 MN/m<sup>2</sup> for mixtures with 2% cement, and from 4219 to 5162 MN/m<sup>2</sup> for mixtures with 4% cement. The highest individual recorded value of the modulus of elasticity is 5236 MN/m<sup>2</sup>, confirming the success of stabilizing Drava River sand with wood ash.



**Figure 3** Relationship between dynamic modulus of elasticity and cement content in the mixture for different curing time

## 4 Conclusion

This study encompassed the investigation of the modulus of elasticity of stabilization mixtures composed of Drava River sand, wood ash, and cement. The modulus of elasticity of stabilization mixtures with different compositions was obtained using non-destructive measurement methods of ultrasonic wave passage through sample mixtures. The study aimed to determine the dependence of the modulus of elasticity on the composition of the stabilization mixture. Analysis of the presented results revealed the following:

- The addition of wood ash to Drava River sand resulted in improved mixture properties, attributed to the improved granulometric composition of the mixture and the action of ash as a hydraulic binder within it. Stabilized mixtures with 2% cement achieved average values of modulus of elasticity amounting to 4059 MN/m<sup>2</sup> for samples aged 7 days, while stabi-

lized mixtures with 0% cement achieved almost the same average values of modulus of elasticity after 28 days of sample curing ( $Ed_{in,1} = 4097 \text{ MN/m}^2$ ).

- The addition of cement to the stabilization mixture resulted in an increase in the dynamic modulus of elasticity, confirming that the modulus of elasticity of the mixture is directly dependent on its composition. The increase in modulus values of mixtures with 2% cement compared to mixtures without cement was significant, reaching 19.6% after 7 days of curing and 20.51% after 28 days of curing. The increase in modulus values with 4% cement compared to mixtures with 2% cement was 3.94% after 7 days and 6.3% for 180 days of curing. In addition to the cement content in the stabilization mixture, the duration of sample curing also affects the modulus of elasticity value. Mixture No. 3 with 4% cement after 180 days of curing achieved the highest value of modulus of elasticity ( $Ed_{in,3} = 5236 \text{ MN/m}^2$ ), while mixture No. 2 with 2% cement for the same curing time had a lower modulus value ( $Ed_{in,2} = 4855 \text{ MN/m}^2$ ).
- Analysis of the results of measured ultrasonic velocities of stabilized mixtures confirmed that ultrasonic velocity is a significant criterion and indicator of material quality. Mixtures No. 1 had average ultrasonic velocities ranging from 2.06 to 2.48 km/s, mixtures No. 2 from 2.35 to 2.83 km/s, and finally, the highest quality mixture No. 3, with 4% cement, had ultrasonic velocities ranging from 2.46 to 3.06 km/s.

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## References

- [1] Senić, P.: Dinamički moduli elastičnosti stabilizacijskih mješavina, Josip Juraj Strossmayer University of Osijek, master thesis, 2022. (in Croatian)
- [2] Babić, B.: Uvod u teorijsko dimenzioniranje kolničkih konstrukcija, University of Zagreb, Faculty of Civil Engineering, 1982. (in Croatian)
- [3] European Commission Directorate General Transport, COST 333 Development of New Bituminous Pavement Design Method, Final Report of the Action, Brussels 1999.
- [4] Barišić, I., Dimter, S., Rukavina, T.: Elastic properties of cement-stabilized mixes with steel slag, *International Journal of Pavement Engineering*, 17 (2016) 9, pp. 753-762, DOI: 10.1080/10298436.2015.1019496
- [5] Dimter, S., Rukavina, T., Minažek, K.: Estimation of elastic properties of fly ash– stabilized mixes using nondestructive evaluation methods, *Construction and building materials*, 102 (2016), 1, pp. 505-514. DOI: 10.1016/j.conbuildmat.2015.10.175
- [6] Yan, K., Gao, F., Sun, H., Ge, D.: Effects of municipal solid waste incineration fly ash on the characterization of cement-stabilized macadam, *Construction and Building Materials*, 207 (2019) 8, pp. 181-189, DOI: 10.1016/j.conbuildmat.2019.02.048
- [7] Zagvozda, M., Dimter, S., Rukavina, T., Netinger Grubeša, I.: Possibilities of bioash application in road building, *Građevinar*, 70 (2018) 5, pp. 393-402, DOI: 10.14256/JCE.2074.2017
- [8] Zagvozda, M., Rukavina, T., Dimter, S.: Wood bio ash effect as lime replacement in the stabilization of different clay subgrades, *International Journal of Pavement Engineering*, 23 (2020) 8, pp. 2543-2553, DOI: 10.1080/10298436.2020.1862839
- [9] Dimter, S., Zagvozda, M., Tonc, T., Šimun, M.: Construction of economical pavement structures with wood ash, 30th International Baltic Road Conference, pp. 1-7, Riga, Latvia 22 - 25 August 2021.
- [10] Dimter, S., Zagvozda, M., Šimun, M., Milovanović, B.: Drvni pepeli - otpadni materijali za održivu

gradnju cesta Slavonije, 29<sup>th</sup> International Scientific Conference Organization and Maintenance Technology OTO 2020, pp. 61-68, Osijek, Croatia, 12.12.2020.

- [11] Dimter, S., Zagvozda, M., Tonc, T., Šimun, M.: Evaluation of Strength Properties of Sand Stabilized with Wood Fly Ash (WFA) and Cement, *Materials*, 15 (2022), 9, 3090, DOI: 10.3390/ma15093090
- [12] Dimter, S., Zagvozda, M., Tonc, T., Zvonarić, M.: Impact of different wood ash fractions on the load-bearing capacity of sand mixtures, 7<sup>th</sup> International Conference on Road and Rail Infrastructure CETRA 2022, pp. 449-456, Pula, Croatia, 11-13 May 2022, DOI: 10.5592/CO/CETRA.2022.1473
- [13] Senić, P., Dimter, S.: Primjena drvnog pepela u cestogradnji, 2<sup>nd</sup> International Student GREEN Conference, pp. 36-37, Osijek, Croatia, 2-3 June 2022.
- [14] Dimter, S., Zagvozda, M., Šimun, M.: Potencijal primjene pepela iz drvne biomase u održivoj gradnji cesta, 15. Dani Hrvatske komore inženjera građevinarstva, Opatija, Croatia, 18-20 June 2021. (in Croatian)
- [15] HRN EN 13286-2: Unbound and hydraulically bound mixtures -- Part 2: Test methods for laboratory reference density and water content – Proctor compaction EN 13286-2:2010/AC:2012
- [16] HRN EN 12504-4: Testing concrete in structures – Part 4: Determination of ultrasonic pulse velocity, EN 12504-4:2021
- [17] Dimter, S., Rukavina, T., Barišić, I.: Application of the ultrasonic method in evaluation of properties of stabilized mixes, *Baltic journal of road and bridge engineering*, 6 (2011) 3, pp. 177-184, DOI: 10.3846/bjrbe.2011.23