JTSE
JOURNAL OF TRANSACTIONS IN SYSTEMS ENGINEERING

Journal of Transactions in Systems Engineering
https://journals.tultech.eu/index.php/jtse
ISSN: 2806-2973
Volume 2, Issue 3
DOI: https://doi.org/10.15157/jtse.2024.2.3.316-324
Received: 14.09.2024; Revised: 20.10.2024; Accepted: 01.11.2024

TULTECH

Research Article

The Influence of Clay Soil Stabilization Using Nickel Slag on Unsoaked CBR Values

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Abstract

The subgrade soil is the most critical layer in road pavement structures, serving as the foundation supporting traffic loads. The strength of this subgrade also influences the required thickness of the pavement layers. In many road construction projects, the subgrade soil often exhibits a California Bearing Ratio (CBR) of less than 5%, indicating low bearing capacity and high swelling potential, necessitating soil stabilization. Nickel slag, a by-product of ferronickel smelting, contains high levels of silicate and lime, making it a suitable additive for soil stabilization. This study investigates the effect of nickel slag on soil characteristics by utilizing four different variations of slag content: 0%, 15%, 30%, and 45%, based on the dry weight of the soil. The soil samples were cured for 0, 3, and 7 days and subjected to liquid limit, plastic limit, and unsoaked CBR testing. According to the Unified Soil Classification System (USCS), the soil was classified as organic clay with medium to high plasticity (OH). The test results revealed that the unsoaked CBR value of the untreated soil was 2.9%. Upon stabilization, the maximum unsoaked CBR value increased to 22.65% with the addition of 45% nickel slag. Furthermore, the soil's plasticity index decreased from 18.25% to 8.64%, significantly reducing the soil's shrinkage potential. Nickel slag has proven to be an effective additive for enhancing subgrade soil properties, improving its bearing capacity, and reducing plasticity, making it a viable option for road pavement stabilization.

Keywords: Clay, stabilization, nickel slag, USCS, CBR.

INTRODUCTION

Infrastructure development in Indonesia, particularly in road construction, is rapidly increasing. According to the Medium-Term Development Plan (2019-2024), improving transportation connectivity between regions and boosting the economy are top priorities [1]. The development of road infrastructure in Indonesia requires very large raw materials and natural materials, yet it has not started using raw materials and materials from recycling or reusing waste or by-products from factory processing. To support the reduction of waste volume and environmentally friendly solutions in the long term, research is needed on using raw materials and by-products from factory processing as a substitute for conventional materials. Indonesia has nickel resource reserves reaching

5,325,790,841 tons of ore, with the realization of Indonesian nickel ore production throughout 2023 of 175,617,183 tons [2]. And contributes 50% of nickel production in the world. Indonesia has great potential in the availability of nickel and has a large factory in nickel processing in the world. Of course, every nickel processing in the factory produces waste or processed residue from nickel, one of which is nickel slag.

The Nickel Processing Company in Banten is located in Cilegon City named PT XYZ, which produces Nickel Pig Iron products used as raw materials for vehicles and batteries. In addition to making the desired products, there is waste and by-products from the nickel processing process, one of which is nickel slag as can be seen in Figure 1.

Figure 1. Nickel Slag Pile

According to the Ministry of Industry of the Republic of Indonesia, in 2019, nickel slag production reached 13 million tons per year [3]. This condition is very dangerous for the environment related to waste generated from nickel processing, so it is necessary to reuse waste generated from nickel processing, one of which is nickel slag.

Nickel slag has chemical components including SiO_2, MgO, and Fe_2O_3, and its mineral components are forsterite, ferroan, clinoenstatite, eckermannite and quartz [4]. SiO_2 affects soil stabilization, which can increase the bearing capacity of the soil, so it is suitable for use in improving poor soil. In road construction, there are various conditions of the base soil found in Indonesia, from hard base soil to soft base soil with a CBR value of less than 4%, one of which is at the location of "Jalan" in "Pandeglang Regency", where the condition of the subgrade soil has a CBR value of 3.275% so that the subgrade soil has poor soil bearing capacity and improvements are needed to the subgrade soil to increase the CBR value of the base soil.

Several variations of nickel slag were added to the subgrade soil to determine changes in the physical properties and CBR value of the subgrade soil so that it can be used according to the requirements of road paving work. The addition of nickel slag variations is 0%, 15%, 30%, and 45% based on the dry weight of the original soil, nickel slag is mixed with soil with a sample soaking time of 0, 3, and 7 days and CBR unsoaked testing is carried out according to the soaking time of the soil test sample, this is done to determine changes in the soil due to the influence of the addition of nickel slag

MATERIALS AND METHODS

Nickel slag material was obtained from PT XYZ in Cilegon city, see Table 1. PT XYZ nickel slag has the most dominant chemical compound composition being SiO_2 (40.39%), MgO (18.66%) and CaO (16.34%) [4].

Table 1. Chemical Compound Composition of Nickel Slag [4]

Chemical Parameter	Test Results
SiO_2	40,39%
Al_2O_3	6,13%
Fe_2O_3	8,86%
K_2O	0,13%
CaO	16,34%
MgO	18,66%
Na_2O	0,06%
Cr_2O_3	1,11%
LoI	5,4%
MnO	0,65%

SiO_2, CaO, Al_2O_3, and Fe_2O_3 are compounds that influence the cement-making process; these compounds play a role in determining the strength of mortar [5], so they can be applied to the soil stabilization process to increase the bearing capacity of the soil and the binding material between soil grains. The nickel slag that is taken is then ground and sieved using sieve No. 100; the nickel slag powder used is that which passes sieve No. 100. The soil used in this study is soil that has been tested in the field using the DCP test, which has a CBR value of 3.275%. Soil collection is carried out using the disturbed soil collection method; the soil is hoed put into a sack and taken to the laboratory. After being taken to the laboratory, the soil is dried to reduce the water content stored in the soil, as shown in Figure 2.

(a) (b)

Figure 2. (a)-Nickel slag powder passing through No. 100 sieve, (b)-Soil

Physical testing of the original soil is carried out to obtain information about the characteristics of the soil being tested; physical testing of the original soil includes soil water content test [5], soil specific gravity [6], grain size analysis [7], soil liquid limit, soil plasticity and soil plasticity index [8].

After the physical testing of the original soil is carried out, then a standard compaction test is carried out [9] to obtain the optimum soil water content value and the dry weight value of the soil where both of these data are very important as a reference for the addition of nickel slag according to the addition of the specified variations.

Making test samples by mixing the original soil with nickel slag variations based on the dry weight of the original soil, with the optimum water content of the original soil, which after being mixed, then makes the Unsoaked CBR test sample [10] after making the CBR test sample according to the specified variation and curing time, continued by inserting the CBR mould containing the soil into plastic and tying it stored in a safe place with room temperature as shown in Figure 3. CBR testing is carried out according to the specified curing time.

(a) (b) (c)

Figure 3. (a)-CBR Test Sample Variation A, curing period 0 days, (b)-CBR Test Sample Variation A, curing period three days, (c)-CBR Test Sample Variation A, curing period seven days.

In addition to the CBR test based on the curing time, there are other tests, namely the soil density test, Liquid Limit, and Plastic Limit. These tests determine changes in the physical characteristics of the soil after the addition of nickel slag as can be seen in the Table 2.

Table 2. Variations in the addition of Nickel Slag

Nickel Slag Mixture Variation %	Tests were carried out based on curing time (0,3,7) days
A (0%)	CBR
B (15%)	CBR
C (30%)	CBR
D (45%)	CBR

EXPERIMENTAL RESULTS

The results of the physical testing for the original soil can be shown in Table 3.

Table 3. Results of physical testing of the original soil

Testing	Value
Specific gravity (Gs)	2,61
Water content (w)	32,45%
Liquid Limit (LL)	61,19%
Plastic limit (PL)	42,93%
Plastic Index (PI)	18,25 %

From the results of the sieve analysis test, where the results of the sieve passing test on sieve No. 200 are greater than 50%, then from the data in Table 3 according to the USCS soil classification standard, it can be concluded that the soil tested is organic clay OH soil with moderate to high plasticity. Soil specific gravity (Gs) testing to determine the mass density of soil grains or particles is the ratio between the weight of soil grains and the weight of distilled water in the air with the same volume at a certain temperature. The original soil-specific gravity test obtained a Gs value = 2.61. In the soil-specific gravity test, the liquid limit (LL) and plastic limit due to the addition of nickel slag variations are shown in the Table 4.

Table 4. Results of physical testing of the original soil

Nickel Slag Mixture Variation %	Specific gravity (Gs)	Liquid Limit (LL)%	Plastic Limit (PL)%	Plastic Index (PI)%
A (0%)	2,61	53,51	42,93	18,25
B (15%)	2,76	51,17	40,36	16,99
C (30%)	2,98	49,03	35,46	13,57
D (45%)	3,03	40,22	31,58	8,64

In Table 4, the addition of nickel slag variations to the soil can increase the soil density value. Based on the analysis results, it can be concluded that the addition of nickel slag can increase the density. This is because nickel slag has a density greater than the soil density, which is 3.03. This means that the addition of nickel slag will increase the mass of grains in the stabilized soil, making it denser and heavier.

The results of the liquid limit test in Table 4 tend to decrease with increasing percentage of nickel slag variation mixture; from the graph, it can be seen that the more nickel slag added, the value of the liquid limit decreases. The decrease occurs because the soil undergoes cementation so that the soil grains become larger, which causes the attractive force between particles to decrease and is able to reduce water absorption in the soil [11].

The plastic limit is the minimum water content of a soil sample in a plastic state where the water content transitions from a semi-solid condition to a plastic condition. From the results of the plastic limit test in Table 4, the plastic limit value was obtained at 42.93% in soil that had not been added with nickel slag; after addition of nickel slag with several variations, the soil plasticity value decreased by 31.58% for Variation D. The Plasticity Index (PI) value decreased from 18.5% to 8.64% after the addition of nickel slag variation D, this condition explains that the soil before being given nickel slag additives has high cohesive properties where the number of clay particles in the soil is very large but after adding nickel slag variation D the soil PI value decreased indicating that there was a reduction in water content in the soil due to the cementation process of nickel slag chemicals with water (SiO_2 and CaO). The effect of CaO contained in nickel slag produces a binding material through a chemical reaction that produces a hydrated gel and a combination of soil particles [12]. A new compound of calcium silicate hydrate is formed as a pozzolanic reaction and then crystallizes to bind the structure together [13].

CBR Unsoaked Testing (0,3,7) Days Curing

After the test specimens were prepared and cured, unsoaked CBR testing was conducted, as shown in Figure 4.

(a) (b) (c)

Figure 4. (a) Compaction of CBR samples; (b) and (c) Unsoaked CBR Testing

The following is a recapitulation of the CBR test results at percentages of 0%, 15%, 30%, and 45% for 0, 3, 7 days of curing as can be seen in Table 5.

Table 5. Unsoaked CBR value of curing results (0,3,7) days

No	Nickel Slag (%)	Nilai CBR Unsoaked (%)		
		0 days	Three days	7 days
1	0	2,9	3,85	5,41
2	15	11,3	12,4	14,1
3	30	14,5	15,3	16,85
4	45	17,55	19,25	22,65

The highest CBR value was obtained from the test results, namely in a mixture of 45% nickel slag, with an average CBR value of 22.65%. Figure 5 depict the change in CBR value due to the addition of nickel slag based on the curing time.

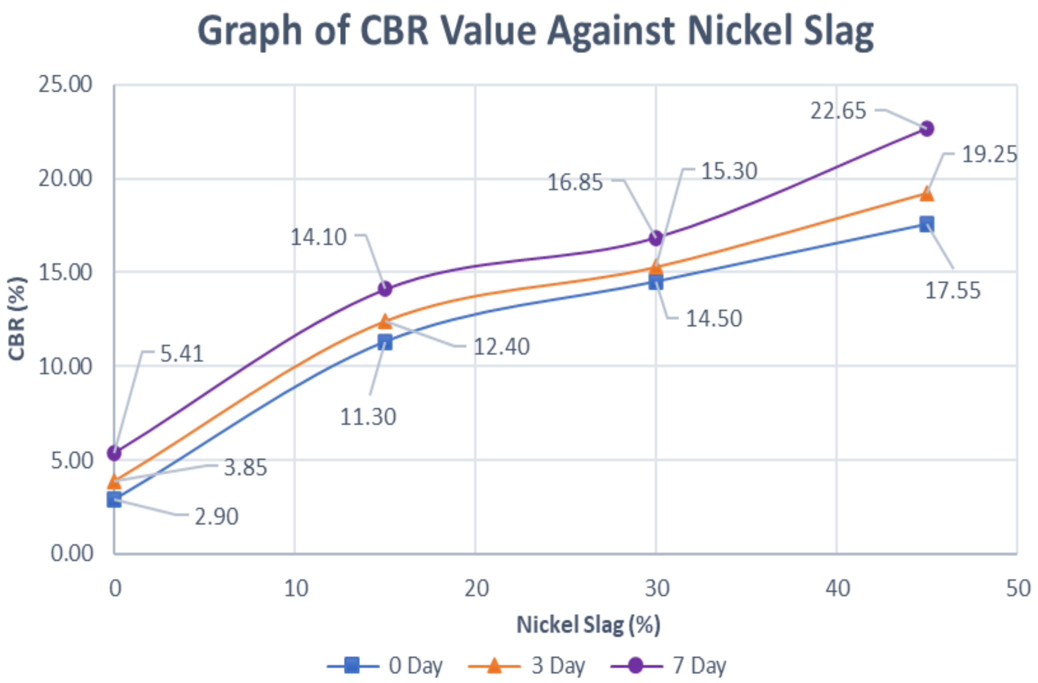

Figure 5. Comparison of the Percentage of Added Materials from the CBR Value at 0.3 and 7 days of curing

Nickel slag is a material that contains cement. Nickel slag is included in the pozzolan category, namely materials containing Silica (SiO_2) and Alumina (Al_2O_3) [14]. Pozzolan does not have the ability to bind unless it reacts with water or a mixture of lime water[15]. Therefore, the addition of nickel slag, soil, and water to the sample can increase the CBR value. As in the CBR value without the addition of nickel slag of 2.90% to 11.30% with the addition of 15% nickel slag (curing for 0 days).

In addition to the effect of adding nickel slag to the sample, the curing duration can also affect the CBR value. This is because this process will affect the water content contained in the soil and affect the characteristics of the soil, which is expected to help reduce the water content at the liquid limit and improve the characteristics of the soil [16], so that it becomes denser and stronger. Like the design CBR value with the addition of 15% nickel slag, at 0 days of curing the CBR value is 11.3% to 14.10% at 7 days of curing. Based on the test results in this study, it can be concluded that nickel slag can be used as a base soil stabilization material [17]. Because the CBR value increased to 22.65% with the addition of 45% nickel slag with 7 days of curing, which exceeds the CBR value required by the Road Pavement Design for base soil, which is greater than 6%.

CONCLUSION

Based on the results of this research work, which involved soil samples stabilized with nickel slag as an additive and cured for 0, 3, and 7 days, the following conclusions can be drawn:

- According to the Unified Soil Classification System (USCS), the soil is classified under the OH group, representing inorganic clay with high plasticity. The untreated soil had a plasticity index (PI) of 18.25%. The addition of nickel slag significantly reduced the PI, with a decrease to 8.64% observed when 45% nickel slag was added.
- The use of nickel slag also improved the California Bearing Ratio (CBR) value of the soil. The untreated soil had a CBR value of 2.9%, placing it in the 'very poor' category with CBR values between 0-3%. After the addition of 45% nickel slag and a curing period of 7 days, the CBR increased to 22.65%, elevating the soil to the 'good' category with CBR values between 20-50%.

These findings suggest that nickel slag is an effective additive for soil stabilization, meeting the required standards for subgrade soil in road pavement construction, as indicated by the improved CBR values.

CONFLICT OF INTERESTS

The authors declare that there is no conflict of interest associated with the publication of this study.

REFERENCES

1. Verico, K., Wibowo H., Yudhistira M.H. Infrastructure for Inclusive Economic Development Volume 2: Case Studies of Accelerated Projects. *Economic Research Institute for ASEAN and East Asia and Ministry of Finance*, Indonesia, **2024**. pp. 1-296.
2. Decree of the Minister of Energy and Mineral Resources Number 132.K/GL.01/MEM.G/2024 Concerning the Balance of National Mineral and Coal Resources and Reserves in 2023. Available online: https://geologi.esdm.go.id/publikasi/laporan-dan-buku/keputusan-menteri-energi-dan-sumber-daya-mineral-nomor-132-k-gl-01-mem-g-2024-tentang-neraca-sumber-daya-dan-cadangan-mineral-dan-batubara-nasional-pada-tahun-2023. (accessed on August 14 2024).
3. Ministry of Industry Raises Potential of Nickel Slag as Industrial Raw Material. Available online: https://www.kemenperin.go.id/artikel/21806/Kemenperin-Angkat-Potensi-Slag-Nikel-Jadi-Bahan-Baku-Industri. (accessed on August 14 2024).
4. Susanto, I., Irawan R.R. and Hamdani, D. Nickel slag waste utilization for road pavement material as strategy to reduce environmental pollution. *E3S Web of Conferences*, **2020**; 202; 05003.
5. ASTM D2216-98. *Standard test method for laboratory determination of water (moisture) content of soil and rock by mass*. Annual Book of ASTM Standards, West Conshohocken, PA, USA, **1998**.
6. ASTM D854. *Standard test methods for specific gravity of soil solids by water pycnometer*. Annual Book of ASTM Standards, West Conshohocken, PA, USA, **2014**.

7. ASTM D422. *Standard test method for particle-size analysis of soils*. Annual Book of ASTM Standards, West Conshohocken, PA, USA, **2007**.
8. ASTM D4318. *Standard test methods for liquid limit, plastic limit, and plasticity index of soils*. Annual Book of ASTM Standards, West Conshohocken, PA, USA, **2010**.
9. ASTM D698. *Standard test methods for laboratory compaction characteristics of soil*. Annual Book of ASTM Standards, West Conshohocken, PA, USA, **2012**.
10. ASTM D1883-07E2; *Standard test method for CBR (California bearing ratio) of laboratory-compacted soils*; Annual Book of ASTM Standards, West Conshohocken, PA, USA, **2007**.
11. Laksono, H. and Rusdiansyah R. The Effect of Nickel Slag Addition on The California Bearing Ratio (CBR) Value of Soaked Laterite Soils in Central and South Kalimantan Provinces. *Revista Ciencia y Construcción*, **2022**; 3(2); pp. 38-47.
12. Koslanant, S., Onitsuka, K. and Negami, T. Influence of salt additive in lime stabilization on organic clay. *Geotechnical Engineering,* **2006**; 37(2); p. 95
13. Rogers C.D.F. and Glendinning S. Improvement of clay soils in situ using lime piles in the UK. *Engineering Geology,* **1997**; 47(3); pp. 243–257.
14. Wu, Q., Wu, Y., Tong, W. and Ma. H. Utilization of nickel slag as raw material in the production of Portland cement for road construction. *Construction and Building Materials,* **2018**, 193; pp. 426–434.
15. McCarthy, M.J. and Dyer, T.D. Pozzolanas and pozzolanic materials. *Lea's Chemistry of Cement and Concrete*, **2019**; 5; pp. 363–467.
16. Gaus, A., Rauf, I., Siregar, F. and Heryanto H. Proximity Porosity and Crystallinity Analysis as Clay/Nickel Slag Characteristics for Material Stabilization Application. *Trends in Sciences,* **2024**; 21(8); 7970.
17. Li, B., Liu; Z., Sun, Q. and Yang, L. Preparation of alkali-activated nickel slag-based cemented tailings backfill: Workability, strength characteristics, localized deformation and hydration mechanism. *Construction and Building Materials*, **2024**, 411, 134639.