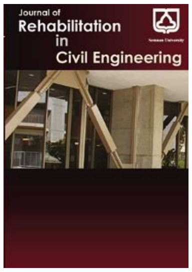
Journal of Rehabilitation in Civil Engineering 10-4 (2022) 33-44



Journal homepage: http://civiljournal.semnan.ac.ir/

Eligibility of Nickel Slag Waste Combined with Stone Ash for Manufacturing Paving Block

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ARTICLE INFO

Article history:
Received: 19 June 2021
Revised: 01 October 2021
Accepted: 06 December 2021

Keywords:
Nickel slag waste;
Stone ash;
Concrete;
Paving block;
Bricks.

ABSTRACT

The application of concrete paving block of nickel slag waste (NSW) to develop low-cost construction materials attracts researchers worldwide owing to the high pessimistic environmental impact of the nickel ore processing industry. It has mild and hard properties which are suitable for the fabrication of paving blocks. This study presents optimization NSW mixed with stone ash for the practical manufacture of concrete paving blocks (CPB). It was prepared in a small aggregate by using disk mill process, then printed by using a mold size of 1200 cm^3 with each variation of the composition. Based on these results, we discover the different compressive strength (CS) from CPB which is compared with the Indonesian standard (SNI). Sample D has excellently fabricated with a composition ratio of 1:1:1:1. It is evident from the results of testing CS and water absorption (WA) with a value of 385.00 Kg/cm^2 and 4.58%, respectively; both values indicate an appropriate product for the city roads. Meanwhile, sample A represents a standard method that is usually applicable for the sidewalk, and samples B and C also have high durability representing the usage for parking areas.

1. Introduction

In the last decades, the rapid development of industry has shown an increase in economic growth in Indonesia country through government regulations regarding the rapid infrastructure development [1, 2]. However, it also produces adverse effects on industrial

How to cite this article:
Pratiwi, Y., Naharudin, N., Ilham, I., Wibowo, D. (2022). Eligibility of Nickel Slag Waste Combined with Stone Ash for Manufacturing Paving Block. Journal of Rehabilitation in Civil Engineering, 10(4), 33-44.
https://doi.org/10.22075/JRCE.2021.23717.1521

activities such as waste production, an uncomfortable environment, and the emergence of various diseases [3]. One common problem is waste management which receives serious attention from the Ministry of Environment [4, 5]. At present, the Indonesian government continues to care for developing environmentally-friendly industries and study the utilization of industrial waste [6, 7]. Especially in the mining industry, it also produces sources of environmental pollution such as NSW, coal waste, and other chemical compounds [8, 9]. Therefore, we must attend to utilize mining waste to reduce solid waste and also producing new materials to be applied to the community [10]. One type of residue from the mining industry process is NSW which is resulted from the smelting process after going through combustion and filtering in smelter processing [11, 12].

Nowadays a lot of nickel smelter industry has been built and developed in the Southeast Sulawesi Province-Indonesia and the average of NSW production is 4,700 Mt, it is also comparable to the increase in mine production [13, 14]. The NSW has been categorized as hazardous and toxic material that potentially produces environmental pollution [15]. Generally, it can be utilized for building construction material caused it containing several chemical compositions as a substitute for the sand mixture or stone [16, 17]. The smelting industry In Southeast Sulawesi has disposed of NSW in the aquatic environment that aims to the stockpiling process around the industrial area [18, 19]. Thus, hazardous and toxic material waste from mining industries in Indonesia has not been thoughtfully good practice.

According to Wibowo et al. [8] that the chemical composition of NSW is consists of SiO_2 51.04%, Al_2O_3 27.41%, Fe_2O_3 14.85%, CaO 0.90%, and MgO 4.05%. After being tested by using the X-Ray Fluorescence (XRF) instrument, it was found that the components of the NSW were practically similar components with sands material such as the high content of SiO_2 and Al_2O_3 i.e. 51.04% and 27.41%, respectively. Thus, it means can be used as a manufacturing CPB. Chemically, preparation for manufacturing concrete can be applied by mixing the CaO and Al_2O_3 compounds react with water to form calcium hydroxide ($Ca(OH)_2$)/aluminum hydroxide ($Al(OH)_2$) (hydration process), this reaction will produce the swelling concrete due to the effect of water inserting into the CPB pores [20]. Meanwhile, the SiO_2 compound in CPB will also react with $Ca(OH)_2$ to form calcium silicate hydrate (CSH) which servers to reduce the number of pores [21]. Therefore, we improve the aggregate material to reduce the number of pores in CPB by adding stone ash. It is essential to improve the CPB properties to increase hardness on NSW pore side because it has contained many silica, alumina alkaline, iron, and lime-silica compounds which are very smooth and amorphous can be used as cement production [22, 23].

The function of stone ash is to stabilize the swelling soils caused by the water absorption, this condition will react between amorphous silica and calcium to produce CSH with reducing pore formation [24, 25]. This is proven by the value of liquid limit, plasticity, and index decreased in various percentages of stone ash [26, 27]. Based on Meyer has reported that stone ash is suitable used as a substitute for sands in manufacturing CPB [28]. Thus this paper discusses the composition of NSW and stone ash for the manufacture of CPB material. In practice, we prepare 4 CPB materials which are given labels A, B, C, and D. Sample A as control was fabricated based on Indonesian standards. We are referring to Indonesian standards because all aspects of production must be assessed through Indonesian standards both in terms of economics, production, and safety. In this case, we compare material quality such as compressive strength and water absorption which can be applied in the community. Therefore, this objective in this study is using nickel slag waste as a paving block manufacture to reduce mining waste.

2. Experimental methods

2.1. Sample preparation

NSW and stone ash samples were collected from Indonesian Morowali Industrial Park (PT. IMIP) with an ore size of 5.0 cm. Subsequently, the sample was dried and crushed by using a laboratory disk mill to obtain the particle size variation of ±0.236 mm and sieved with a particle size of 50 mesh (0.297 mm). It is certainly due to replace the sand as fine aggregate and also obtained uniform particle sizes [29, 30]. Finally, the sample was weighed using a scale based on the composition of variations ingredients (Table 1).

Table 1. Variation in paving block mix composition (%w/w).

Sample	Cement %	Gravel %	Sand %	NSW %	Stone Ash %
A (Control)	25	25	50	0	0
B	25	25	0	40	10
C	25	25	0	30	20
D	25	25	0	25	25

2.2. Fabrication of paving block

In this study, we mix the cement, gravel, sand, NSW, and stone ash to form the concrete paving block with the variation of the composition materials as shown in Table 1. The CPB was prepared with six pieces (three pieces for CS test and three for WA test). Based on Table 1, sample A is a control that is compared with the 3 samples (B, C, and D), and it is a standard material for fabricating the CPB. Meanwhile, samples B, C, and D are a variety of samples test with NSW and stone ash. Furthermore, all materials were inserted into a square mixing container with a size of 50 cm×50 cm×5 cm according to the variation samples in Table 1. It is given enough water in the middle of the dough and stirs until evenly distributed for 5-10 minutes to produce the mixture binds to each other (homogeneous).

After homogeneous, the mixture is put into a mold size of 20 cm × 10 cm × 6 cm to form CPB. This process is pressed with 0.30 MPa to produce solid material. Then, the printed paving block is dried at the ambient temperature for 24 h and given the number identification to mark each test specimen. To obtain the high-solid material, we immerse the paving block for 7 days and it dried for 28 days at ambient temperature (Figure 1). After that, the specimens are ready to be tested for CS and WA. Concrete CS is considered to reach 100% after 28 days old concrete (Indonesian standard) [31, 32].

Figure 1. The manufacturing of CPB for 28 days at ambient temperature.

2.1. Characterizations

2.1.1. Compressive strength test

CPB was tested of CS by using Digital Compression Machine (2000 kN) to obtain the CS data after objects experience crushing test. It was tested at 28 days namely samples A, B, C, and D, each of which amounted to 3 pieces in the form of blocks with a size of 20 cm × 10 cm × 6 cm. Before being given a compressive, the weight of the sample was recorded, then the compressive load is given slowly to the test sample by operating the pump lever until the test object is destroyed. The load scale pointing needle decrease or increases, the scale indicated by the needle is recorded as the maximum load that can be carried by the test object.

2.1.2. Water absorption test

Samples A, B, C, and D were prepared each amounted to three pieces and immersed in water until saturated (24 h) then weighed in a wet condition. After that, it is dried in the oven at 105°C for 24 h then weighed in a dry state until constant weight.

3. Results and discussion

3.1. Compressive strength test

This study uses variations of the CPB composition according to Table 1 which is a mixture of NSW and stone ash as a substitute for fine aggregate. The samples object used in this study is a block with a size of 20 cm × 10 cm × 6 cm (1200 cm^3). The measured parameters are CS by using Eq. 1 as measured by compression testing. The CS test results for samples A, B, C, and D can be seen in Table 2. Based on Table 2 shows the sample A with a weight of 2.701 Kg produces a CS of 201.665 Kg/cm^2. This data is a comparison with the treatment of samples B, C, and D. From the data can be seen that samples B, C, and D with a weight of 2.916 Kg, 2.945 Kg, and 2.936 Kg were producing a CS of 320.83 Kg/cm^2, 350 Kg/cm^2, and 385 Kg/cm^2, respectively. A large load value is how much weight is pressed against the compressive area for 200 cm^2. The similarity of samples weight does not affect the compressive load, this is due to differences in the composition of the NSW of each sample. NSW has a significant impact on its ability to replace the role of sand. A ratio of 1: 1: 1: 1 (Sample D) and the same surface area shows that the compressive strength test value is very high with a value of 385 Kg/cm^2. High silica composition in slag is expected to improve the perfect interface because the hydration process that occurs between cement and aggregate has reduced the pore interface [8]. In addition, high energy is required for the destruction of concrete. According to Cho et al. [33] there are two types of nickel slag namely high and low slag which are categorized as porous slag properties. In this case, we use high slag in the form of dark brown fine sand (ferronickel slag powder) which has low pores. The effects of possible damages in the specimens by cycles of thermal expansions and contractions, as well as the cycles of moisture movement and shrinkage are considered to reflect in the compressive strengths [34].

Figure 2 exhibits that the high load value was proportional to the high of CS. It is due to sampling D has a good composition in the process of mixing and making the paving block. Based on Table 1, sample D has the same composition by 1:1:1:1 where the role of NSW and stone ash to substitute the sand for manufacturing CPB, meanwhile the cement and gravel to increase the concentrate and adhesive agent [35, 36]. Based on the data, we report that the NSW and stone ash can be used for manufacturing CPB with a composition ratio of 1:1:1:1. Then, we grouping of CPB to be categorized in the Standard National of Indonesia (SNI) No. 03-0691-1996 to obtain the feasibility of materials [31].

Table 2. The results of CS test.

Sample code	Weight of test object (Kg)	Load (Kg)	compressive area (cm^2)	Actual compressive strength (Kg/cm^2)	Factor chamfered	compressive strength conversion (Kg/cm^2)
A	2.70	40,333	200	201.66	1.0	201.66
B	2.92	64,166	200	320.83	1.0	320.83
C	2.95	70,000	200	350.00	1.0	350.00
D	2.94	77,000	200	385.00	1.0	385.00

Table 3. The CS results of CPB by SNI 03-0691-1996 (Indonesia standard) [31].

Compressive strength (Kg/cm^2)	Feasibility	Application
356.09	A	Road
173.35	B	Parking
127.47	C	Pedestrians
86.68	D	Garden

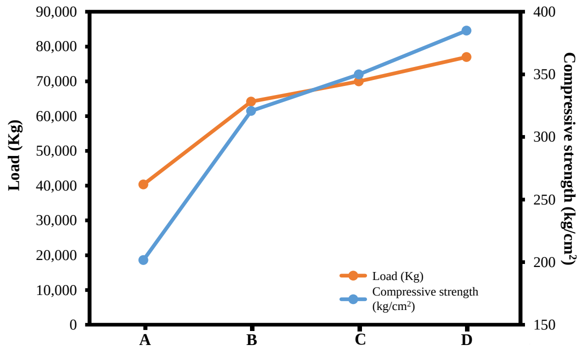

Fig. 2. Graph of the relationship between the load value with CS.

Table 2 is a data of the CS test, then we compare with the SNI 03-0691-1996 standard which applied to the Indonesia community. The results of the comparison of CS data can be seen in Table 4. Based on SNI 03-0691-1996 [31] (Table 3), the paving block has been categorized into 4 feasibility namely A, B, C, and D with the minimum CS value of 356.90 Kg/cm^2, 173.35 Kg/cm^2, 127.46 Kg/cm^2, and 86.66 Kg/cm^2, respectively. The analysis results of the CS test in samples A, B, C, and D can be seen in Table 4 and Figure 3.

Table 4 and Figure 3 shows that sample D has high CS compared with samples A, B, and C. It is certainly due to the SiO_2 being the most influential element in determining the CS of CPB which are found in NSW and stone ash. This element works as a binding of all CPB mixes so that it is hard and united with one another. In addition, NSW has a high content of CaO and SiO_2 because the CaO compound in the CPB will react with water during the hydration process to $Ca(OH)_2$, this reaction will be the expansion of the CPB.

Table 4. Results feasibility of CS test.

Sample	Compressive strength (Kg/cm^2)	Compressive strength (Kg/cm^2) [31]	difference	Feasibility	Application
A	201.66	173.35	28.31	B	Parking
B	320.83	173.35	147.48	B	Parking
C	350.00	173.35	176.65	B	Parking
D	385.00	356.09	28.91	A	Road

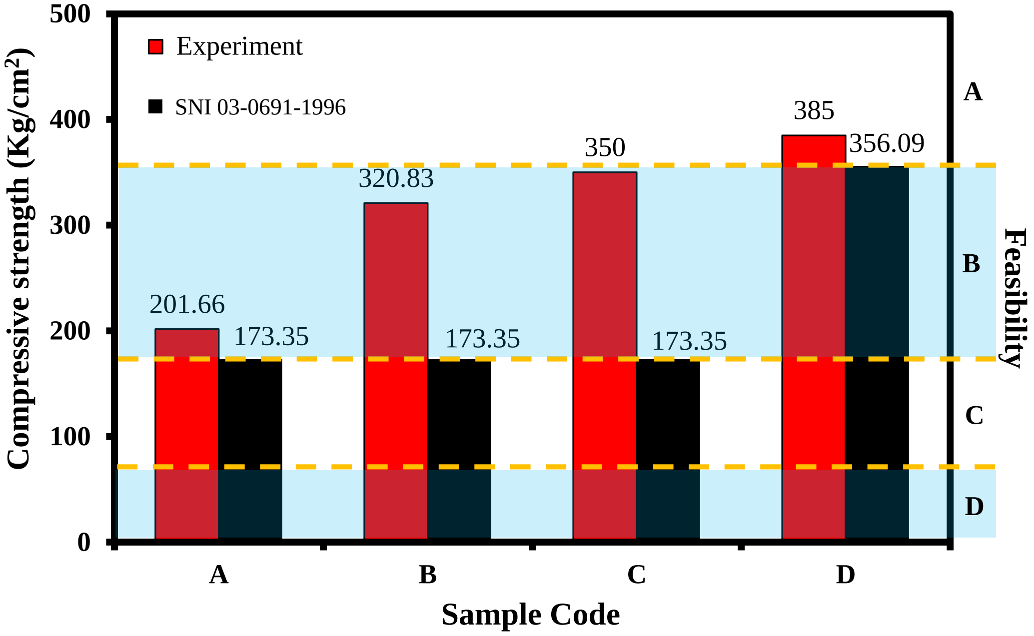

Fig. 3. Comparison of data analysis of the experiment with SNI 03-0691-1996.

Meanwhile, the SiO_2 compound in the paving block will react with $Ca(OH)_2$ to form CSH, this reaction which will reduce the number of pores in the CPB. In the economic case, the use of NSW for substituting of sand is more profitable because the use of more NSW also gives better results in terms of the CS [18, 37].

In this study, it was shown that the more stone ash was used, the higher the CS of concrete. Stone ash is still suitable to be used as a material for manufacturing CPB because it has smooth aggregate grains into the pores thereby increasing the hardness properties of a material. It is contained the smooth silica compound which is amorphous so that it can harden when mixed with cement. The chemical reaction that occurs between amorphous silica and lime is the calcium silicate (Ca_2O_4Si) compound which is difficult to dissolve in water [24, 25].

3.2. Water Absorption Test

Furthermore, we test the WA of CPB which aimed to observe the effect of WA on the samples, and tested the endurance of the material. Water is a liquid material capable to enter the smallest slits. Generally, it has a high absorption value then the pore and the gap in samples will be larger as well. In this test, the water absorption was carried out using specimens that have aged 28 days of the drying period and immersed for 24 h in a soaking tub. After that, it is weighed in a wet condition and dried by using an oven at a temperature of 105°C for 24 h. The WA test results can be seen in Table 5. Table 5 shows that sample A has incubated for 24 h in an immersion tub had a wet weight of 2.74 Kg, then dried in the oven with a dry weight of 2.58 Kg. So, it is calculated by using Eq. 2 that the power of absorption into the paving block of 6.17%.

Table 5. The results test of WA from CPB.

Sample	Wet weight (Kg)	Dry weight (Kg)	Water absorption (%)
A	2.74	2.58	6.17
B	3.01	2.89	4.18
C	2.96	2.83	4.44
D	2.98	2.85	4.58

Sample A was compared with samples B, C, and D to observe the absorption performance, the high absorption of material will produce the damage of CPB. Subsequently, the samples B, C, and D exhibit the wet weight value of 3.01 Kg, 2.96 Kg, and 2.98 Kg with the dry wet weight of 2.89 Kg, 2.83 Kg, and 2.85 Kg have produced WA of 4.18%, 4.44%, and 4.58%, respectively. No visible signs of cracking or damage were found in any of the specimens after the wet-dry cycles. However, some thin whitish deposit was observed on the surface after the wet-dry cycles. This thin deposit on the surface is believed to be caused by leaching out of some hydrated product from inside of the specimens [34].

Based on this research, samples B, C, and D have a low absorption compared with the standard sample because the NSW is the hard material so that is less WA and it is not the same with clay which can be save of water content. In another hand, stone ash also contains silica compounds which are very smooth and amorphous so that it can harden when mixed with cement and strengthen the concrete press [38]. In addition, fly ash can be used to stabilize the mixture for expansive soils and replacement of cement or as aggregates of mortar, similar to sand [39, 40]. This is evidenced by defining the necessary quantity of water, the volume of blocked air, the water/cement ratio, and the quantity of binder required [41]. Nickel slag waste has a high content of CaO and SiO_2 of 64.14% and 19.86% which needs to be considered from the chemical properties because it can be colloidal in water. In this case, CaO in the concrete will react with water (rain) during the hydration process to form $Ca(OH)_2$, this reaction will cause the concrete to expand.

Whereas SiO_2 will react with $Ca(OH)_2$ to form calcium silicate hydrate (CSH), this reaction will reduce the number of pores in the concrete but it will expand to be easily destroyed. In economic terms, the use of slag substitution to sand is more profitable because the use of more slag also gives better results in terms of the compressive strength produced [42]. At the same time, we also compare the SNI 03-0691-1996 against the WA of the CPB. Based on Indonesia

Standard is the CPB with WA contents between 3%-10% still belong to good stability (Table 6). Table 6 exhibits that sample A has WA of 6.17% which falls into the category of quality C concrete bricks intended for pedestrians. While the absorption of sample B is 4.18%, sample C is 4.44%, and sample D is 4.58% so that the absorption speed above is included in the category of quality B concrete bricks intended for the parking area. The results of WA test analysis can be seen in Table 7 and Figure 4.

Table 6. The WA results of CPB by SNI 03-0691-1996 (Indonesia standard) [31].

Water absorption (%)	Feasibility	Application
3	A	Road
6	B	Parking
8	C	Pedestrians
10	D	Garden

Figure 4 shows the highest percentage of WA in sample A with a composition of 25% cement, 25% gravel, and 50% sand which is 6.17%. Then followed by sample D with a composition of 25% cement, 25% gravel, 25% NSW, and ash stone 25% which is WA of 4.58%. In sample C with a 25% cement composition, 25% gravel, 30% NSW, and 20% stone ash, the absorption was reduced by 4.44%. The lowest absorptive capacity was found in sample B with 25% cement composition, 25% gravel, 40% NSW and 10% stone ash-producing 4.18% absorption. Because samples B, C, and D no longer use the composition of the sand but use the composition of NSW and stone ash instead of sand. The absorption of water in the sand is very high because the sand is composed of 70% of large particles of 0.02 – 2.00 mm. The CPB whose structure is not porous is tough to absorb water quickly because the pore structure or cavity contained in the paving block dramatically affects the size of the absorption of water.

Table 7. Analysis results of WA test.

Sample	Water absorption (%)	Water absorption (%) (SNI 03-0691-1996)	difference	Feasibility	Application
A	6.17	8	1.83	C	Pedestrians
B	4.18	6	1.82	B	Parking
C	4.44	6	1.56	B	Parking
D	4.58	6	1.42	B	Parking

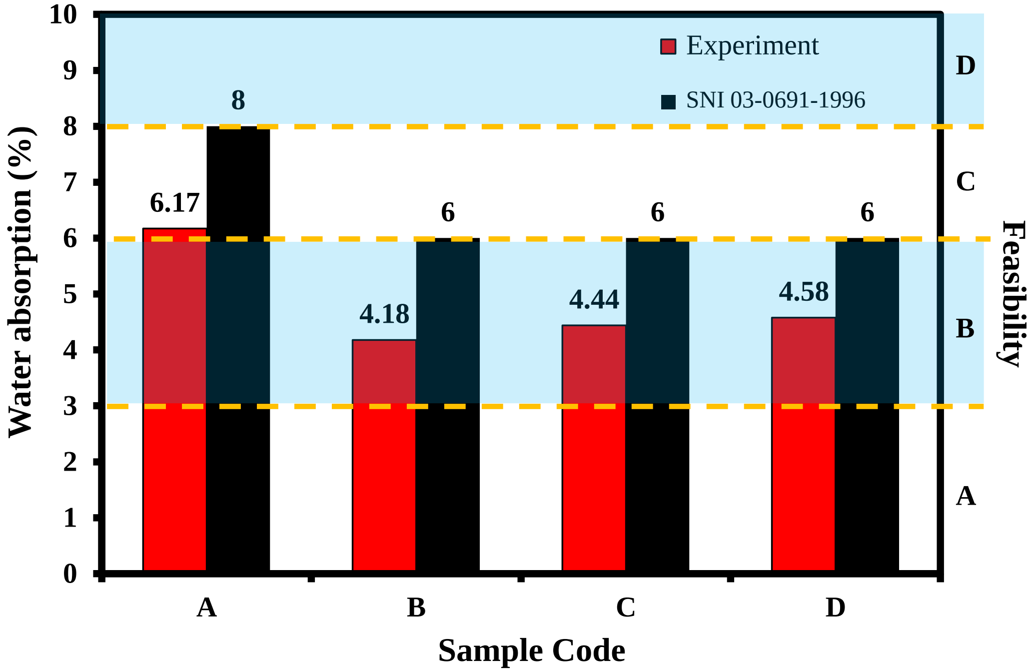

Fig. 4. Analysis results of WA test.

The use of NSW is quite high, resulting in minimal water absorption. It is certainly due to the high NSW content as a substitute for sand that can reduce WA in CPB. In this case, the CaO compound in the paving block mixture will react with water during the hydration process to $Ca(OH)_2$ this occurs reaction will be expanding. Meanwhile, the SiO_2 compound in the concrete mixture will react with $Ca(OH)_2$ to form CSH, this reaction will reduce the number of pores in the concrete.

The WA is a significant factor affecting the strength of brittle material, which is influenced by various factors including material properties, use of material size, pore shape, and many other things [43]. Based on Figure 4, it can be concluded that sample A with feasibility C value can be applied to the pedestrians. Meanwhile, Samples B, C, and D with feasibility B value can be applied to the parking area.

4. Conclusion

The potential for practical application of NSW and stone ash as raw materials for manufacturing the CPB has been examined, where the sample D is excellent at paving block fabrication with the composition 1:1:1:1. This is evident from the results of testing CS and WA with the value of 385.00 Kg/cm^2 and 4.58%, which can be applied on city roads. Meanwhile, sample A is a standard that usually for manufacturing CPB can only be as appropriated for pedestrians, and samples B and C have good endurance to use as a parking areas, respectively. This helps to produce the CPB with the utilization of slag and stone ash wastes for better engineering properties.

Acknowledgments

The authors are grateful for financial support from the LPPM-University of Muhammadiyah Kendari.

References

[1] Nansadiqa, L., Masbar, R., Majid, M. S. A. (2019). "Does economic growth matter for poverty reduction in Indonesia." East African Scholars Journal of Economics, Business and Management, Vol. 2, No. 2, pp. 46–52

[2] Rath, B. N., Hermawan, D. (2019). "Do information and communication technologies foster economic growth in Indonesia?" Buletin Ekonomi Moneter Dan Perbankan, Vol. 22, No. 1, pp. 103–122

[3] Chowdhary, P., Bharagava, R. N., Mishra, S., Khan, N. (2020). "Role of industries in water scarcity and its adverse effects on environment and human health." Environmental Concerns and Sustainable Development, Springer, 235–256

[4] Damanhuri, E., Handoko, W., Padmi, T. (2014). "Municipal solid waste management in Indonesia." Municipal Solid Waste Management in Asia and the Pacific Islands, Springer, 139–155

[5] Meidiana, C., Gamse, T. (2010). "Development of waste management practices in Indonesia." European Journal of Scientific Research, Vol. 40, No. 2, pp. 199–210

[6] Nurdin, M., Zaeni, A., Rammang, E. T., Maulidiyah, M., Wibowo, D. (2017). "Reactor design development of chemical oxygen demand flow system and its application." Analytical and Bioanalytical Electrochemistry, Vol. 9, No. 4, pp. 480–494

[7] Wibowo, D., Ruslan, Maulidiyah, Nurdin, M. (2017). "Determination of COD based on Photoelectrocatalysis of FeTiO3.TiO2/Ti Electrode." IOP Conference Series: Materials Science and Engineering. doi:10.1088/1757-899X/267/1/012007

[8] Wibowo, D., Sufandy, Y., Irwan, I., Azis, T., Maulidiyah, M., Nurdin, M. (2020). "Investigation of nickel slag waste as a modifier on graphene-TiO2 microstructure for sensing phenolic compound." Journal of Materials Science: Materials in Electronics, pp. 1–9

[9] Wibowo, D., Basri, B., Adami, A., Sumarlin, S., Rosdiana, R., Wa, N., Ilham, I. (2020). "Analisis Kandungan Logam Nikel (Ni) dalam Air Laut dan Persebarannya di Perairan Teluk Kendari, Sulawesi Tenggara." Indonesian Journal of Chemical Research, Vol. 8, No. 2, pp. 144–150. doi:10.30598//ijcr.2020.8-dwi

[10] Hartono, D. M., Suganda, E., Nurdin, M. (2018). "How Land Stripping Affects Quality of River in Pomalaa Nickel Mining , South East Sulawesi , Indonesia.", Vol. 15, No. 4, pp. 47–56. doi:10.3233/AJW-180057

[11] Ilham, Hartono, D. M., Suganda, E., Nurdin, M. (2017). "Metal distribution at river water of mining and nickel industrial area in Pomalaa Southeast Sulawesi Province, Indonesia." Oriental Journal of Chemistry, Vol. 33, No. 5, pp. 2599–2607. doi:10.13005/ojc/330557

[12] Haryadi, H. (2016). "Analisis Dampak Pembangunan Smelter Nikel terhadap Perekonomian Daerah di Provinsi Sulawesi Tenggara." Buletin Sumber Daya Geologi, Vol. 11, No. 1, pp. 25–39

[13] Kurniawan, A. R., Murayama, T., Nishikizawa, S. (2021). "Appraising affected community perceptions of implementing programs listed in the environmental impact statement: A case study of Nickel smelter in Indonesia." The Extractive Industries and Society, Vol. 8, No. 1, pp. 363–373

[14] Upe, A., Equatora, M. A. J. H., Zainur Wula, M. A. (2020). "Mining and Peasant Societies Resistance: Political Ecology Perspective." International Journal of Psychosocial Rehabilitation, Vol. 24, No. 4

[15] Susanto, I., Ranastra Irawan, R., Hamdani, D. (2020). "Nickel slag waste utilization for road pavement material as strategy to reduce environmental pollution." E3S Web of Conferences (Vol. 202), 5003

[16] Saha, A. K., Majhi, S., Sarker, P. K., Mukherjee, A., Siddika, A., Aslani, F., Zhuge, Y. (2021). "Non-destructive

prediction of strength of concrete made by lightweight recycled aggregates and nickel slag." Journal of Building Engineering, Vol. 33, pp. 101614

[17] Edwin, R. S., Ngii, E., Talanipa, R., Masud, F., Sriyani, R. (2019). "Effect of nickel slag as a sand replacement in strength and workability of concrete." IOP Conference Series: Materials Science and Engineering (Vol. 615), IOP Publishing, 12014

[18] Zhang, G., Wang, N., Chen, M., Wang, Y., Li, H. (2019). "Iron Recovery from Nickel Slag by Aluminum Dross: Viscosity Evolution in Different Periods." REWAS 2019, Springer, 143–152

[19] Sarita, U. (2021). "Overview the local barrow material of nickel slag mixture as an aggregate foundation layer." IOP Conference Series: Earth and Environmental Science (Vol. 622), IOP Publishing, 12037

[20] El Nouhy, H. A. (2013). "Properties of paving units incorporating slag cement." HBRC Journal, Vol. 9, No. 1, pp. 41–48. doi:10.1016/j.hbrcj.2012.12.004

[21] Ajay, V., Rajeev, C., Yadav, R. K. (2012). "Effect of micro silica on the strength of concrete with ordinary Portland cement." Research Journal of Engineering Sciences, Vol. 2278, pp. 9472

[22] Prince, A. T. (1954). "Liquidus Relationships on 10% MgO Plane of the System Lime-Magnesia-Alumina-Silica." Journal of the American Ceramic Society, Vol. 37, No. 9, pp. 402–408

[23] Muzakkar, M. Z., Nurdin, M., Ismail, I., Maulidiyah, M., Wibowo, D., Ratna, R., Saad, S. K. M., Umar, A. A. (2019). "TiO2 Coated-Asphalt Buton Photocatalyst for High-Performance Motor Vehicles Gas Emission Mitigation." Emission Control Science and Technology, Vol. 6, pp. 28–36

[24] Garrault-Gauffinet, S., Nonat, A. (1999). "Experimental investigation of calcium silicate hydrate (CSH) nucleation." Journal of Crystal Growth, Vol. 200, Nos. 3–4, pp. 565–574

[25] Zheng, K. (2016). "Pozzolanic reaction of glass powder and its role in controlling alkali–silica reaction." Cement and Concrete Composites, Vol. 67, pp. 30–38

[26] Okafor, F. O., Okonkwo, U. N. (2009). "Effects of rice husk ash on some geotechnical properties of lateritic soil." Nigerian Journal of Technology, Vol. 28, No. 1, pp. 46–52

[27] Sabat, A. K. (2012). "A study on some geotechnical properties of lime stabilised expansive soil–quarry dust mixes." International Journal of Emerging Trends in Engineering and Development, Vol. 1, No. 2, pp. 42–49

[28] Meyer, C. (2009). "The greening of the concrete industry." Cement and Concrete Composites, Vol. 31, No. 8, pp. 601–605

[29] Nishigaki, M. (2000). "Producing permeable blocks and pavement bricks from molten slag." Waste Management, Vol. 20, Nos. 2–3, pp. 185–192

[30] Wattanasiriwech, D., Saiton, A., Wattanasiriwech, S. (2009). "Paving blocks from ceramic tile production waste." Journal of Cleaner Production, Vol. 17, No. 18, pp. 1663–1668

[31] Badan Standar Nasional Indonesia. (1996). *Bata Beton (Paving Blok)* SNI 03-0691-1996

[32] Badan Standar Nasional Indonesia. (1990). "Metode Pengujian Kuat Tekan Beton." SNI 03-1974-1990

[33] Cho, B.-S., Kim, Y.-U., Kim, D.-B., Choi, S.-J. (2018). "Effect of ferronickel slag powder on microhydration heat, flow, compressive strength, and drying shrinkage of mortar." Advances in Civil Engineering, Vol. 2018

[34] Saha, A. K., Sarker, P. K. (2018). "Durability of mortar incorporating ferronickel slag aggregate and supplementary cementitious materials subjected to wet–dry cycles." International Journal of Concrete Structures and Materials, Vol. 12, No. 1, pp. 1–12

[35] Cai, X., Wu, Y., Guo, X., Ming, Y. (2012). "Research review of the cement sand and gravel (CSG) dam." Frontiers of Structural

and Civil Engineering, Vol. 6, No. 1, pp. 19–24

[36] Zuccheratte, A. C. V., Freire, C. B., Lameiras, F. S. (2017). "Synthetic gravel for concrete obtained from sandy iron ore tailing and recycled polyethyltherephtalate." Construction and Building Materials, Vol. 151, pp. 859–865

[37] Putranto, T. W. C., Wigati, N. F. S., Pradana, H. P. (2019). "The utilization of ceramic shard waste and landfill mining residue as a paving block material in the effort to extend landfill lifetime." IOP Conference Series: Earth and Environmental Science (Vol. 245), IOP Publishing, 12003

[38] Luhar, S., Cheng, T.-W., Luhar, I. (2019). "Incorporation of natural waste from agricultural and aquacultural farming as supplementary materials with green concrete: A review." Composites Part B: Engineering, Vol. 175, pp. 107076

[39] Moghaddam, S. C., Madandoust, R., Jamshidi, M., Nikbin, I. M. (2021). "Mechanical properties of fly ash-based geopolymer concrete with crumb rubber and steel fiber under ambient and sulfuric acid conditions." Construction and Building Materials, Vol. 281, pp. 122571

[40] Luhar, S., Chaudhary, S., Luhar, I. (2018). "Thermal resistance of fly ash based rubberized geopolymer concrete." Journal of Building Engineering, Vol. 19, pp. 420–428

[41] Foti, D., Lerna, M., Sabbà, M. F., Vacca, V. (2019). "Mechanical characteristics and water absorption properties of blast-furnace slag concretes with fly ashes or microsilica additions." Applied Sciences (Switzerland), Vol. 9, No. 7. doi:10.3390/app9071279

[42] Edwin, R. S., Ngii, E., Talanipa, R., Masud, F., Sriyani, R. (2019). "Effect of nickel slag as a sand replacement in strength and workability of concrete." IOP Conference Series: Materials Science and Engineering, Vol. 615, No. 1. doi:10.1088/1757-899X/615/1/012014

[43] Luhar, S., Chaudhary, S., Luhar, I. (2019). "Development of rubberized geopolymer concrete: Strength and durability studies." Construction and Building Materials, Vol. 204, pp. 740–753