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Original Research Article

Performance of Nickel Slag as a Stabilization Material for Soft Soil

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Abstract: The chemical soil stabilization method is an effort to improve soil bearing capacity according to soil work specifications in construction. The use of conventional stabilization materials, such as cement and lime, is considered environmentally unfriendly. Utilizing by-products from the mining industry becomes an alternative that can be developed in soil improvement efforts. This research aims to examine the influence of nickel slag on the enhancement of soil bearing capacity as observed through its unconfined compressive strength value. In this study, the concentration of added nickel slag as a stabilization material is 3%, 6%, 9%, and 12% by dry soil weight. The test specimens used are cylinders with a diameter of 5 cm and a height of 10 cm. Unconfined compressive strength testing is conducted after the specimens are cured for 14 days. The results of this study indicate that the clay soil used is classified as organic clay with high plasticity based on the USCS classification, with an unconfined compressive strength value of 0.2 kg/cm2. The addition of nickel slag with concentrations of 3%, 6%, 9%, and 12% results in respective increases in unconfined compressive strength by 46%, 50%, 68%, and 47%. These findings demonstrate that the optimum nickel slag content of 6% provides the maximum unconfined compressive strength. Therefore, it can be concluded that nickel slag, as a source of silica, has the potential to be used as an alternative material in soft soil improvement.

Keywords: Chemical stabilization, slag nickel, soft soil, Unconfined Compression Strength.

INTRODUCTION

The prevalence of soft soil in Indonesia reaches 10% of its total land area, predominantly found in coastal regions with a land slope ranging from 0 to 2% (Kimpraswil, 2002). In general, soft soil exhibits high compressibility, substantial water absorption, and impermeability (Das B. M., 2019), contributing to its low load-bearing capacity. The diminished ability to support loads significantly affects the stability of constructions placed atop it, including buildings, bridges, and roads.

Soil stabilization is an effort aimed at enhancing the load-bearing capacity of soil to meet the technical criteria for structures built on soft ground. Chemical soil improvement is considered the most efficient and effective stabilization method, especially for large-scale earthworks like road foundation construction. This method involves the use of chemical materials such as cement, lime, and NaCl as binding agents in the soil. However, the use of these materials is considered uneconomical and contributes to environmental pollution, given the high energy consumption and carbon dioxide emissions associated with the process (Andrew, 2017) (Ouedraogo, Coulibaly, Ouedraogo, & Messan, 2015).

The concept of environmentally conscious development has reshaped the paradigm in material engineering, with the evolution of stabilization materials focusing on the utilization of industrial waste and recycled materials (Das B. M., 2013). Material engineering in construction, employing by-products or waste from industries, is grounded in the properties of the pozzolanic reaction (Menéndez, Sanjuán, García-Roves, Argiz, & Recino, 2020). Common chemical mechanisms of soil stabilization include cation exchange, flocculation and agglomeration, pozzolanic reactions, and carbonate cementation (Firoozi A. , Olgun, Ali Asghar Firoozi, & Baghini, 2017). This aspect results in chemical stabilization efforts

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exhibiting higher and more significant resistance to the enhancement of soil bearing capacity (Mariri, Moayed, & Kordnaeij, 2019).

The chemical engineering of materials as binding agents in current efforts to stabilize soft soil involves replacing conventional binding materials (such as cement and lime) with substances derived from various waste/residue sources in various industries. These include the utilization of the combustion residues of rice husks (Muntohar, 2011); (Muhammad, Syahril, Suyono, Muchtar, & Sirait, 2022); (K. Raja, 2022), the use of burnt coconut shell residues (Sadikon & Keria, 2023); (Rauf I. , Samang, Harianto, & Arsyad, 2020), and the utilization of mining waste (Rauf I. , Samang, Harianto, & Arsyad, 2019); (Kabeta & Lemma, 2023).

North Maluku is the second-largest province in Indonesia in terms of nickel production, with nickel reserves reaching 1.4 million tons. In the process of extracting nickel into ferro-nickel, by-products are generated in the form of solid and liquid materials, one of which is nickel slag. The chemical composition of the nickel slag obtained from the Nickel Industry in Obi Island includes SiO_2 content at 44.89%, Fe_2O_3 at 25.11%, MgO at 20.27%, and CaO at 3.34%, classifying it as Pozzolan type F (Rauf, Gaus, Sultan, & Heryanto, 2023).

Metode Penelitian

Lokasi Pengambilan Material Uji

The soft soil material used in this study was obtained from agricultural land located within the administrative region of East Halmahera Regency, in North Maluku. Astronomically, it is situated at 1°4'50.38" N and 128°11'39.27" E, as shown in Figure 1a. Furthermore, the nickel slag material was sourced from the ferro-nickel processing industry located on Obi Island, South Halmahera Regency, at coordinates 1°33'47.24"S and 127°25'12.09"E (Figure 1b).

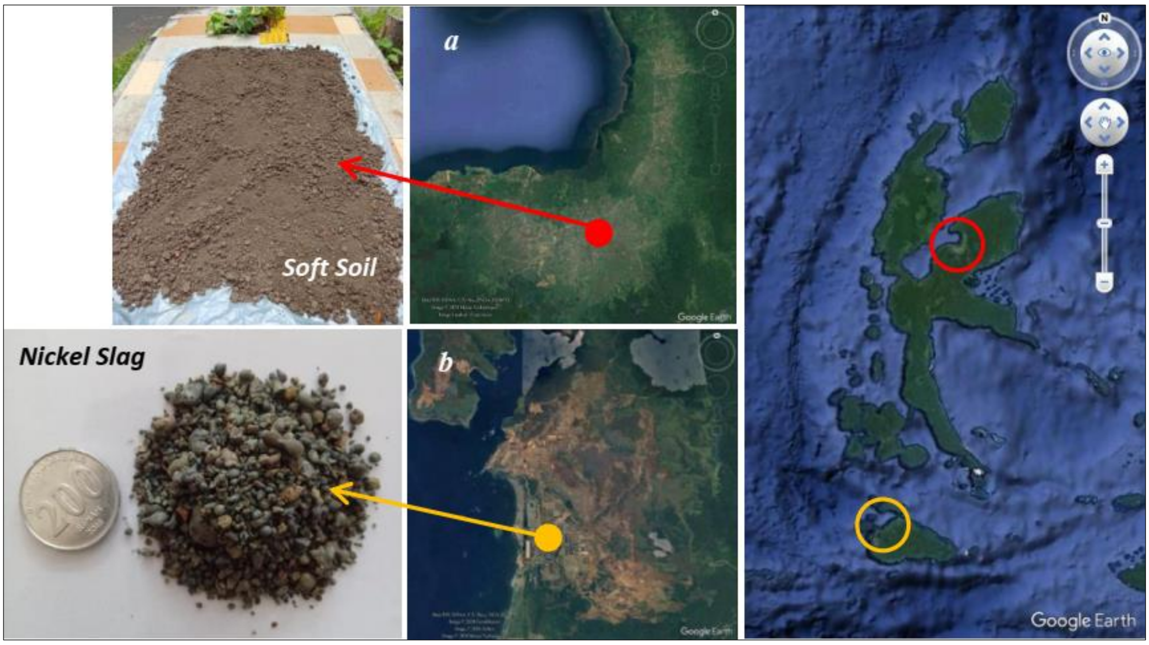

Figure 1: Lokasi pengambilan material uji dan bentuk fisik material uji

Specimens Preparation

The preparation of materials begins with the drying of soft soil and nickel slag under sunlight to ensure that each material does not undergo changes in chemical composition due to excessive heating. The particle size distribution of each material is made uniform through a screening process, where the soil material used is that which has passed through a No. 40 sieve, while for the nickel slag material, it is the one that has passed through a No. 200 sieve. Previously, the granular nickel slag material was finely ground using a crushing machine; this was done to enhance the reactivation of stabilization material (Janz & Johansson, 2002).

Testing of Unconfined Compressive Strength

The test specimens in this research are cylindrical with a diameter of 5 cm and a height of 10 cm. The variations of nickel slag used in each test specimen are 3%, 6%, 9%, and 12% of the weight of the soft soil used. The compaction testing results will yield dry density and optimum water content for each nickel variation, and these values will be the basis for the production of unconfined compression test specimens.

The mixing process of soft soil and nickel slag is conducted according to the calculated weight ratio. Soft soil and nickel slag are placed in plastic bags for curing for 24 hours, aiming to ensure a homogeneous mixture matrix. After curing, the next step is the fabrication of test specimens. Water is added to the mixture matrix according to the optimum water content obtained from compaction tests. The mixing process is carried out by gradually adding water for 10 minutes or until the mixture is considered homogeneous (Carașca, 2016). In the final stage, the mixture matrix is placed in a mold for the molding process following the applicable standards.

Laboratory tests in this research adhere to the American Standard Testing and Material (ASTM) standards, such as: water content test (ASTM D-2216), specific gravity test (ASTM D 854-58), Atterberg limits test (ASTM D 4318-95), gradation analysis (ASTM D1140), soil density test (ASTM D1557), and unconfined compressive strength test (ASTM D2166-06). The unconfined compressive strength test is conducted after the test specimens have been cured for 28 days using a machine for unconfined compressive strength testing, as shown in Figure 2. The deformation rate is set at 2.5 mm/minute. Load dial readings are taken at every 0.01 inch of deformation until the test specimen collapses. The readings of deformation and load are recorded and analyzed.

Figure 2: UCT Testing Equipment and Specimens

ANALYSIS AND DISCUSSIONS

Properties of Soft Soil

The results of the physical properties testing on soft soil, as shown in Table 1, indicate that the obtained specific gravity value is 1.87. The grain gradation of the soil sample is predominantly clay, with a percentage of 78%. The liquid limit, plastic limit, and plasticity index values are 63.92%, 42.16%, and 21.73%, respectively. Based on these values and the plot of LL against PL on the Casagrande graph (Figure 3), it can be concluded that the soft soil used is classified as organic clay with high plasticity.

Table 1: Soft Soil Properties

Soft Soil Properties	Value
Specific Grafity (Gs)	1.87
Water Content ($w_{opt,}$ %)	36.08
Sieve Analysis	
• Sand (%)	8
• Silt (%)	14
• Clay (%)	78
Batas-Batas Atterberg	
• Liquid Limit (LL)	63.92
• Plastic Limit (PL)	42.16
• Plasticity Index (PI)	21.73

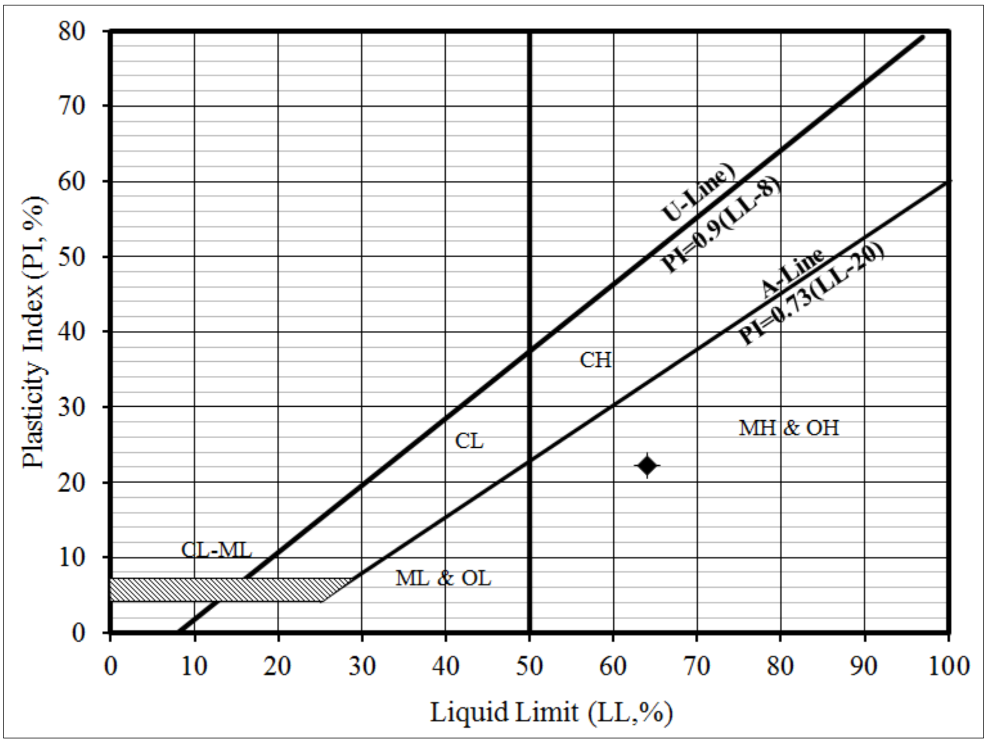

Figure 3: Classification of clayey soil based on USCS

Relationship between Nickel Slag Concentration and Unconfined Compressive Strength Values

The stress-strain behavior resulting from the compressive strength tests of each test specimen after curing for 28 days in this study is illustrated in Figure 4. The results, in general, show that the addition of nickel slag increases the values of unconfined compressive strength and decreases the strain values of the clayey soil. In other words, the soft soil material stabilized with nickel slag experiences an improvement in stiffness. Furthermore, the stress-strain curve from these measurements also indicates that the highest unconfined compressive strength is obtained at a nickel slag concentration of 6%.

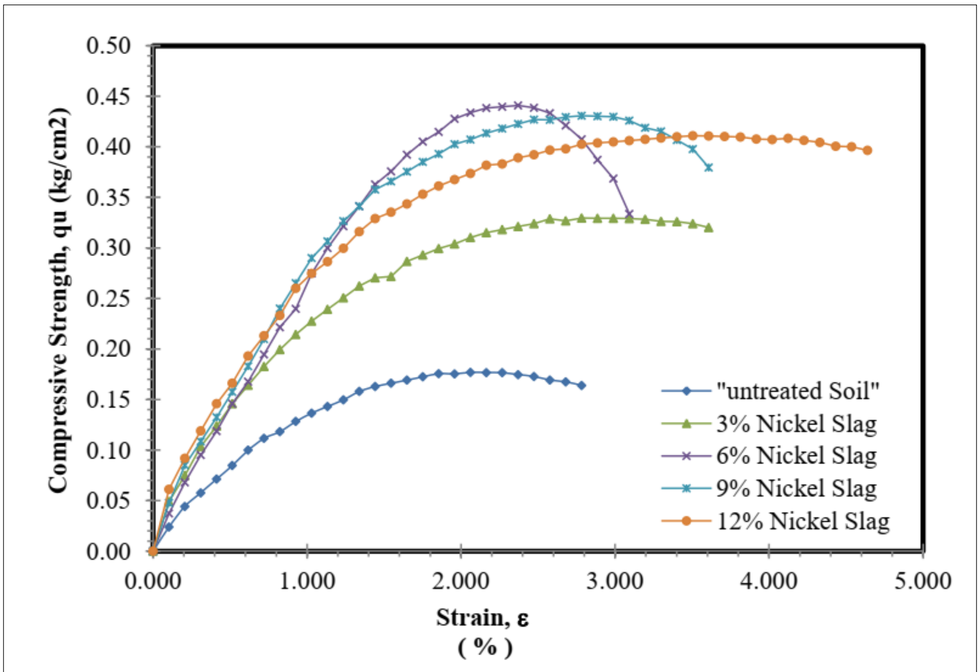

Figure 4: Stress-strain curve of soil stabilized with nickel slag

The performance of nickel slag on the unconfined compressive strength values of the organic soil used in this study is presented in Figure 5. These results indicate that nickel slag with concentrations of 3%, 6%, 9%, and 12% can increase the respective unconfined compressive strength values by 0.350 kg/cm2, 0.462 kg/cm2, 0.448 kg/cm2, and 0.431 kg/cm2. The increase in unconfined compressive strength (qu) in clayey soil stabilized with nickel slag reaches its maximum value at a concentration of 6%, then experiences a decrease at concentrations of 9% and 12%. This reduction in unconfined compressive strength (qu) may be attributed to excessive interactions between nickel slag particles and soil particles, leading to a decrease in soil cohesion.

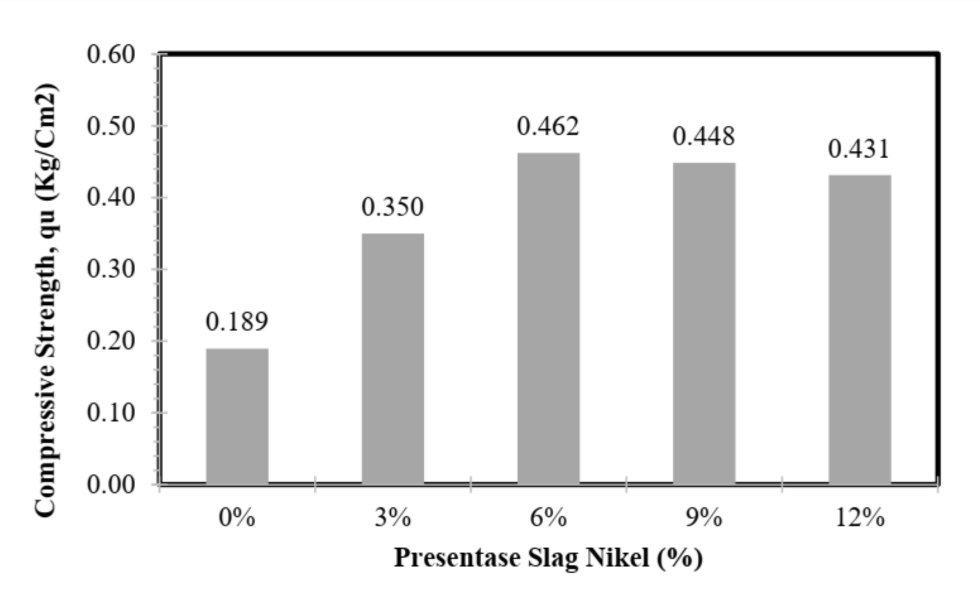

Figure 5: The correlation between nickel slag content and UCT values

CONCLUSIONS

The strength characteristics of soil treated with nickel slag are analyzed in this study, leading to the following conclusions based on the obtained results:

- The clayey soil used in this study is classified as high plasticity organic clay (OH) based on the Unified Soil Classification System (USCS). This classification is derived from soil property tests, where the soft soil used has a specific gravity (Gs) less than 2, is predominantly clay with a percentage greater than 50%, and has a plasticity index (IP) and liquid limit (LL) of 21.73% and 63.92%, respectively.
- Nickel slag plays a significantly influential role in improving the bearing capacity of clayey soil. Based on the results of unconfined compressive strength tests, it is shown that at nickel slag concentrations of 3%, 6%, 9%, and 12%, the unconfined compressive strength values can increase by 87%, 147%, 140%, and 130%, respectively, compared to the original soil. At concentrations of 9% and 12%, there is a decrease in the unconfined compressive strength values. This may be attributed to excessive interactions between nickel slag particles and soil particles, leading to a reduction in soil cohesion.

REFERENCES

- Amhadi, T. S., & Assaf, G. J. (2019). Overview of Soil Stabilization Methods in Road Construction. *GeoMEast 2018* (pp. 21-33). Switzerland : Springer .
- Andrew, R. M. (2017). Global CO2 emissions from cement production. *Earth Syst. Sci. Data Discuss*, 1-52.
- Basha, E. A., Hashim, R., & Muntohar, A. S. (2004). Stabilization Of Clay And Residual Soils Using Cement - Rice Husk Ash Mixtures. *Jurnal Teknik Sipil*, 51-84.
- Carașca, O. (2016). Soil improvement by mixing: techniques and performances. *Energy Procedia* , 85-92.
- Das, B. M. (2013). *Chemical and Mechanical Stabilization. In: Transportation in the New Era Millenium.*
- Das, B. M. (2019). *Advanced Soil Mechanics, Fifth Edition.* London: CRC Press.
- Disfani, M. M., Mohammadinia, A., Narsilio, G., & Aye, L. (2020). Performance evaluation of semi-flexible permeable pavements under cyclic loads. *International Journal of Pavement Engineering*, 336-346.
- Dodson, V. (1990). Pozzolans and the pozzolanic reaction. In: Concrete Admixtures. *Springer*, 120-159.
- ESDM. (2021). *Peluang Investasi Nikel di Indonesia.* Jakarta: Kementerian Energi dan Sumber Daya Mineral.
- Firoozi, A. A., Olgun, C., Firoozi, A. A., & Baghini, M. S. (2017). Fundamentals of soil stabilization. *International Journal of Geo-Engineering*, *8*(26), 1-16.
- Firoozi, A., Olgun, C., Ali Asghar Firoozi, A., & Baghini, M. S. (2017). Fundamentals of Soil Stabilization. *8*(26).

- Harianto, T., Marfu'ah, N., Rauf, I., & Leatemia, T. (2020). Experimental Study of Natural Materials Utilization as a Stabilization Agent on Soft Soil. *IOP Conference Series: Materials Science and Engineering*, 012029.
- Ibrahim, O. A., Çabalar, A. F., & Abdulnafaa, M. D. (2018). Improving Some Geotechnical Properties Of An Organic Soil Using Crushed Waste Concrete. *The International Journal of Energy & Engineering Sciences*, 110-112.
- Janz, M., & Johansson, S. E. (2002). *The Function of Different Binding Agents in Deep Stabilization.* Swedish Deep Stabilization Research Centre.
- Kabeta, W. F., & Lemma, H. (2023). Modeling the application of steel slag in stabilizing expansive soil. *Modeling Earth Systems and Environment , 9*, 4023–4030.
- Kimpraswil, D. P. (2002). *Panduan Geoteknik 4: Pengujian tanah lunak (Pt T 09-2002-B).* Jakarta: Kimpraswil.
- Komang, A. U., Harianto, T., Muhiddin, B., & Arysad, A. (2022). Compressive Strength Characteristics of Trass Stabilized Dredged Soil. *Journal of The Civil Engineering Forum*, 301-308.
- Larsson, R. (1996). Chapter 1 : Organic Soils. In *Development in Geotechnical Engineering* (pp. 4-30).
- Mariri, M., Moayed, R., & Kordnaeij, A. (2019). Stress-Strain Behavior of Loess Soil Stabilized with Cement, Zeolite, and Recycled Polyester Fiber. *Journal Material of Civil Engineering*.
- Menéndez, E., Sanjuán, M. Á., García-Roves, R., Argiz, C., & Recino, H. (2020). Sustainable and Durable Performance of Pozzolanic Additions to Prevent Alkali-Silica Reaction (ASR) Promoted by Aggregates with Different REaction Rates. *Applied Science, doi:10.3390/app10249042*, 1-24.
- Muhammad, R., Syahril, S., Suyono, A., Muchtar, & Sirait, T. (2022). Nilai Kuat Tekan Bebas pada Tanah Lunak yang Distabilisasi Menggunakan Limbah Abu Sekam Padi dan Asam Fosfat. *Potensi: Jurnal Sipil Politeknik, 24*(2).
- Mukramin, S. C., Sompie, O., & Sumampauw, J. (2018). Pengaruh Penambahan Semen, Trass dan Batu Apung Terhadap Kuat Geser Tanah Lempung. *Jurnal Sipil Statik*, 471-480.
- Muntohar, A. S. (2019). Engineering characteristics of the compressed-stabilized earth brick. *Construction and Building Materials, 25*, 4215-4220.
- Navagire, O. P., Sharma, S. K., & Rambabu, D. (2022). Stabilization of black cotton soil with coal bottom ash. *Materialstoday*, 979-985.
- Ouedraogo, E., Coulibaly, O., Ouedraogo, A., & Messan, A. (2015). Mechanical and thermophysical properties of cement and/or paper (cellulose) stabilized compressed clay bricks. *Journal of Materials and Engineering Structures, 2*(2), 68-76.
- Pramudyo, T., Sollu, W. P., Hermawan, W., Defrizal, W. W., Sidarta, B. (2019). *ATLAS : Sebaran Batuan Lmepung Bermasalah di Indonesia.* Bandung: Badan Geologi Kementerian ESDM.
- Raja, K., Venkatachalam, S., Vishnuvardhan, K., Krishnan, R. S. R., Selvan, V. T., & Vetriselvan, N. (2022). A review on soil stabilization using rice husk ash and lime sludge. *Materials Today: Proceedings*, *65*, 1205-1212.
- Rauf, I., Gaus, A., Sultan, M. A., & Heryanto, H. (2023). Analysis And Characterization Of Nickel Industry By-Products As Pozzolan Materials. *Civil Engineering and Architecture*.
- Rauf, I., Samang, L., Harianto, T., & Arsyad, A. (2019). Pengaruh Pemeraman terhadap Nilai Kuat Tekan Bebas Tanah Lempung Stabilisasi Limbah Aspal Buton. *Seminar Nasional Teknik Sipil IX.* Surakarta.
- Rauf, I., Samang, L., Harianto, T., & Arsyad, A. (2020). Compressive strength of lightweight geocomposit soil-EPS stabilized with palm oil-tea fly ash. *Conference Series: Earth and Environmental Science, 419*.
- Rauf, I., Samang, L., Harianto, T., & Arsyad, A. (2020). Correlation of UCS and CBR on Lightweight Geocomposite of Soil-EPS Stabilized by Waste of Buton Asphalt . *Material Science Forum, 998*, 311-316.
- Sadikon, S., & Keria, R. (2023). Soil stabilization using coconut fiber: Experimental on unconfined compressive strength performance. https://doi.org/10.1063/5.0111339.
- Warrick, A. (2002). *Soil Physics Companion. (ed.).* London, New York, Washington: CRC Press LLC. Boca Raton.