NICKEL SLAG AS A FINE AGGREGATE OF CONCRETE TO REDUCE THE USE OF NATURAL SAND AND OVERCOME THE IMPACT OF MINING PRODUCTION WASTE

1st Muammar Makmur[*1], 2nd Rahmat Madjid[2], 3rd Adris Ade Putra[2], 4th Endro Sukotjo[2]

[*1] Student of Doctoral in Management Science, Consentration in Engineering Management, Halu Oleo University, Kendari, Indonesia, e-mail: muammarmakmur@yahoo.co.id ,phone: +6285389016473

[2] Management Science, Consentration in Engineering Management, Halu Oleo University, Kendari, Indonesia.

ABSTRACT

The development of the industrial world is increasingly rapid. Industry is a major source of environmental problems and contributes significantly to the depletion of natural resources, one of which is the use of natural sand. The use of natural sand continues to increase along with the increase in infrastructure development. So from these problems, an alternative fine aggregate is needed to save our environment. The solution that can be used is to use mining waste, one of which is nickel slag which is very large in many nickel producing countries in the world.

This study aims to determine how much influence of nickel slag as a substitute for fine aggregate on the workability and compressive strength of concrete. Method used in the study was experimental, namely making a concrete mixture with cylindrical (15 x 30) cm test objects with a compressive strength plan of 20 MPa which would be tested at the age of 7, 14 ,28 and 56 days. Planning of concrete proportion mixture using mix design method of Indonesian Standard SNI 03-2834-2000.

The results in this study show that nickel slag as a substitute for fine aggregate affects the level of concrete workability. The testing results of concrete compressive strength, by adding 50% nickel slag as a fine aggregate can increase concrete strength by 25.8% at the age of 56 days. While with the use of 100% nickel slag decreased at the age of 28 days when compared to normal concrete (0% nickel slag), but had compressive strength that was almost the same as normal concrete (0% nickel slag) at the age of 56 days. The use of nickel slag as fine aggregate in concrete mixtures can provide advantages, which are of economic value because the materials used in making concrete are waste. In addition, with the use of nickel slag as a substitute for fine aggregate, it can reduce the use of natural sand.

Key words: Sand, Nickel Slag, Concrete, Compressive Strength

I. INTRODUCTION

The development of the industrial world is increasingly rapid. Industry is a major source of environmental problems and contributes significantly to the depletion of natural resources, one of which is the use of natural sand. The use of natural sand continues to increase along with the increase in infrastructure development. So from these problems, an alternative fine aggregate is needed to save our environment. The solution that can be used is to use mining waste, one of which is nickel slag which is very large in many nickel producing countries in the world.

Nickel slag is one type of residue from the industrial process, namely from the nickel ore smelting process after going through the combustion and filtering process. Nickel slag is the largest waste from nickel processing in many parts of the world, one of which is in Indonesia. Nickel slag is produced by smelting nickel ore in large quantities and can cause environmental and health problems.

.

Figure 1. Nickel Slag Waste

Figure 2. Nickel slag as a backfill on the beach

The amount of waste in the form of nickel slag produced by several mining companies in Indonesia must now be handled or managed properly so that it can give benefit to the community. The physical form of nickel slag resembles coarse aggregate and fine aggregate. So from the above problems, to overcome this, the author intends to find other alternative sources as a substitute for concrete making composition materials that are more environmentally friendly and as an innovation for concrete needs.

The aims of this study is to determine how much influence the workability and compressive strength of concrete by using nickel slag as a substitute for fine aggregate at the age of 7, 14, 28 and 56 days. The planned concrete Compressive strength is 20 Mpa with a slump value in the range of 75-150 mm.

2. LITERATUR REVIEW

2.1 Natural Sand

Sand is a very important mineral for society and must be maintained for environmental sustainability, and sand mining has become an environmental issue along with the increasing need for sand in industry and construction (M. Naveen Saviour 2012). Sand is a natural material that is needed in the world of construction, especially in the concrete and mortar (Padmalal et al. 2014). The need for sand is increasing in the construction industry (Dan Gavriletea 2017) (Torres and Brandt 2017). Cost of concrete is also affected by 2/3 of the use of sand (Mundra et al. 2016).

In Indonesia, concrete making always uses river sand. The use of river sand is considered easy to process and has better quality compared to other sand (Koehnken L 2018). But there have been many impacts from river sand mining in various parts of the world. In India, illegal mining of river sand causes flooding (M. Naveen Saviour 2012). Rivers in China have experienced scouring, widening of channels, and damage to bridge foundations (Bendixen M, Best J, Hackney C 2019). So from these problems, an alternative to sand (fine aggregate) for construction is needed to save our environment.

2.2 Nickel Slag

Nickel slag also known as product of ferronickel alloy production (Nguyen et al. 2019) (X. Liu et al. 2020). As a result, nickel slag needs to be cared for immediately in order to address major environmental problems (Q. Liu et al. 2020).

Figure 3. The physical shape of nickel slag as a fine aggregate

In the context of sustainable development, proper exploitation of nickel, an industrial waste discharged from the manufacturing of stainless steel and nickel, is crucial. (Chen et al. 2020). When making concrete, using nickel slag as aggregate offers a cost-effective way to recycle these leftovers of industry while preserving the supply of natural rock material. (Yang et al. 2020).

Portland cement is substituted with ferronickel slag powder in a ratio of 15% by weight of the binder (Cho et al. 2018). A byproduct of nickel processing called ferronickel slag (FNS) is utilized as a substitute for fine aggregates (Saha and Sarker 2017). For possible usage in concrete, the alkali-silica reactivity of cementitious materials using fine ferronickel slag (FNS) aggregates was experimentally assessed (Choi and Choi 2015).

Table 1. Physical properties test results of nickel slag (Sugiri 2005)

Testing	Porous nickel slag	Solid nickel slag	Normal concrete-Heavy concrete
Volume weight	1327	1913	2,420
Spesific Gravity (SSD)	2,835	3,215	3,858
Spesific gravity (Dry)	2,692	3,179	3,848
Water (%)	0,11	0,11	0,1
Absorption (%)	5,301	1,151	0,1

Table 2. The chemical composition of nickel slag (Sugiri 2005).

Compound	Amount (%)
SiO_2	41,41
Al_2O_3	2,58
Fe_2O_3	30,44
MgO	22,75
$Na_2O + K_2O$	0,68

Using solid waste (slag) in concrete mixtures has several benefits, including: (Newman and Choo 2003) :

a. Increase the compressive strength of concrete.
b. Ratio between flexibility and compressive strength of concrete is incresed
c. Reduce variations in compressive strength of concrete.
d. Increase the sulfate resistance in seawater.
e. Reduces alkaline silica attack.
f. Reduces heat hydration and lowers temperature.
g. Improves finishes and gives bright color to concrete.
h. Increases durability due to volume changes.

3. METHOD

3.1 Material Testing Methods

Material testing methods and the mix design refer to the Indonesian National Standard (SNI) which includes:

a. Specific gravity and absorption inspection of coarse aggregates (SNI 03-1970-1990)
b. Specific gravity and fine aggregate absorption inspection (SNI 03-1969-1990)
c. Aggregate moisture content check (SNI 03-1971-1990)
d. Weight inspection of aggregate contents (SNI 03-1973-1990)
e. Manufacture of test specimens (SNI 03-2493-1991)

3.2 Mix Design

Mix design is a procedure for making concrete mixtures, both cylindrical and cube shapes. The mix design method in this study refers to the Indonesian National Standard (SNI-03-2834-2002) using the shape of cylindrical test objects. The planned concrete quality is 20 MPa with a range of slump values between 7.5-15 cm.

Table 3. Concrete Mix Design Results

Nickel Slag (%)	Material	Volume (Kg)
0%	Cement	2,2471
	Coarse Aggregate	5,3019

Nickel Slag (%)	Material	Volume (Kg)
	Sand (Fine Agrgegate)	3,5346
	Nickel Slag (Fine Agrgegate)	0
	Water	1,2359
20%	Cement	2,2471
	Coarse Aggregate	5,3019
	Sand (Fine Agrgegate)	2,82768
	Nickel Slag (Fine Agrgegate)	0,70692
	Water	1,2359
50%	Cement	2,2471
	Coarse Aggregate	5,3019
	Sand (Fine Agrgegate)	1,7673
	Nickel Slag (Fine Agrgegate)	1,7673
	Water	1,2359
50%	Cement	2,2471
	Coarse Aggregate	5,3019
	Sand (Fine Agrgegate)	0
	Nickel Slag (Fine Agrgegate)	3,5346
	Water	1,2359

The results of the concrete mix design in table 3 are the proportion of the mixture for 1 cylindrical size test object (15 x 30) cm.

3.3 Testing

a. Compressive Strenght

Procedures for testing concrete compressive strength refer to SNI 03-1974-1990 with the following steps:

1) Placing the specimen on the press machine centrically and running the press testing machine.
2) Perform loading.
3) Record the maximum load incurred.
4) Calculates compressive strength based on maximum load obtained per unit area.

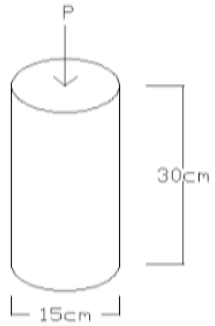

Figure 4. Loading on test specimens

For the formula used in determining the compressive strength result as follows:

$$f'c = \frac{P}{A} \qquad \text{Equation (1)}$$

b. Slump Test

The meaning of concrete slump is the decrease in height at the center of the top surface of fresh concrete measured as soon as the slump test mold is lifted. Concrete slump testing aims to determine the *consistency* of fresh concrete. With a slump inspection, we can obtain the slump value used as a benchmark or standard for fresh concrete.

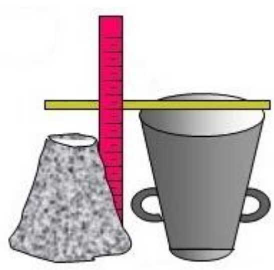

Figure 5. Slump Value Determination

Concrete slump testing refers to SNI 03-1972-1990 with the following steps:

a. Dampen the mold (abrahams cone) and place the mold on a flat, damp, non-water-absorbing surface.
b. Fill the funnel with fresh concrete three times the filling.
c. Compact fresh concrete at each filling by piercing 25 times with a compactor stick evenly.

d. When finished on the third layer, flatten the surface thoroughly.
e. Pull the funnel up slowly so that it is completely upright.
f. Measure the subsidence of the upper surface of the concrete mortar.

4. RESULT

4.1 Material Test Data

a. Nickel Slag

Here are the nickel slag test results:

Table 4. Physical Properties Test Results of Nickel Slag

No	Parameter	Value	Unit
1	Specific Gravity (SSD)	2,83	gr/cm^3
2	Volume Weight	1,45	gr/cm^3
3	Moisture	1,32	%
4	Absorption	0,06	%

b. Coarse Aggregate

Here are the results of coarse aggregate testing:

Table 5. Test Results of Physical Properties of Coarse Aggregate

No	Parameter	Nilai	Satuan
1	Specific Gravity (SSD)	2,68	gr/cm^3
2	Volume Weight	1,59	gr/cm^3
3	Moisture	0,10	%
4	Absorption	0,65	%

4.2 Slump Test Results

The slump value is planned to be in the range of 75 – 150 mm. Here are the results of the slump test.

Table 6. Slump Test Results

No	Nickel Slag (%)	Slump Test (mm)
1	0%	80
2	20%	105
3	50%	130
4	100%	160

In table 6 it can be seen that in general the use of nickel slag as a substitute for fine aggregate has an effect on the level of concrete workability.

4.3 Compressive Strength Test Results

Concrete samples were tested for compressive strength when aged 7 days, 14 days, 28 days and 56 days with 3 pieces each. Compressive strength testing of concrete is carried out using the Universal Testing Machine tool. The results of compressive strength testing of concrete at the age of 7 days, 14 days, 28 days and 56 days can be seen in the following table and graph.

Table 7. Concrete Compressive Strength Test Results 0% Nickel Slag

Sample	Compressive Strength (MPa)			
	7 Days	14 Days	28 Days	56 Days
1	12,8	18,1	21,4	21,8
2	13,2	18,7	22,1	22,9
3	12,1	17,2	20,3	21
Average	12,7	18,0	21,2	21,9

Table 8. Compressive Strength Test Results of Concrete 20% Nickel Slag

Sample	Compressive Strength (MPa)			
	7 Days	14 Days	28 Days	56 Days
1	14	19,6	23,54	28,3
2	14,4	20,5	24,31	29,1
3	13,2	18,9	22,33	26,6
Average	13,8	19,6	23,3	28,0

Table 9. Concrete Compressive Strength Test Results 50% Nickel Slag

Sample	Compressive Strength (MPa)			
	7 Days	14 Days	28 Days	56 Days
1	14,6	20,9	24,6	29,7
2	15,1	21,6	25,4	30,6
3	13,8	19,8	23,3	28,3
Average	14,5	20,7	24,4	29,5

Table 10. Compressive Strength Test Results of Concrete 100% Nickel Slag

Sample	Compressive Strength (MPa)			
	7 Days	14 Days	28 Days	56 Days

1	10,2	14,4	17,1	20,8
2	10,5	15,0	17,68	21,4
3	9,5	13,7	16,24	19,8
Average	10,1	14,4	17,0	20,7

Based on the results of concrete compressive strength testing, the addition of 50% nickel slag as a fine aggregate can increase concrete strength by 25.8% at the age of 56 days. While with the use of 100% nickel slag decreased at the age of 28 days when compared to normal concrete (0% nickel slag), but had compressive strength that was almost the same as normal concrete (0% nickel slag) at the age of 56 days.

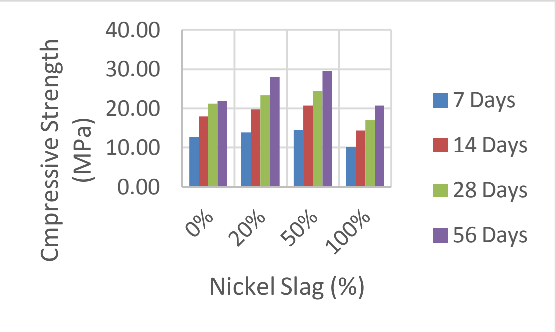

Figure 6. Average compressive strength chart

The influence of nickel slag as a substitute material for fine aggregate results in a free lime binding reaction produced in the cement hydration process by silica contained in nickel slag. The use of nickel slag shows two influences in concrete, namely as a fine aggregate and as a pozzolan material.

The use of nickel slag as fine aggregate in concrete mixtures can provide advantages, which are of economic value because the materials used in making concrete are waste. In addition, this research is one solution in overcoming nickel *slag* waste which until now is increasing.

5. CONCLUSION

The conclusions that can be drawn from this study are as follows:

1. The results of the slump test are obtained, the use of nickel slag as a substitute for fine aggregate has an effect on the level of concrete workability.
2. Based on the results of concrete compressive strength testing, the addition of 50% nickel slag as a fine aggregate can increase concrete strength by 25.8% at the age of 56 days. While with the use of 100% nickel slag decreased at the age of 28 days when compared to normal concrete (0% nickel slag), but had compressive strength that was almost the same as normal concrete (0% nickel slag) at the age of 56 days.
3. The use of nickel slag as fine aggregate in concrete mixtures can provide advantages, which are of economic value because the materials used in making concrete are waste. In addition, with the use of nickel slag as a substitute for fine aggregate, it can reduce the use of natural sand.

REFERENCES

Bendixen M, Best J, Hackney C, Iversen LL. 2019. *Time Is Running out for Sand*. Nature Publishing Group.

Chen, Yuning, Tao Ji, Zhengxian Yang, Wei Zhan, and Yong Zhang. 2020. "Sustainable Use of Ferronickel Slag in Cementitious Composites and the Effect on Chloride Penetration Resistance." *Construction and Building Materials* 240: 117969. https://doi.org/10.1016/j.conbuildmat.2019.117969.

Cho, Bong Suk, Young Uk Kim, Do Bin Kim, and Se Jin Choi. 2018. "Effect of Ferronickel Slag Powder on Microhydration Heat, Flow, Compressive Strength, and Drying Shrinkage of Mortar." *Advances in Civil Engineering* 2018. https://doi.org/10.1155/2018/6420238.

Choi, Young Cheol, and Seongcheol Choi. 2015. "Alkali-Silica Reactivity of Cementitious Materials Using Ferro-

Nickel Slag Fine Aggregates Produced in Different Cooling Conditions." *Construction and Building Materials* 99: 279–87. https://doi.org/10.1016/j.conbuildmat.2015.09.039.

Dan Gavriletea, Marius. 2017. "Environmental Impacts of Sand Exploitation. Analysis of Sand Market." *Sustainability (Switzerland)* 9 (7). https://doi.org/10.3390/su9071118.

Koehnken L, Rintoul M. 2018. *Impacts of Sand Mining on Ecosystem Structure. Swiss: Process & Biodiversity in Rivers WWF*.

Liu, Qiong, Shanghong Chen, Wei Lin, Ai Qi, and Zhaohui Chen. 2020. "Experimental Behaviors of Prefabricated Members Made of Ferronickel Slag Concrete." *Construction and Building Materials* 261. https://doi.org/10.1016/j.conbuildmat.2020.120519.

Liu, Xiaoming, Tingyu Li, Weiguang Tian, Y. Wang, and Y. Chen. 2020. "Study on the Durability of Concrete with FNS Fine Aggregate." *Journal of Hazardous Materials* 381 (January 2019): 120936. https://doi.org/10.1016/j.jhazmat.2019.120936.

M. Naveen Saviour. 2012. "Environmental Impact of Soil and Sand Mining: A Review." *International Journal of Science, Environment* 1 (3): 125–34.

Mundra, Sanjay, P.R. Sindhi, Vinay Chandwani, Ravindra Nagar, and Vinay Agrawal. 2016. "Crushed Rock Sand – An Economical and Ecological Alternative to Natural Sand to Optimize Concrete Mix." *Perspectives in Science* 8: 345–47. https://doi.org/10.1016/j.pisc.2016.04.070.

Newman, John, and Ban Seng Choo. 2003. "Advanced Concrete Technology." *Advanced Concrete Technology*, 1–1433. https://doi.org/10.1016/B978-0-7506-5686-3.X5246-X.

Nguyen, Quang Dieu, M. S. H. Khan, Arnaud Castel, and Taehwan Kim. 2019. "Durability and Microstructure Properties of Low-Carbon Concrete Incorporating Ferronickel Slag Sand and Fly Ash." *Journal of Materials in Civil Engineering* 31 (8): 1–13. https://doi.org/10.1061/(asce)mt.1943-5533.0002797.

Padmalal, D, K Maya, Environmental Impacts, and Selected Case Studies. 2014. *Sand Mining*. New York: Springer.

Saha, Ashish Kumer, and Prabir Kumar Sarker. 2017. "Sustainable Use of Ferronickel Slag Fine Aggregate and Fly Ash in Structural Concrete: Mechanical Properties and Leaching Study." *Journal of Cleaner Production* 162: 438–48. https://doi.org/10.1016/j.jclepro.2017.06.035.

Sugiri, Saptahari. 2005. "Penggunaan Terak Nikel Sebagai Agragat Dan Campuran Semen Untuk Beton Mutu Tinggi." *Jurnal Infrastruktur Dan Lingkungan Binaan* 1 (1).

Torres, By Aurora, and Jodi Brandt. 2017. D011087a2B8B72C828Fa3E4F92910E3a.

Yang, Tao, Zuhua Zhang, Qiang Wang, and Qisheng Wu. 2020. "ASR Potential of Nickel Slag Fine Aggregate in Blast Furnace Slag-Fly Ash Geopolymer and Portland Cement Mortars." *Construction and Building Materials* 262: 119990. https://doi.org/10.1016/j.conbuildmat.2020.119990.