

EFFECT OF BASALT DUST ADDITION ON GEOTECHNICAL PARAMETERS OF NON-COHESIVE SOIL

Iwona CHMIELEWSKA *

*Assistant Prof., PhD; Bialystok University of Technology, Faculty of Civil Engineering and Environmental Sciences, Wiejska 45A, 15-351 Bialystok, Poland
ORCID 0000-0001-6356-1188
E-mail address: *i.chmielewska@pb.edu.pl*

6.05.2025, Revised: 29.05.2025, Accepted: 05.08.2025

Abstract

Waste utilization is a desirable practice resulting from the constantly expanding closed-loop economy, which aims to decrease greenhouse gas emissions and energy consumption by minimizing waste generation and reducing raw materials usage. One of the types of waste materials that can be used for geotechnical engineering purposes is basalt dust, a by-product of the crushing process of basalt rocks. Due to its gradation and chemical composition, basalt dust is commonly used in construction engineering, horticulture, and agriculture. Moreover, it can be applied as a mineral soil additive. The study aimed to investigate the potential use of basalt dust as a partial replacement for non-cohesive soil. The paper presents the results of compactibility, permeability, compressibility, and shear strength tests. Investigations were performed under laboratory conditions on samples with the addition of 5, 10, and 15% basalt dust to the dry mass of soil. The results enabled the identification of the effect of basalt dust on geotechnical parameters, including coefficient of permeability, compaction parameters, constrained modulus, compression and recompression indexes, and internal friction angle.

Keywords: Laboratory tests; Stone dust; Sustainable geotechnical engineering; Waste materials.

1. INTRODUCTION

Nowadays, waste materials are increasingly utilized across various fields, including industry, agriculture, civil engineering, and geoengineering. It is a direct result of the constantly expanding closed-loop economy, which aims to decrease greenhouse gas (GHG) emissions and energy consumption by reducing raw materials usage and minimizing waste generation. Waste materials applied in broadly defined geotechnical engineering include fly ash, blast furnace slag, clinker dust, properly prepared spent car tires, plant and animal fibers, coffee grounds, eggshells, and shells [1]. Stone quarry dust is another waste material that can be used for geotechnical engineering purposes. Its utilization perfectly meets the principles of a closed-loop economy and sustainable geoengineering.

One of the types of stone dust is basalt dust, a by-

product of the crushing process of basalt rocks. Its mineral and chemical composition is the same as the composition of the rock from which it originated, while its grain size distribution is closely related to the production process of crushed basalt aggregates. In general, basalt dust is primarily characterized by the occurrence of silicon dioxide (SiO_2), iron oxide (Fe_2O_3), calcium oxide (CaO), and aluminum oxide (Al_2O_3) [2, 3]. Meanwhile, the mineral composition is mainly dominated by plagioclase and pyroxene [2]. Considering the gradation, basalt dust consists predominantly of a silty fraction characterized by grain sizes of 0.002-0.063 mm. The grain size distribution of basalt dust is similar to that of Portland cement [2].

Due to the composition and grain size distribution, basalt dust is widely used in construction engineering [2,4,5]. The possibility of its application in horticulture

and agriculture as a fertilizer and nutrient is also widely reported [3, 6–8]. Additionally, studies conducted with quarry stone dust indicate its successful usage in soil stabilization. Okagbue and Onyeobi [9], Öncü and Bilsel [10], and Umar et al. [11] reported that marble dust reduces the plasticity, compressibility, and permeability of problematic soils. In contrast, its addition increases the strength measured by the unconfined compressive strength and California bearing ratio. Moreover, the researchers observed a positive effect of time on soil strengthening. The investigations provided by Abdelkader et al. [12], Amulya et al. [13], and Eltwati et al. [14] showed a similar effect of granite dust addition on soil strengthening. The researchers additionally reported on the impact of marble and granite dust addition on improving the compaction parameters of tested soils by increasing the maximum dry density (ρ_{dmax}) and reducing the optimum water content (w_{opt}).

The existing studies on basalt dust as a soil additive presented in the literature are mainly concerned with its effect on improving soil properties regarding soil fertility and crop nutrition [3, 6–8, 15–17]. However, the author's preliminary research on compaction parameters revealed that the addition of basalt dust increases the maximum dry density and reduces the optimum water content of non-cohesive soil. This finding motivates further investigation, the results of which are presented in this paper.

The study aims to research the potential use of basalt dust as a partial replacement for mineral non-cohesive soil, thereby reducing the use of natural raw materials. The paper presents the results of compactibility, per-

meability, compressibility, and shear strength tests. Investigations were performed under laboratory conditions on samples with the addition of 5, 10, and 15% basalt dust to the dry mass of non-cohesive soil. The results enabled the identification of the effect of basalt dust addition on geotechnical parameters, including compaction parameters (ρ_{dmax} and w_{opt}), coefficient of permeability (k and k_{10}), constrained modulus (M), compression and recompression indexes (C_c and C_r), and internal friction angle (Φ).

2. MATERIALS

The basalt dust used in this study was sourced from the “Krzeniów” basalt deposit located in Lower Silesia, about 100 km west of Wrocław. The basalt rocks of this region resulted from volcanic activity during the Tertiary period, and their physical and



Figure 1.
Digital microscope image of the tested basalt dust (1000x magnification)

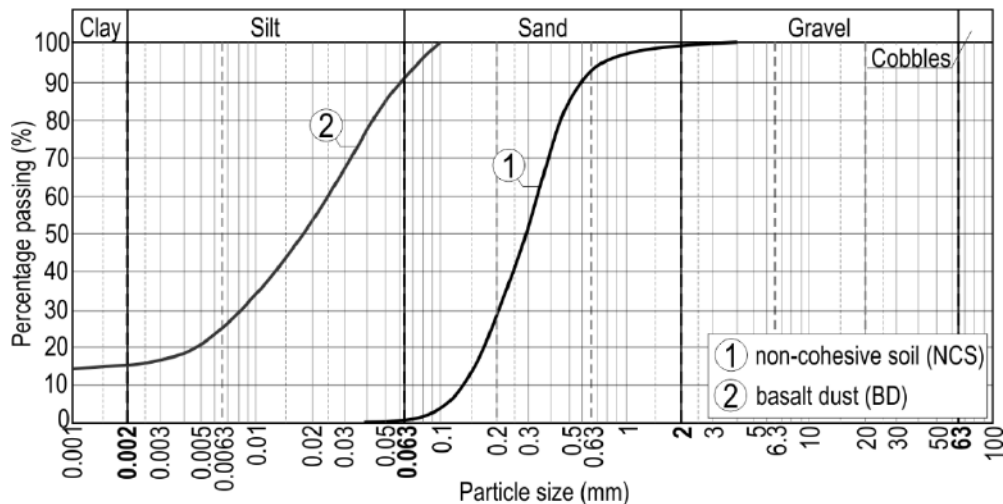


Figure 2.
The grain-size distribution curves determined for the tested non-cohesive soil and basalt dust

chemical properties are closely related to the formation process in volcanic chimneys.

The main constituents of the considered basalt dust are silicon dioxide (SiO_2) at 42.9%, iron oxide (Fe_2O_3) at 12.9%, aluminum oxide (Al_2O_3) at 12.8%, calcium oxide (CaO) at 10.5%, and magnesium oxide (MgO) at 10.5%. The rest of the components are trace amounts of potassium, sodium, and phosphorus oxides. Regarding the graining, the basalt dust consists of approximately 75% of particles in the 0,002–0,063 mm size range. The grains are characterized by irregular, sharp-edged, and angular shapes, as illustrated in Figure 1. The detailed grain size distribution of the considered basalt dust (BD) is presented in Figure 2.

The non-cohesive soil (NCS) analyzed in this study was sourced from deposits in northeastern Poland. It is characterized by fluvio-glacial origin and predominantly quartz composition. The particle diameters of the non-cohesive soil range from 0.04 to 4 mm (Fig. 2). Table 1 shows the basic geotechnical properties of non-cohesive soil (NCS) and basalt dust (BD) related to particle size distribution and specific dry density.

Table 1.
Basic properties of the tested materials

Property	Value	
	NCS	BD
Particle size distribution		
Gravel (%)	0.2	–
Sand (%)	99.7	9.9
Silt (%)	0.1	75.2
Clay (%)	–	14.9
Coefficient of uniformity (C_u)	2.43	> 25.0
Coefficient of curvature (C_c)	0.84	> 2.56
Specific dry density (t/m^3)	2.65	2.76

According to ISO 14688-1 standard [18], the tested non-cohesive soil classifies as medium sand (mSa). Meanwhile, the gradation of basalt dust corresponds to the particle distribution of clayey SILT (clSi). Additionally, Table 1 indicates that the non-cohesive soil and basalt dust are characterized by poor and well gradation, respectively.

3. METHODOLOGY

Research was performed on samples of non-cohesive soil with basalt dust addition of 5%, 10%, and 15% to the dry mass of the soil. Both materials were dried at 110°C before testing. The standard Proctor method

was used to determine compaction parameters: the maximum dry density (ρ_{dmax}) and optimum water content (w_{opt}). The samples were compacted in Proctor mould A in three layers (25 blows on every layer) with a 2.5-kg rammer falling from a height of 305 mm, corresponding to the compaction energy equal to approximately 0.6 MJ/m³ [19].

The permeability, compressibility, and shear strength tests were performed under applicable international standards [20–22] on samples characterized by ρ_{dmax} and w_{opt} parameters determined for particular contents of basalt dust.

The specimens with a diameter of 112 mm and a height of 60 mm were used in permeability testing. The research was conducted at a constant gradient ranging from 0.3 to 0.8. The volume of water flowing through the sample over a specific time and the water temperature were measured during the test. Volume measurements were taken for the bottom-up and top-down flow directions and then averaged. Finally, the tested and corrected to 10°C coefficients of permeability (k and k_{10} , respectively) were established.

Compressibility tests were performed using a set of oedometers equipped with automatic registration of displacement sensor readings. Tests were carried out on cylindrical samples with an initial height of 20 mm and a diameter of 63.5 mm, placed in non-deformable rings with top and bottom porous stones. The samples were tested at different vertical stresses σ_v' , including 16, 32, 64, 128, 256, and 512 kPa. The height of the specimens at a particular stress level was measured until the settlement stabilization. The samples were protected from moisture loss throughout the testing process, which included the primary loading, unloading, and secondary loading. Based on the test results, the constrained modulus for primary compression (M), as well as the compression and recompression indexes (C_c and C_r , respectively), were determined. The constrained modules were calculated based on the changes in sample height (h) under an applied stress (σ_v'). Whereas, the C_c and C_r parameters were obtained using the dependence of the void ratio e on the vertical effective stress plotted in the logarithmic scale $\log \sigma_v'$, considering the primary loading (C_c index) and unloading (C_r index) sequences.

The shear strength of the tested materials was determined in a direct shear apparatus. The square box with the dimensions of 80x80 mm was used. The samples were tested at the normal stresses (σ_n) of 25, 50, 100, 150, and 200 kPa at a 1 mm/min constant shear

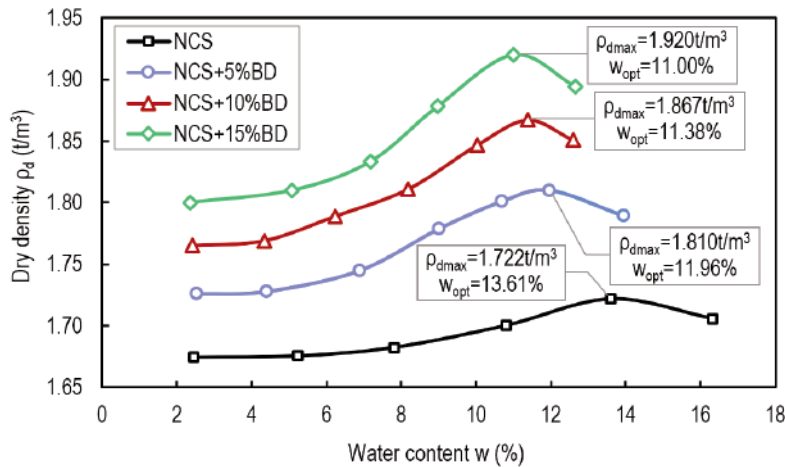


Figure 3.
Compaction curves of tested non-cohesive soil and soil-dust mixtures

rate. The horizontal forces and displacements were measured automatically. Direct shear tests were interrupted at the horizontal displacement equal to 8 mm, 10% of the shear box dimension. The tests allowed for determining the maximum shear stress (τ) as a function of σ_n value, enabling the evaluation of the internal friction angle (Φ) of tested materials.

4. RESULTS

Figure 3 illustrates the compaction curves of untreated non-cohesive soil (NCS) and those determined for soil with 5, 10, and 15% basalt dust (BD) addition. The figure also includes the obtained values of maximum dry density (ρ_{dmax}) and optimum water content (w_{opt}).

Figure 3 shows that the highest ρ_{dmax} value of 1.920 t/m^3 was achieved for a mixture of sand and basalt dust at 15%. This quantity of dust increased the maximum dry density by approximately 11 % compared to the untreated non-cohesive soil. The addition of 5 and 10% of basalt dust increased the ρ_{dmax} value by 5 and 8%, respectively. It can also be seen from Figure 3 that the optimum water content of the tested mixtures decreases with the increased percentage of basalt dust. Specifically, the w_{opt} values reduced by approximately 12, 16, and 19% for the additions of 5%, 10%, and 15% basalt dust, respectively. The improvement of compaction parameters by increasing the ρ_{dmax} and decreasing the w_{opt} results from modifying the non-cohesive soil gradation by fine particles of the basalt dust.

The results of the permeability tests conducted on

samples of non-cohesive soil and soil-dust mixtures compacted at optimum water content (w_{opt}) to the maximum dry density (ρ_{dmax}) are presented in Table 2. The table shows the values of the permeability coefficient (k) calculated directly from the test data and the values corrected to 10°C (k_{10}).

Table 2.
Tested and corrected coefficients of permeability

Material	k (m/s)	k_{10} (m/s)
NCS	$1.72 \cdot 10^{-4}$	$1.20 \cdot 10^{-4}$
NCS+5%BD	$8.00 \cdot 10^{-5}$	$5.57 \cdot 10^{-5}$
NCS+10%BD	$6.76 \cdot 10^{-5}$	$4.71 \cdot 10^{-5}$
NCS+15%BD	$4.60 \cdot 10^{-5}$	$3.20 \cdot 10^{-5}$

The highest k and k_{10} coefficients were obtained for non-cohesive soil, characterized by the lowest fine particles content and compaction compared to the rest of the tested materials. The permeability coefficients determined for untreated non-cohesive soil are similar to those reported in the literature for medium and coarse sands [23]. The addition of basalt dust resulted in a reduction of the k and k_{10} values. The lowest permeability coefficients were obtained for a mixture of sand and 15% basalt dust content. This amount of additive caused an average decrease in the values of k and k_{10} by approximately 73%. Meanwhile, the 5 and 10% contents of basalt dust reduced the permeability coefficients by 53% and 61%, respectively. The coefficients of permeability determined for mixtures of non-cohesive soil and basalt dust correspond to the values reported in the literature for fine sands [23].

Figure 4 illustrates the dependences of the void ratio (e) on vertical stress (σ_v') obtained for the considered non-cohesive soil and soil-dust mixtures. The figure also includes the values of the initial void ratio (e_0), compression index (C_c), and recompression index (C_r). Before compressibility testing, all samples were compacted to the maximum dry density at the optimum water content.

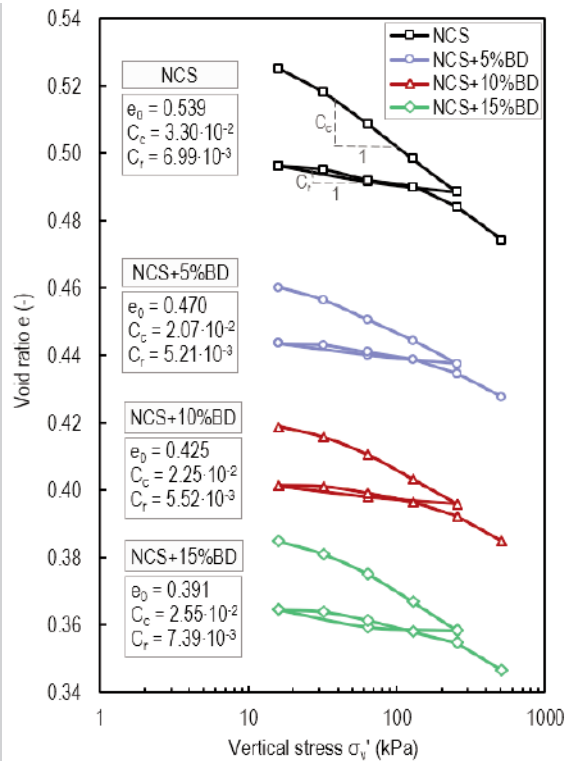


Figure 4.
The e - σ_v' relationships obtained from one-dimensional compressibility tests

Figure 4 shows a relatively wide variety of void ratio (e) depending on the percentage of basalt dust, which is directly related to the content of fine particles and compaction of the considered materials. The values of compression and recompression indexes presented in Figure 4 indicate that non-cohesive soil with a 5% addition of basalt dust is characterized by the lowest primary and secondary compressibility, with $C_c = 2.07 \cdot 10^{-2}$ and $C_r = 5.21 \cdot 10^{-3}$, respectively. The highest effect of primary loading on the change in void ratio was found for untreated non-cohesive soil ($C_c = 3.30 \cdot 10^{-2}$). Meanwhile, the non-cohesive soil with 15% dust content is characterized by the highest secondary compressibility, with a C_r coefficient of $7.39 \cdot 10^{-3}$. Analyzing the results of the tests shown in Figure 4, the ratio of C_c/C_r for the considered materials ranged from 3.5 to 4.7. Whereas, the determined compression index values are comparable to those reported in the literature for compacted sands [24].

Based on the compressibility tests, the constrained modulus for primary compression (M) was determined and presented in Figure 5 as a function of vertical stress (σ_v'). Additionally, linear M - σ_v' relationships were defined, and the corresponding R^2 determination coefficients were provided (Fig. 5).

As shown in Figure 5, the lowest values of the constrained modulus for primary compression, ranging from 1.8 to 38.9 MPa, depending on the vertical stress level, were obtained for the untreated non-cohesive soil. In contrast, at the vertical stress (σ_v') within the 16 to 64 kPa range, the highest modulus M was determined for non-cohesive soil with a 10% addition of basalt dust. While at the stress σ_v' ranging from 128 to 512 kPa, the highest constrained modulus for

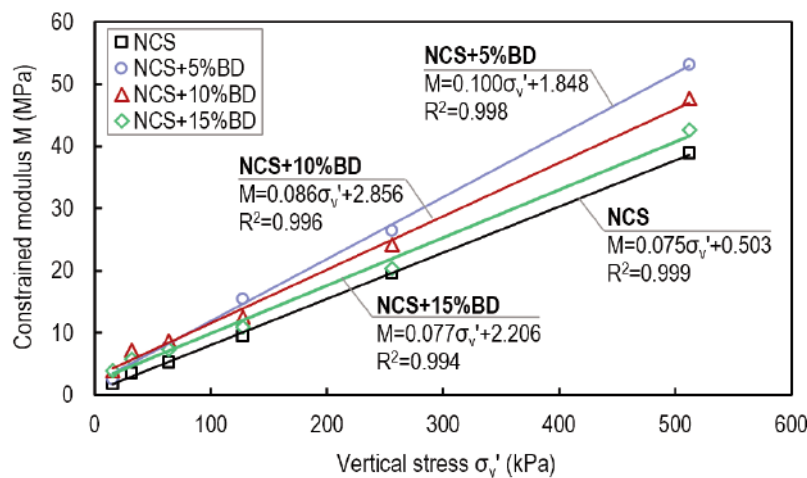


Figure 5.
The constrained modulus for primary compression M of the tested materials in relation to the effective stress σ_v'

primary compression was established for soil containing 5% dust. Considering vertical stress $\sigma_v' = 32$ kPa, the M value obtained for non-cohesive soil with 10% dust content was approximately two times greater than that determined for the untreated soil (Fig. 5).

Figure 6 illustrates the relationship between shear stress (τ) and horizontal displacement (s), including information on the coordinates of the peak points (s_p , τ_p) that identify the maximum shear stress with the corresponding displacement. In this study, only the internal friction angle values (Φ) were analyzed, which are also provided in Figure 6. The samples of non-cohesive soil and soil containing 5, 10, and 15% basalt dust were prepared by compacting at optimum water content (w_{opt}) to the maximum dry density (ρ_{dmax}).

Based on Figure 6, it can be concluded that the internal friction angles of all tested materials are comparable, ranging from 39.4 to 43.0°. The addition of 5% basalt dust decreased the Φ angle by approximately 3% compared to the value received for untreated non-cohesive soil. The highest internal friction angle was obtained for the non-cohesive soil containing 10% basalt dust, which was 6% greater than that determined for the soil without additives. However, the Φ values received for the 10 and 15% basalt dust contents differ by only 0.1°. The internal friction angles obtained in direct shear tests are similar to the values presented in the literature for dense sands [25].

5. CONCLUSIONS

The research presented in this study confirms that the addition of basalt dust impacts the geotechnical parameters, favorably affecting parameters related to compactability, permeability, compressibility, and shear strength of non-cohesive soil. Therefore, the basalt dust can be potentially used as a partial soil substitute. However, it is challenging to specify one amount of basalt dust that most significantly improves all tested physical and mechanical properties. Therefore, the conclusions below consider each geotechnical parameter separately.

1. The addition of basalt dust increases the maximum dry density (ρ_{dmax}) and decreases the optimum water content (w_{opt}) of non-cohesive soil. Specifically, a 15% addition of basalt dust, which has the most significant effect on compactability parameters, resulted in an 11% increase in the ρ_{dmax} and a 19% decrease in the w_{opt} compared to

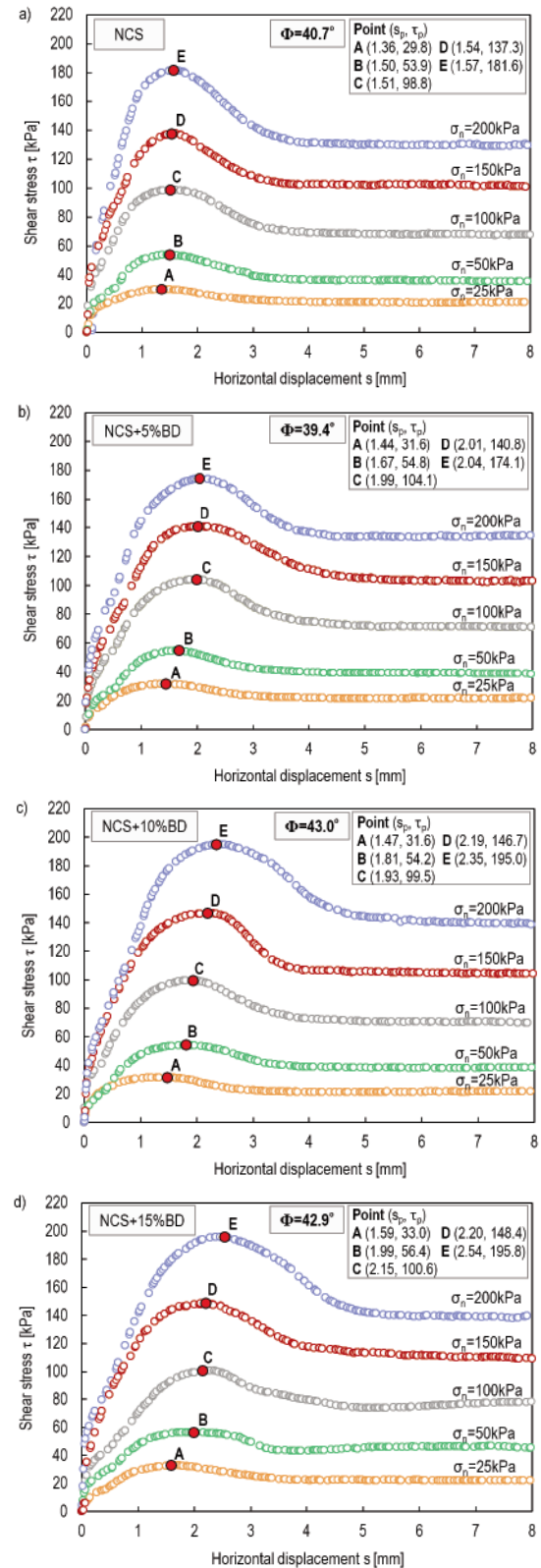


Figure 6. The τ - s relationships obtained from direct shear tests for the considered materials: (a) NCS; (b) NCS+5%BD; (c) NCS+10%BD; (d) NCS+15%BD

untreated soil. The 5% basalt dust content has the slightest effect on the compactibility characteristics of the considered soil.

2. The permeability of non-cohesive soil decreases with increasing basalt dust content. A 15% dust addition resulted in an approximately 73% decrease in tested and corrected permeability coefficients (k and k_{10} , respectively).
3. The addition of basalt dust results in a reduction in the compression index (C_c) and an increase in the primary constrained modulus (M). The 5% and 10% dust content had the most significant effect on the above-mentioned compressibility-related parameters. Specifically, a 5% dust content resulted in a 37% reduction in the C_c parameter, while a 10% dust addition caused an approximately 100% increase in the M value at a vertical effective stress (σ_v') of 32 kPa, compared to soil without additives. Generally, the addition of 15% basalt dust affected the C_c and M parameters the least, unfavorably impacting the recompression index (C_r).
4. The effect of the addition of basalt dust on the internal friction angle (Φ) is relatively small. The 10% and 15% dust content caused approximately a 6% increase in the Φ value, while 5% dust addition decreased it by about 3%. The percentage differences are related to the parameters of the untreated non-cohesive soil.

ACKNOWLEDGMENTS

This work was supported by Polish financial resources on science under project no. WZ/WB-III/2/2025.

REFERENCES

- [1] Jastrzębska, M., Knapik-Jajkiewicz, K., & Kowalska, M. (2024). Zrównoważona geotechnika. Wybrane materiały alternatywne (Sustainable geotechnics. Selected alternative materials). Warszawa: Wydawnictwo Naukowe PWN SA.
- [2] Dobiszewska, M., & Beycioğlu, A. (2020). Physical Properties and Microstructure of Concrete with Waste Basalt Powder Addition. *Materials*, 13, 3503, 1–18.
- [3] Seidel, E. P., Ertel, L. G., Pan, R., Da Silva Franco, J. A., & Dos Santos, D. G. (2021). Basalt Rock Powder and Organic Compounds in Corn Crops. *Scientia Agraria Paranaensis*, 20(3), 287–294.
- [4] Binici, H., Yardim, Y., Aksogan, O., Resatoglu, R., Dincer, A., & Karpuz, A. (2020). Durability properties of concretes made with sand and cement size basalt. *Sustainable Materials and Technologies*, 23(4), 1–9.
- [5] Kostrzewa-Demczuk, P., Stępień, A., Dachowski, R., & Krugielka, A. (2021). The use of basalt powder in autoclaved brick as a method of production waste management. *Journal of Cleaner Production*, 320, 1–11.
- [6] Conceição, L. T., Silva, G. N., Silva Holsback, H. M., De Figueiredo Oliveira, C., Marcante, N. C., De Souza Martins, É., De Souza Santos, F. L., & Santos, E. F. (2022). Potential of basalt dust to improve soil fertility and crop nutrition. *Journal of Agriculture and Food Research*, 10, 100443, 1–8.
- [7] Luchese, A. V., De Castro Leite, I. J. G., Da Silva Giarretta, A. P., Linhares Alves, M., Pivetta, L. A., & Missio, R. F. (2023). Use of quarry waste basalt rock powder as a soil remineralizer to grow soybean and maize. *Heliyon*, 9(3), 14050, 1–11.
- [8] Nunes, J. M. G., Kautzmann, R. M., & Oliveira, C. (2014). valuation of the natural fertilizing potential of basalt dust wastes from the mining district of Nova Prata (Brazil). *Journal of Cleaner Production*, 84, 649–656.
- [9] Okagbue, C. O., & Onyeobi, T. U. S. (1999). Potential of marble dust do stabilise red tropical soils for road construction. *Engineering Geology*, 53, 371–380.
- [10] Öncü, F. & Bilsel, H. (2018). Utilization of waste marble to enhance volume change and strength characteristics of sand-stabilized expansive soil. *Environmental Earth Sciences*, 77(12), 461, 1–13.
- [11] Umar, I. H., Lin, H., & Ibrahim, A. S. (2023). Laboratory Testing and Analysis of Clay Soil Stabilization Using Waste Marble Powder. *Applied Sciences*, 13(16), 9274, 1–23.
- [12] Abdelkader, H. A. M., Ahmed, A. S. A., Hussein, M. M. A., Ye, H., & Zhang, J. (2022). An Experimental Study on Geotechnical Properties and Micro Structure of Expansive Soil Stabilized with Waste Granite Dust. *Sustainability*, 14(10), 6218, 1–24.
- [13] Amulya, G., Baig Moghal, A. A., & Almajed, A. (2021). A State-of-the-Art Review on Suitability of Granite Dust as a Sustainable Additive for Geotechnical Applications. *Crystals*, 11, 1526, 1–16.
- [14] Eltwati, A. S., Tarhuni, F., & Elkaseh, A. (2020). Engineering Properties of Clayey Soil Stabilized with Waste Granite Dust. *International Journal of Advance Science and Technology*, 29(10), 750–757.
- [15] Gillman, G. P., Burkett, D. C., & Coventry, R. J. (2001). A laboratory study of application of basalt dust to highly weathered soils: effect on soil cation chemistry. *Australian Journal of Soil Research*, 39(4), 799 – 811.

- [16] Richardson, J. B. (2025). Basalt Rock Dust Amendment on Soil Health Properties and Inorganic Nutrients–Laboratory and Field Study at Two Organic Farm Soils in New England, USA. *Agriculture*, 15(1), 52, 1–18.
- [17] Rodrigues, M., Cambrussi Bortolini, P., Kosera Neto, C., De Andrade, E. A., Dos Passos, A. I., Palczewski Pacheco, F., Nanni, M. R., & de Melo Teixeira, L. (2024). Unlocking higher yields in *Urochloa brizantha*: the role of basalt powder in enhancing soil nutrient availability. *Discover Soil*, 1, 4, 1–17.
- [18] International Organization for Standardization. (2017). Geotechnical investigation and testing – Identification and classification of soil. Part 1: Identification and description (ISO Standard No. 14688:1).
- [19] European Committee for Standardization. (2012). Unbound and hydraulically bound mixtures. Part 2: Test methods for laboratory reference density and water content – Proctor compaction (EN standard No. 13286-2).
- [20] International Organization for Standardization. (2019). Geotechnical investigation and testing – Laboratory testing of soil. Part 11: Permeability tests (ISO Standard No. 17892-11).
- [21] International Organization for Standardization. (2017). Geotechnical investigation and testing – Laboratory testing of soil. Part 5: Incremental loading oedometer test (ISO Standard No. 17892-5).
- [22] International Organization for Standardization. (2018). Geotechnical investigation and testing – Laboratory testing of soil. Part 10: Direct shear tests (ISO Standard No. 17892-10).
- [23] Wiłun, Z. (2013). *Zarys geotechniki (Fundamentals of geotechnics)*. Warszawa: Wydawnictwa Komunikacji i Łączności.
- [24] Hough, B. K. (1969). *Basic Soils Engineering*. New York: Ronald Press Company.
- [25] Day, R. W. (2010). *Foundation Engineering Handbook. Design and Construction with the 2009 International Building Code*. New York: McGraw Hill.