Overview the local barrow material of nickel slag mixture as an aggregate foundation layer

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Abstract. Southeast Sulawesi Province has numbered material sources, used as barrow to meet road infrastructure needs. Nickel slag production was a waste material of the nickel mining manufacture carry on to growth in this province. This research is one of the exertions to use waste nickle mining manufacture by mixing local barrow material. The mixture of materials is expected to meet specification of pavement layer for road constructions. This research uses quarry sirtu material in Nanga-Nanga and Lasolo Villages as foundation layer material. The method used is an experimental method on the form of gradation, compaction of modified proctor and CBR test. The result showed that the barrow material with nickel slag composition to material from Nanga-Nanga was 60:40 and Lasolo 50:50 met the grade specification as B class foundation material. Base on the AASHTO classification, this material mixture was included within the A1 category. According to CBR test result with unsoaked compaction conditions, Lasolo material has a CBR value of 26.83% dan Nanga-Nanga material reaches 61.78%. The mixture of material Lasolo is not good enough to be used as a highway barrow material. Whereas mixture Nanga-Nanga with nickel slag is applicable for highway capping layer material.

1. Introduction
Nickel slag is granular slag, which is formed by natural cooling or water quenching from the melt formed during the smelting process of nickel metal, which contains FeO, SiO2, Al2O3 and MgO is the main ingredient component [1]. Based on data, the amount of nickel slag production in Indonesia currently reaches 13 million tons for each year and have a great potential to be used as raw material for cement, construction, road infrastructure or recycled as raw material for steel [2]. Southeast Sulawesi Province has few nickel mining locations and the production of nickel slag as waste material for the nickel mining industry continues to increase. In addition, this area has several sources of embankment material that are used to meet road infrastructure needs. One of the efforts to utilize this waste is by mixing nickel slag with local barrow as an effort to improve material quality.

Multiple authors in some publications indicated that Copper Slag possibly in possession of the suitable engineering properties for use as a replacement for natural sand in some geotechnical uses [3]. To make effective use of nickel slag, it is necessary to carry out few engineering properties’ tests on soil mixing compositions. This is to obtain a mixing composition that meets technical requirements. Saha (2017) stated that the grain size distribution of nickel slag is suitable for use as the fine aggregate in concrete. The optimum level of sans substitute by ferronickel slag is 50% for increasing the compressive strength of mortar [4]. The author conducted experiments in the laboratory by mixing local stockpile material and nickel slag from two different locations. This study aimed to determine the composition and gradation of mixing local materials and nickel slag that meet the specifications of road barrow material.
2. Literature review

2.1. Grain size
The size of the soil grains rides the diameter of the soil particles that make up the soil mass. The examination of grain size in the laboratory is carried out in two ways, namely sieve analysis. Sieve analysis is performed for coarse-grained soils that are held by sieve No. 200. The embankment material meets the AASHTO M147-65 2012a and 2012b standard specifications according to the following Table 1 below.

| Sieve designation (Standard) (mm) | Mass percentage passing |
|----------------------------------|-------------------------|
| 2 in                             | 100                     |
| 1 in                             | 100                     |
| 3/8 in                           | 75 – 95                 |
| No. 4 (4.75)                     | 30 – 65                 |
| No. 10 (2.00)                    | 20 – 45                 |
| No. 40 (0.425)                   | 15 – 30                 |
| No. 200 (0.075)                  | 5 – 20                  |

2.2. Plasticity
Plasticity is a property of soil due to containing clay, which describes the ability of the soil to adapt to changes in shape at a constant volume without cracking. The Atterberg limit in Figure 1 shows the relationship between variation in moisture content and total soil volume under conditions of liquid limit, plastic limit and shrinkage limit. The plasticity index (PI) is the water content interval where the soil is still flexible, which is useful for soil identification and classification. If the soil has a high IP, then the soil contains a lot of clay grains. This condition affects the value of the stress and strain values of the soil mass.

2.3. Soil Classification
The Unified Soil Classification System (USCS) and the American Association of State Highway and Transportation Officials (AASHTO) are used in this study. The USCS classification method is carried out by calculating C_u (coefficient of uniformity) and C_c (coefficient gradation) suing the equation (1) – (2). The summary of USCS system is depicted in Table 2 and Figure 2.

[Table 1. Leveling requisites for soil-aggregate materials [5].]

| Sieve designation | Mass percentage passing |
|-------------------|-------------------------|
| Standard (mm)     |                         |
| 2 in              | 100                     |
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| 3/8 in            | 75 – 95                 |
| No. 4 (4.75)      | 30 – 65                 |
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[Figure 1. Evolution of Atterberg Limit in variation of moisture content [6].]
\[ C_u = \frac{D_{60}}{D_{10}} \]  

\[ C_c = \frac{(D_{30})}{(D_{60})(D_{10})} \]  

$D_{10}$ is defined as 10% of the total grain weight with a diameter smaller than certain grain size. Other measures, such as $D_{10}$, $D_{60}$, and $D_{10}$, are defined in the same way. Where, the values of $D_{10}$, $D_{10}$, and $D_{60}$, are known from the graph of the relationship between the percentage of grains that pass through the filter (%) and the size of the grains (mm).

**Table 2. Unified Soil Classification System** [7].

| Criteria for assigning grouping representations | Group symbol |
|-----------------------------------------------|--------------|
| Gravels More than 50% of coarse fraction retained on No. 4 sieve | Clean gravels Cu≥4 and 1≤Cc≤3 | GW |
| | Less than 5% fines$^a$ Gravel with fines More than 12% fines$^{ab}$ | Cu<4 and/or 1>1Cc>3 PI<4 or plot below “A” line (Fig.2) PI>7 or plot above “A” line (Fig.2) | GM GC |
| Gravels 50% or more of coarse fraction passes on No. 4 sieve | Clean sands Cu≥6 and 1≤Cc≤3 | SW |
| | Less than 5% fines$^b$ Gravel with fines More than 12% fines$^{bc}$ | Cu<6 and/or 1>1Cc>3 PI<4 or plot below “A” line (Fig.2) PI>7 or plot above “A” line (Fig.2) | SM SC |
| Silts and clays Liquid limit less than 50 | Inorganic PI>7 or plot above “A” line$^d$ (Fig.2) | CL |
| | Organic LL oven/not dried <0.75 | ML OL |
| Silts and clays Liquid limit less than 50 | Inorganic PI plots on or above “A” line (Fig.2) | CH |
| | Organic LL oven/not dried <0.75 | MH OH |

$^a$Gravels with 5 to 12% fine need dual symbols: GW-GM, GW-GC, GP-GM, GP-GC

$^b$Sands with 5 to 12% fine need dual symbols: SW-SM, SW-SC, SP-SM, SP-SC

$^c$If 4≤Pl≤7 and plots in the hatched area in Figure 2, use dual symbolization: GC-GM or SC-SM

$^d$If 4≤Pl≤7 and plots in the hatched area in Figure 2, use dual symbolization: CL-ML

Soil is well-graded if it has a gradient coefficient of 1<Cc<3 with $C_u>4$ for gravel, and $C_u>6$ for sand [8]. Soil is said to be very well graded, if $C_u>15$.

**Figure 2.** Plasticity chart for classification according to USCS [6].
The AASHTO classification system divides land into 8 groups, A-1 to A-7 including sub-groups of land, as shown in Table 3 and Figure 3. Each group is evaluated against the group index calculated by empirical formulas and Atterberg limits. The group index (GI) is used to further evaluate the soils in the group, using equations (3).

\[
GI = (F_{200-35}) [0.2 +0.005 (LL-40)] + 0.01 (F_{200-15}) (PI-10)
\]  

(3)

F200 = percentage passing through the sieve no. 200, LL = liquid limit and PI = plasticity index. If the group index (GI) is high, the land uses less accuracy. Granular soils are classified into A-1 to A-3. Soil A-1 is a well-graded gravel soil, while A-3 is granular soil (less than 35% passes sieve No. 200), but still contains silt and clay. Fine-grained soils are classified from A-4 to A-7, namely clay-silt soils.

**Table 3. Type of road subgrade materials by AASHTO classification system [9].**

| General Classification | Granular materials (35% or less total sample passing No. 200) | Silty-clay materials (more than 35% of total sample passing no. 200) |
|------------------------|-------------------------------------------------------------|---------------------------------------------------------------------|
| Group classification   | A-1 | A-2 | A-3 | A-4 | A-5 | A-6 | A-7 |
| Sieve analysis (percentage passing) | A-1-a | A-1-b | A-2-4 | A-2-5 | A-2-6 | A-2-7 | A-4 | A-5 | A-6 | A-7-5 | A-7-6b |
| No.10                  | 50 max. |
| No. 40                 | 30 max. 50 max. 51 max. |
| No. 200                | 15 max. 25 max. 10 max. 35 max. 35 max. 35 max. 35 max. 36 min. 36 min. 36 min. 36 min. |
| Characteristics of fraction passing No. 40 | 40 max. 41 min. 40 max. 40 min. 40 max. 41 min. 40 max. 40 min. |
| Liquid limit           | 40 max. 41 min. 40 max. 40 min. 40 max. 41 min. 40 max. 40 min. |
| Plasticity index       | 10 max. 10 min. 11 min. 11 min. 10 max. 10 min. 11 min. 11 min. |
| Usual types of significant constituent materials | 6 max. NP |
| Stone fragments, gravel, and sand | Silty or clayey gravel and sand |
| Silty soils Clayey soils |
| General subgrade rating | Excellent to good |
| Fair to poor |

**Figure 3. Range of liquidity and plasticity index for soil [6].**
2.4. Compaction

The soil density is measured from the dry volume weight ($\gamma_d$). When the dry volume weight reaches the maximum ($\gamma_{dma}$), the water content is called the optimal water content ($w_{opt}$), as is shown in Figure 4. If the water content is greater than the optimum water content, the increase in water content reduces the dry volume weight. The compaction test method implemented in the laboratory uses five variations of water content, each for standard and modification compaction. Standard compaction is carried out with a pounder weighing 2.5 kg with a dropping height of 30.5 cm, which is compacted on three layers and pounded 25 times per layer. Modified compaction using a pound is weighing 4.54 kg with a dropping height of 45.72 cm, which is compacted in five layers and pounded 25 times per layer.

![Figure 4. Principles of compaction [6].](image)

2.5. California Bearing Ratio

The samples were compacted with the optimum moisture content of each of the standard and modified compaction methods. The value of CBR is a measure of bearing capacity to compress with definite compaction, and a certain moisture content compared to the bearing capacity of standard crushed stone at the same penetrating values (0.1 inch and 0.2 inch). CBR values were determined for compacted samples with 25 and 56 collisions per layer under soaked conditions. The minimum CBR value of the sample that must be met can be seen in Table 4 below.

| Pavement layer              | Minimum CBR % |
|-----------------------------|---------------|
| Base                        | 95            |
| Sub-base                    | 70            |
| Capping/selected material   | 35            |

3. Methods

Prepare materials for soil tests from Nanga-Nanga, Lasolo and nickel slag from PT. Antam-Pomala. Several variations of the sample were mixed. Material testing was carried out at the Republic Clay Management Soil Mechanics laboratory. The summary of research method is presented in Figure 5.
4. Result and discussion

Tests were carried out on two types of local material samples with a composition of 50:50 and 60:40. The results of the sieve analysis are shown in Table 5. Based on the combined data of local embankment material with nickel slag, it can be seen that the mixing composition that meets the gradation requirements is 50:50 and 60:40 for Lasolo and Nanga-Nanga materials, respectively. The results of the sieve analysis can be seen in Figure 6 and Figure 7. The condition of the material after mixing can be seen in Table 6.

Table 5. Grading requirements for soil-aggregate materials

| Sieve designation Standard (mm) | Grading A Location, composition and percentage passes | Lasolo 50:50 | Nanga-Nanga 50:50 | Nanga-Nanga 60:40 |
|---------------------------------|--------------------------------------------------|-------------|------------------|------------------|
| 2 in                            | 100                                              | 100         | 100              | 100              |
| 1 in                            | -                                               | 88          | 72               | 80               |
| 3/8 in                          | 30 – 65                                          | 45          | 39               | 55               |
| No. 4 (4.75)                    | 25 – 55                                          | 26          | 19               | 33               |
| No. 10 (2.00)                   | 15 – 40                                          | 15          | 13               | 18               |
| No. 40 (0.425)                  | 8 – 20                                           | 7           | 5                | 10               |
| No. 200 (0.075)                 | 2 – 8                                            | 4           | 0                | 3                |

Table 6. Condition of mixed barrow materials with slag nickel

| Location and Composition | Sieve Analysis | Gavel (%) | Sand (%) | Clay/Silt (%) | Cc | Cu | LL (%) | PL (%) | PI (%) | GI (%) |
|--------------------------|----------------|-----------|----------|---------------|----|----|--------|--------|--------|--------|
| Lasolo 50:50             | 74             | 22        | 4        | 3.01          | 17.42 | 24.35 | 18.59  | 5.76   | -3.31  |
| Nanga-Nanga 60:40        | 67             | 30        | 3        | 2.94          | 30.05 | 16.07 | 13.08  | 2.19   | -1.64  |
Based on the results of the analysis of $C_c$ and $C_u$ above, the value of $C_c$ meets the requirement’s of 1<$C_c$<3. The value $C_u$ qualifies because $C_u$ > 4. The PI value for Lasolo material is 5.76% in the shaded zone, while the Nanga-Nanga material has PI value of 2.19 < 4. Classification of soil with the USCS system, it is known that Lasolo Material is in the category of gravels with fines (GC-GM). Thus, the Nanga-Nanga Materials are categorized into groups GM (Gravel Silt).

Based on the AASHTO classification system, in general this material is granular. Based on the percentage passed on the sieve analysis number 10, 40 and 200. Furthermore, the Plasticity Index and the Group Index value these two materials are classified into groups A-1-a. Supported on the results of soil is categorized using both the USCS and AASHTO systems. It was found that nickel slag was mixed with local Lasolo and Nanga-Nanga materials with a composition of (50:50) % and (60:40) respectively classified as silt gravel with good gradations.

The results of compaction testing on the two compositions of the material mixture with nickel slag give the optimum water content ($\omega$) and dry unit weight ($\gamma_d$) shown in Figure 8. Dry fill weight tends to enlarge with constant water content or slightly expand from the standard compaction water content. This is contrary to soil compaction, which generally increases dry unit weight along with decreasing optimum moisture content. The new phenomenon shows that when soil is mixed or stabilized using nickel slag,
the moisture content swell with increasing dry unit weight. The Nanga-Nanga material tends to be heavier due to the higher nickel slag content, which is 60%, compared to Lasolo which is 50%.

![Graph showing dry unit weight vs moisture content](image_url)

**Figure 8.** Relationship dry unit weight ($\gamma_d$ gr/cm$^3$) vs moisture content ($\omega$-%) on modified compaction

The results of laboratory tests on local materials mixed with nickel slag obtained CBR values as in Table 7 below. Energy or compaction effort increases, resulting in an increase in CBR value. There is a significant difference between the CBR value of Lasolo and Nanga-Nanga material after the addition of nickel slag. This affects the use of materials in construction.

| CBR test          | Standard            | Modified           |
|-------------------|---------------------|--------------------|
|                   | Lasolo 50:50        | Nanga-Nanga 60:40  | Lasolo 50:50       | Nanga-Nanga 60:40  |
| Unsoaked (%)      | 8.64                | 34.72              | 26.83              | 61.78              |
| Soaked (%)        | -                   | -                  | -                  | -                  |

The material requirements in Table 4, value CBR Soaked respectively as a sub-base and capping layer /selected material is not less than 70% and 35%. The values in Table 7 are unsoaked CBR with modified compaction. Nanga-Nanga local material mixed with nickel slag with a 60:40 ratio meets specifications. For Lasolo material with a ratio of 50:50, because the CBR value of the material is in unsoaked conditions, the material can be used in areas with low water content or at high levels. Lasolo material has the potential if the mixing composition becomes 60:40. If forced to use in areas with large moisture content or poor drainage, then the embankment must be subjected to extra compaction/modification.

5. Conclusion

Supported on the results of sieve analysis, nickel slag mixed with local materials Lasolo and Nanga-Nanga with a composition of 50:50 and 60:40 commonly, is categorized as GM-GC (Gravels with fines) with nicely grades. Based on the SNI 8378 and SNI 8379 2017 specifications, nickel slag mixed with
Lasolo and Nanga-Nanga materials with modified compaction meets the required minimum CBR value of 35%, so it can be used as a capping layer / selected material.

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**References**

[1] Wu Q, Wu Y, Tong W, and Ma H 2018 Utilization of nickel slag as raw material in the production of Portland cement for road construction *Constr Build Mater* **193** pp 426–34

[2] Rahadi D 2020 Ministry of Trade and Industry of the Republic Indonesia proposed the potential for nickel slag to become industrial raw material *Industri.kontan.co.id*. assessed July 2 https://industri.kontan.co.id/news/kemenperin-angkat-potensi-slag-nikel-jadi-bahan-baku-industri

[3] Dhir RK, Brito J de, Mangabhai R, and Lye CQ 2017 Use of copper slag in geotechnical applications. *Sustainable Construction Materials: Copper Slag* pp 211–245

[4] Saha AK and Sarker PK 2017 Compressive Strength of Mortar Containing Ferronickel Slag as Replacement of Natural Sand *Procedia Engineering* **171** pp 689-694

[5] Wang GC 2018 The utilization of slag in civil infrastructure construction *Woodhead Publishing* p 444

[6] Das BM. 2004 *Principle of geotechnical engineering Seventh* Gowans H Stamford USA: Cengage Learning, Inc

[7] Rao N S V K 1999 *Foundation design: theory and practice* John Willey & Sons

[8] Nicholson PG 2014 *Soil improvement and ground modification methods Elservier*

[9] Hunt RE 2006 Geotechnical Engineering Investigation Handbook *Environmental and Engineering Geoscience* **12**

[10] BSN 2017 SNI 8378-2017: Specification of the foundation layer and the sub-base layer using slag Jakarta: BSN

[11] BSN 2017 SNI 8379-2017: Using Slag For Road Construction Jakarta: BSN