Original Article
ISSN (Online): 2350-0530
ISSN (Print): 2394-3629

International Journal of Research - GRANTHAALAYAH
January 2024 12(1), 26–33

BEHAVIOR OF PHYSICAL AND DENSITY PROPERTIES OF SOFT SOIL STABILIZED WITH NICKEL SLAG

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Received 21 December 2023
Accepted 20 January 2024
Published 06 February 2024

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DOI
10.29121/granthaalayah.v12.i1.2024.5485

Funding: This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

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ABSTRACT

Soft soils have become a significant challenge in geotechnical engineering, due to their low bearing capacity and susceptibility to deformation. Chemical stabilization using nickel slag is an alternative solution and is considered more environmentally friendly. This article focuses on the utilization of nickel slag as a binder material aimed at behavior of physical and mechanical properties of soft soil stabilized with nickel slag soft soil. The nickel slag was carried out with variations of 3%, 6%, 9% and 12% by weight of soil. All the test using ASTM procedure in order to gain physical and mechanical value. The results of this study showed that plasticity index decrease with the increasing of slag nickel concentration, where it is an indication of a change in soil consistency, shifting from initially soft to now medium. Futher, the optimum dry density (□d-opt) value of the original soil used was 1.09 gr/cm3, while the optimum dry density (□d) values at 3%, 6%, 9% and 12% nickel slag addition were 1.12 gr/cm3; 1.15 gr/cm3; 1.19 gr/cm3 and 1.22 gr/cm3, respectively. These results show that the presence of nickel slag can increase influence the physical and density properties of soft soil, which indicates that nickel slag has the potential to be used as a stabilization material in soft soil.

Keywords: Soil Stabilization, Soft Soil, Nickel Slag

1. INTRODUCTION

Earthwork is an important part of civil construction, such as roads, bridges, weirs, buildings, etc. However, in reality not all soils have mechanical properties capable of providing a safe base for infrastructure. The inherent variability in soil characteristics necessitates the development of ground improvement techniques to guarantee the safety and service life of construction. Among these techniques, chemical soil stabilization has emerged as a key solution, harnessing the power of chemical additives to alter the properties of soils and make them suitable for construction purposes.

Soil stability is an important factor in determining the overall performance and safety of a structure. Unstable soils can cause a variety of problems, ranging from differential settlement and structural damage to reduced bearing capacity and increased risk of foundation failure Das (2019). Conventional soil stabilization methods, such as mechanical compaction and soil replacement, have limitations, especially when dealing with problematic soil types such as expansive clay or loose sand Amhadi & Assaf (2019). Chemical soil stabilization, on the other hand, presents a more effective approach and provides significant leverage in addressing the challenges of improving soil properties in a controlled manner.

In principle, chemical stabilization efforts can reduce soil pores through the bonding of binder particles with soil material Firoozi et al. (2017). The volume of pores in the soil decreases in line with the drying process which results in reduced pore numbers and soil permeability values. This is why chemical stabilization efforts have a higher and significant resistance to increasing soil bearing capacity Mariri et al. (2019). This soil cementation mechanism will then increase the density and strength of the soil in receiving loads, thus meeting technical requirements, especially in road foundation construction. Dodson (1990) explains that the mechanism of increasing soil bearing capacity occurs through pozzolanic reactions and hydration, which are well-known reactions among calcium hydroxide alumina and/or silica and water. The final products of these reactions depend on the content of the available silica and alumina, which can be calcium aluminate hydrate, calcium silicate hydrate and calcium aluminoslica hydrate.

Cement and lime are the most commonly used materials as stabilization materials, however, the use of these two materials has a major impact on the environment because the manufacturing process produces a very large amount of carbon gas. Therefore, the development of material engineering currently leads to the use of natural materials or industrial waste that is pozzolanic in nature as an alternative stabilization material in soft soil.

The ASTM 593-82 standard classifies pozzolanic materials based on their source, namely: (a) natural pozzolan is a material derived from volcanic materials containing active silica, such as: trass, pumice, perlite, and (b) artificial pozzolan which is a material derived from combustion products, such as: fly ash, sediment ash, slag, etc. Soil stabilization engineering that utilizes pozzolan has been widely done, such as: utilization of natural pozzolan in the form of trass Komang et al. (2022), in the form of overboulder and zeolite Harianto et al. (2020). Furthermore, the utilization of artificial pozzolan has been presented by several researches, such as: the utilization of button asphalt waste Rauf et al. (2020), the use of coal bottom ash Navagire et al. (2022).

The increasing need for nickel has encouraged the development of the nickel industry in various countries, including Indonesia. North Maluku is one of the provinces with the second largest nickel reserves in Indonesia. Nickel processing produces by-products such as slag, fly ash, sedimentary ash and nickel sludge. These by-products have great potential to be used as stabilization material in soft soil, because they have pozzolanic properties. The results of XRF and XRD testing on nickel slag material from Obi Island show that this nickel slag material has a mineral content of SiO2 of 44.89%, Fe2O3 of 25.11%, MgO of 20.27% and CaO of 3.34% Rauf et al. (2023). The mineralogical content dominated by silica indicates that this material is pozzolanic, so that nickel slag can be used as a stabilization material for the soft soil.

This research aims to analyze the effect of nickel slag used as stabilization material on clay soil. The effect of nickel slag variation as stabilization material is based on the change of clay density value while still considering the value of its physical characteristics.

2. MATERIAL AND METHODS

2.1. MATERIALS QUARRY

The soil samples used in this study are soft clay soils taken from Subaim village, which is administratively located in East Halmahera Regency, North Maluku Province. This is based on the mapping of the distribution of problematic clay soils that has been carried out by the Indonesian Ministry of Energy and Mineral Resources. Meanwhile, the nickel slag material that will be used as stabilization material, it is obtained from the nickel processing industry where located on the island of Obi which is included in the administrative area of South Halmahera Regency. The visualization of each materials used and their quarry presented in Figure 1.

Figure 1

Figure 1 Visualization of Samples and Materials Quarry in North Maluku.

2.2. SAMPLES PREPARATION

The initial stage of sample preparation is the drying process where the clay and nickel slag are dried under the sun. This is done to ensure that there is no change in the chemical structure of the soil material and nickel slag due to excessive heating. For uniformity of material granules, the soil used is soil that has been filtered and passed the No. 40 sieve. The nickel slag in the form of granules is mashed using a grinding machine and filtered using a No. 200 sieve to be used as a stabilizing material, because the size of the gradation greatly affects the reactivation of the binder material Janz & Johansson (2002).

In this study, the examination of the physical characteristics of clay soil was carried out using tests which included: Water Content Test with ASTM D-2216 method, Specific Weight Test with ASTM D 854-58 method, Atterberg Limits Test with ASTM D 4318-95 method, Grain Analysis Test with ASTM 422-72 and ASTM D 1140-54 methods. Meanwhile, The Soil Density Test uses the standard proctor method which refers to ASTM D1557. The compaction technique plays a crucial role in affecting the gravimetric and volumetric characteristics of a remoulded specimen, such as mass density and porosity. These structural variances can lead to distinctions in the soil's mechanical performance Disfani et al. (2020).

The percentage of nickel slag used varies from 3%, 6%, 9% and 12%, which is based on the original soil weight ratio, this is based on the opinion that the addition of additives above 15% is not cost efficient. Before making the compacted test specimens, the soil and nickel slag that had been pulverized were mixed and put into a plastic bag to cure for 24 hours for homogeneous water distribution Basha et al. (2004). After that, the test specimens were made by mixing water into the mixed matrix by adding water little by little and stirring for 10 minutes until the mixture was homogeneous Carașca (2016). At the final stage, the mixed matrix was put in a mold and compaction was carried out based on the standards used.

3. RESULTS

3.1. PHYSICAL CHARACTERISTICS OF NICKEL SLAG STABILIZED CLAY SOIL

The results of testing the physical properties of clay soil before and after stabilization efforts are shown in Table 1. Based on the sieve analysis, it shows that the soil used is a clay material with a percentage of 72%. The specific gravity (Gs) of the clay used has a value of 1.64, while the Gs of nickel slag is 2.87. From mixing these two materials, the specific gravity for the 3%, 6%, 9% and 12% variations were 1.23, 1.22, 1.21 and 1.20, respectively. These results certainly explain that the addition of nickel slag to soil will reduce its specific gravity and the amount depends on the percentage of nickel slag material added.

Table 1

Table 1 Physical Properties of Nickel Slag Stabilized Soil

Physical Characteristics	Value				
	0%	3%	6%	9%	12%
Specific gravity (Gs)	1.87	2.12	2.34	2.36	2.38
Optimum moisture content (wopt, %)	36.08				
Sieve Analysis					
• Sand (%)	8				
• Silt (%)	14				
• Clay (%)	78				
Atterberg Limits					
• Liquid Limit (LL)	63.92	61.63	59.31	57.25	54.26
• Plastic Limit (PL)	42.16	44.95	47.29	48.13	48.13
• Plasticity Index (PI)	21.73	16.69	12.02	8.86	6.38

Figure 2

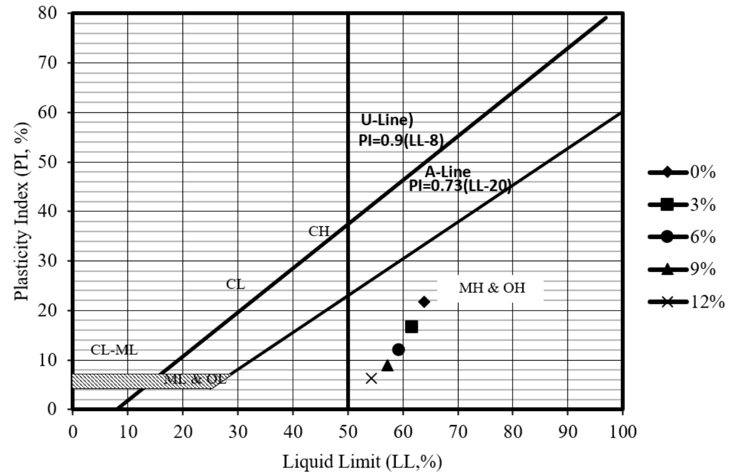

Figure 2 Classification of Clay Based on Casagrande Diagram

From the values of the Atterberg limits, the clay soil used in this study can be grouped based on the USCS (Unified Soil Classification System) classification. This determination is based on the plasticity index (PI) and liquid limit (LL) values plotted on the Casagrande soil classification diagram, where for a PI value of 21.73 and an LL value of 63.92, the clay soil used is organic clay soil with high plasticity, as shown in Figure 2. In addition, the results of this test also show that the variation of nickel slag addition affects the values of the Atterberg limits on clay soil. The addition of nickel slag at 3%, 6%, 9% and 12% affected the plasticity index values of the mixture matrix by 16.69; 12.02; 8.86; and 6.38, respectively. Thus, it can be stated that the presence of nickel slag in clay soil will reduce its plasticity index.

3.2. DENSITY VALUE OF NICKEL SLAG STABILIZED SOIL

The results of testing the density of clay materials without and with the addition of nickel slag are shown in Figure 3. In general, it can be seen that the presence of nickel slag as a stabilizing material in soft soil affects the absorption of moisture content in clay soil, where the higher the percentage of nickel slag, the higher the density value of the mixed material obtained. In the nickel slag variation, the optimum dry soil density is in the range of 30% - 36% moisture content.

Figure 3

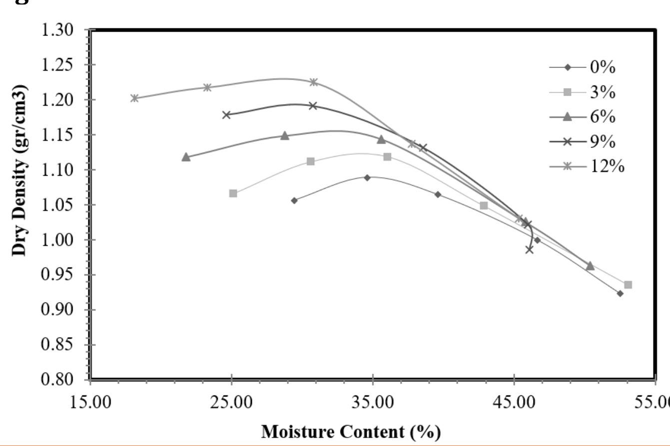

Figure 3 Relationship Between Dry Density and Moisture Content

The relationship between the percentage of nickel slag content added to the clay soil is shown in Figure 4. These results indicate that the dry density characteristics (γ_{dry}) of the soil and nickel slag mixture matrix continue to increase, where for nickel slag content of 3%, 6%, 9% and 12% resulted in dry density values (γ_{dry}) of 1.12 gr/cm^3; 1.15 gr/cm^3; 1.19 gr/cm^3 and 1.23 gr/cm^3 respectively. These values illustrate that the presence of slag as a stabilizing agent in organic clay soil with high plasticity, has not significantly increased the density value of the mixed material.

Figure 4

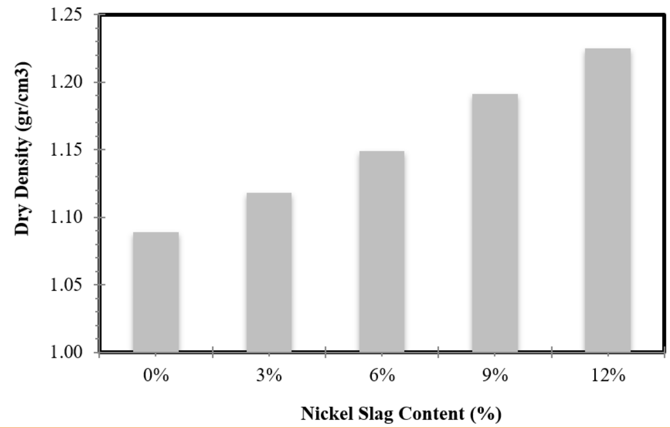

Figure 4 Relationship Between Percentage of Nickel Slag and Dry Density

4. DISCUSSIONS

The overview of the results presented generally shows that nickel slag has the potential to be developed as an alternative material in soft soil stabilization efforts. In this study, the clay soil obtained from Subaim village has sand, silt and clay fractions of 8%, 14% and 78%, respectively. Based on the PI and LL values, the soil is classified as organic clay with high plasticity (OH). The technical characteristics of this material are generally low bearing capacity, easy deformation and high permeability Larsson (1996), where the amount of water absorption is the main factor affecting its mechanical properties. The high-water absorption in organic clay materials is due to the fibrous structure of the organic material which contains more voids within its internal structure, thus having a high-water absorption capacity Warrick (2002).

Stabilization efforts made through the use of nickel slag waste in this study showed changes in the physical and mechanical characteristics of the soil - slag matrix. The results obtained at the Atterberg limits showed a decrease in the liquid limit (LL) between 3.46% - 11.64% and plasticity index (PI) between 14.83% - 82.61%, while the plastic limit (PL) value increased between 3.45% - 7.96%. The effect of nickel slag on the change of Atterberg limits is a physical compensation between the ratio of plastic organic soil and non-plastic nickel slag material, which is similar to sand or gravel. In addition, the addition of nickel slag to the clay soil used can increase the dry density values varying between 2.66% - 12.47% depending on the nickel slag content used, which of course is the result of changes in the physical properties of the matrix of the soil mixture with nickel slag.

5. CONCLUSIONS

This study aims to determine the possibility of improving the geotechnical properties of organic soil by using by-products of the Nickel Processing Industry, in the form of crushed nickel slag. Based on the results obtained, there are several important points that can be concluded, namely: The liquid limit (LL) and plasticity index (PI) of organic soil decrease as the percentage of nickel slag used increases, which is shown in the change in soil classification. Changes in the physical properties of soil certainly affect its mechanical properties, where in this study an increase in nickel slag content can increase the maximum dry density of organic soil and cause the percentage of development to increase to a certain extent, then begin to decline.

CONFLICT OF INTERESTS

None.

ACKNOWLEDGMENTS

None.

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