

## An Innovation of High Performance Concrete by Replacing Cement with Nickel Slag Powder

Bunga Yubi Nabiilah<sup>1</sup>, L. Oksri-Nelfia<sup>2\*</sup>, Sotya Astutiningsih<sup>3</sup>

<sup>1</sup>Student, <sup>2</sup>Lecturer, Jurusan Teknik Sipil, Universitas Trisakti, Jakarta

<sup>3</sup>Associate Professor, Departemen Teknik Metalurgi dan Material, Universitas Indonesia, Jakarta

\*email: [lisa@trisakti.ac.id](mailto:lisa@trisakti.ac.id)

### ABSTRACT

Nickel slag is a solid waste produced from the nickel smelting process. At present, in Indonesia, the total capacity of domestic nickel smelting reaches 5 million tons/year with the assumption of NPI or FeNi production with a Ni level of 10%, requiring the input of Ni ore raw materials around 40 million tons/year in which around 30 million tons will become waste/slag. Currently, the area of Southeast Sulawesi has a potential of huge nickel resources of 97.4 billion tons, which spread over 480 thousand hectares of land. This has led to a continuous increase in the demand of concrete towards infrastructural development in Indonesia. Therefore, the aim of this research is to reuse nickel slag powder in the context of environmentally friendly by analyzing the tensile strength using nickel slag powder (NSP) as a cement substitution material for the manufacture of high-performance concrete. Specimens were made with water-cement ratio of 0.31 and compared with 100% OPC Type 1 cement (as reference). Furthermore, the NSP substitution of cement were 5%, 10%, 15%, 20%, 25% and 30% with a concrete age of 3, 7, 14 and 28 days. Analysis of physical characteristics of nickel slag powder and cement were carried out by using the Le Chatelier method, while the mechanical characteristics comprised ease of work in the field (workability) and split tensile strength. The manufactured concrete was made by using Sika Viscocrete 8015 superplasticizer admixture with split tensile strength test results for NSP

substitution at 28 days  $\geq$  5% of the value of compressive strength.

**Keywords:** High-performance concrete, Nickel slag powder, Split tensile strength,

### INTRODUCTION

The development of science in concrete technology has made it possible for the optimization of waste products. Therefore, many studies seek to improve the quality of coarse or fine aggregate using substitute materials. Furthermore, nickel slag powder is also used as an additive to increase the adhesion of its binder.

PT. INCO produces around 70,000 - 72,000 tons of nickel slag annually. Nickel mining waste at this company is managed by PT. Growth Java which has the authority to prevent it from being hazardous and toxic (B3). This research utilized nickel slag as a partial substitution of cement to produce high strength concrete. The reuse of nickel slag powder (NSP) for the manufacture of new concrete is an effort to be attentive to environmental sustainability given the amount of nickel slag that has accumulated in large amounts in Southeast Sulawesi.

According to Sudarsana (2015), the use of nickel slag in concrete mixtures tends to improve its mechanical properties with reference to the compressive strength. Some of the concrete produced with waste had higher strength, performance, and durability than the conventional concrete (Al-Jabri, K. S., Hisada, M., Al-Saidy, A. H., & Al-Oraimi, 2009). Tests were conducted to investigate the

performance of NSP as a cement substitution in the strength of concrete. This research aims to further examine the positive impact of this powder on the strength of concrete and determines the possibility of using this waste as an alternative to natural materials in the future. Furthermore, the tests presented consist of Workability and Split tensile strength.

### **Research objective**

The objective of this research is as follows:

1. To determine the effect of using NSP as a substitute for cement on mechanical characteristics (split tensile strength) in high-performance concrete.
2. To determine the possibility of using NSP as a substitute for cement.

### **Novelty of Research**

NSP was used as a substitute for cement in the manufacture of high strength concrete. Prior to this research, no studies have been conducted to specifically examine this substitution of using high magnesium of nickel slag powder. Furthermore, the physical and mechanical characteristics of nickel slag powder were analyzed.

### **Research Limitations**

The following are the limitations of this study:

1. Nickel slag powder used in this study was obtained from PT. Growth Java, Cilegon.
2. Mechanical testing of mixed concrete materials was carried out in the Laboratory of PT. Jaya Beton Indonesia.
3. The split tensile strength tests were carried out within a period of 3, 7, 14 and 28 days with 0%, 5%, 10%, 15%, 20%, 25% and 30% using a superplasticizer type Sika Viscocrete 8015.
4. This research uses Ordinary Portland Cement (OPC Type 1) with coarse

aggregate max was 20 mm and fine aggregate max was 5 mm.

## **LITERATURE REVIEW**

### **High-performance concrete by replacing cement**

Environmental pollution is directly proportional to the material resources and the greenhouse effect; therefore, it is important to minimize energy impacts and CO<sub>2</sub> during construction. This research creates new environmentally friendly materials through concrete durability, material conservation, use of waste, and SCMs (Supplementary Cementing Materials) and concrete recycling (Oksri-Nelfia, L., Mahieux, P. Y., Amiri, O., Turcry, P., Lux, 2016). Wastes and SCMs such as fly ash, GGBFS (Granulated Blast Furnace Slag), silica fume, rice husk ash, and metakaolin can be used as partial replacements for cement. These materials have the ability to increase the durability of concrete, reduce the risk of thermal cracking and CO<sub>2</sub> (Berndt, 2009).

Scientists focused on the high percentage of cement replacement using other alternative materials capable of increasing concrete durability (Sun, L., Zhao, Q., Xiang, J., Shi, J., Wang, L., Hu, S., Su, 2007). One of the studies using different types of NSP and partial substitution as an aggregate of cement in high strength concrete was carried out by Sugiri (2005). Al-Jabri, K. S., Hisada, M., Al-Saidy, A. H., & Al-Oraimi (2009) concluded that the effect of cement substitution with copper slag increases the strength of concrete.

Based on the available literature, this study further examines the use of this substance as a substitute for cement in high strength concrete.

### **The effect of cement substitution with NSP**

This research used NSP which was crushed by PT. Growth Java with grain size <0.075 mm. The chemical composition analysis shows that high levels of MgO in it fails to reduce the strength of concrete (Wang, W. H., Li, H., Ge, L. J., Yang, D. Y., Yue, 2014). In

addition, the study of NSP used 0%, 20%, 30% of this substitute of cement with a water-cement ratio of 0.47 (Oksri-Nelfia, L., AKbar, R and Astutiningsih, 2019) to eliminate the use of waste in making normal concrete. It is concluded that the best partial cement substitution of NSP is 10% ~ 20%, while the specific surface area is 480 m<sup>2</sup>/kg to 540 m<sup>2</sup>/kg. In general, the substitution of 20% NSP with a specific surface area of 306 m<sup>2</sup>/kg contributes positively to the mechanical properties of concrete and produces good durability.

## RESEARCH METHODOLOGY

### NSP characterization

The object of research is nickel slag processed by PT. Growth Java, Cilegon, with its characteristics derived from X-Ray Fluorescence testing (XRF) (Astutiningsih, S., Suharno, 2019) as it is shown in Table 1.

Table 1. Chemical and mineral characterization

Parameter	Analysis
	(XRF) #200
Ni	0.02
Co	n/a
Fe	2.78
Fe <sub>2</sub> O <sub>3</sub>	1.7
CaO	24.73
MgO	19.4
Na <sub>2</sub> O	0.22
Al <sub>2</sub> O <sub>3</sub>	9.6
SiO <sub>2</sub>	41.18
P <sub>2</sub> O <sub>5</sub>	0
SO <sub>3</sub>	0.93
K <sub>2</sub> O	0.2
TiO <sub>2</sub>	0.25
Cr	1.04
Cr <sub>2</sub> O <sub>3</sub>	0.66
MnO	0.82
Moisture	n/a
LOI	n/a

The results of XRF (Astutiningsih, S., Suharno, 2019) above show that NSP contains silica, alumina, calcium, and magnesia which is quite high. To ensure the grain size used in this study was <0.075 mm, the powder was sieved with a #200 sieve with the granules referred to as NSP. Physical characterization was carried out by testing the density of NSP using the "Le Chatelier method" (refer to ASTM C.188) at the Concrete Laboratory of Trisakti University. The density of NSP value is later used as an indicator to design a mixture of concrete.

### Concrete Composition with Nickel Slag Powder Substitution

The use of NSP in concrete mix design composition is 0%, 5%, 10%, 15%, 20%, 25% and 30%. Mix designs were made according to SNI 03-6468-2000 regulations which refer to ACI 211.4R-93 with a water-cement ratio was 0.31. Figure 1 showed the illustration of the concrete mix composition. This study uses a superplasticizer mixture because the small amount of water-cement ratio causes difficulty in making concrete in the field, with the superplasticizer used to increase the workability value.

### Concrete Substitution Nickel slag powder specimens

This research utilized three specimens for each test (3, 7, 14 and 28 days). The concrete workability test was carried out using a slump test with Abrams cones (H = 150 mm, Ø = 100 mm), while the split strength test was carried out on cylindrical specimens (Ø = 100mm and H = 200mm). The slump test refers to SNI 1972-2008 with the specimens stored in water at a temperature of 20 °C (water curing) prior to the split strength test time (3, 7, 14 and 28 days). The calculation of split tensile strength is based on SNI 2491:2014 (2014).

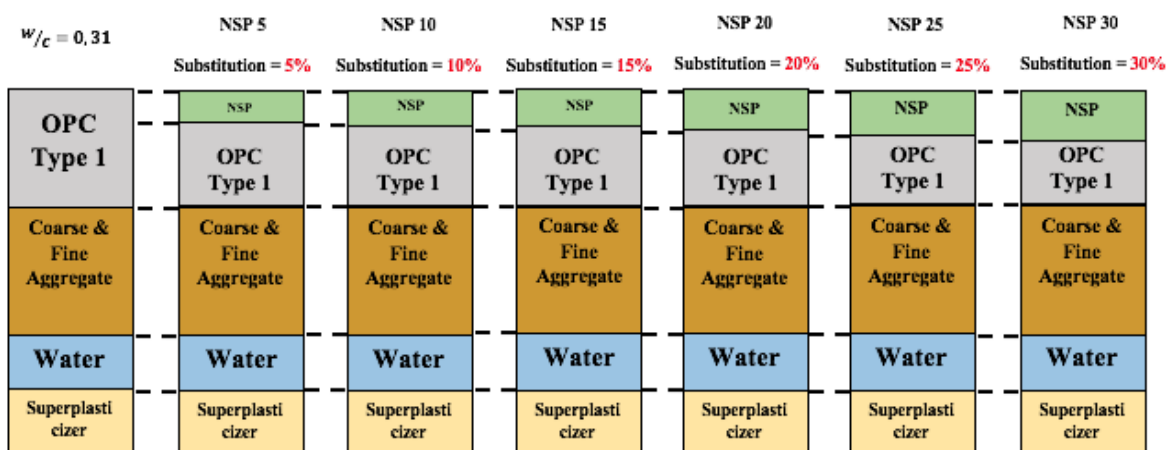


Figure 1. Illustration of concrete mix composition

## RESULT AND DISCUSSION

### Physical Characterization of Nickel slag powder

The physical characteristics test for NSP and cement was carried out using the Le Chatelier method. The test results show that NSP has a lighter density than cement (Table 2).

Table 2. Physical analysis of NSP and cement

Materials	Density ( $g/cm^3$ )
OPC Type 1	3.14
NSP	2.797

According to Sugiri (2005), the lighter density of nickel slag allows the use of it as the cement substitution, because the finer the powder, the closer the surface area ability approaches the cements smoothness. Both substances are evenly spread on a concrete paste mixture to increase its strength.

### Composition and properties of high-performance concrete

NSP is used as supplementary cementitious materials (SCMs) with a substitution of 0%, 5%, 10%, 15%, 20%, 25% and 30%. The calculation of concrete mix design is based on SNI 03-6468-2000

which refers to ACI 211.4R-93 (Table 3) although this regulation governs the manufacture of high-performance concrete using fly ash. This material is one type of pozzolanic material. Nickel slag powder is also included in the type of pozzolanic material which has been confirmed by the XRF analysis results based on  $W/(c+p)$  ratio of 0.31. The superplasticizer used in this study was Sika Viscocrete 8015, while the gravel used to mix its composition was 20 mm, sand, and OPC Type 1 cement from Indocement Tunggul Prakarsa, Tbk. In addition, 0% of cement substitute samples were used as a comparison.

The mold had a diameter of 10 cm and a height of 20 cm, with a total of 17 samples used to conduct a cast. The proportion of superplasticizer (SP) is 1% of the mass of cement.

Table 3. Composition and properties of high-performance concrete

Material	Ref	NSP 5	NSP 10	NSP 15	NSP 20	NSP 25	NSP 30
Water (kg/m <sup>3</sup> )	96.32	84.86	85.14	85.42	85.70	85.98	86.26
OPC Type 1 (kg/m <sup>3</sup> )	591.94	562.34	532.74	503.15	473.55	443.95	414.35
NSP (kg/m <sup>3</sup> )	0	29.60	59.19	88.79	118.39	147.98	177.58
Gravel 10/20 mm (kg/m <sup>3</sup> )	1109.38	1109.38	1109.38	1109.38	1109.38	1109.38	1109.38
Sand 0/5 mm (kg/m <sup>3</sup> )	590.85	587.54	584.22	580.90	577.58	574.26	570.94
Superplasticizer (kg/m <sup>3</sup> )	5.92	5.62	5.33	5.03	4.74	4.44	4.14
Slump (mm)	210	230	230	240	250	250	250

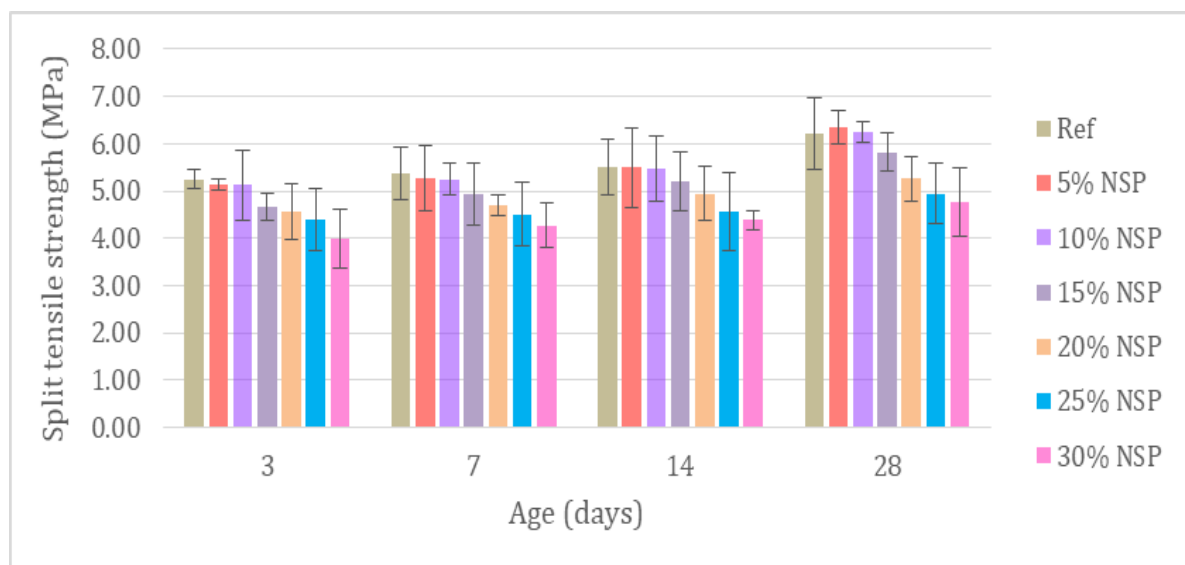


Figure 2. Split tensile strength on concrete with Nickel slag powder substitution

### The influence of Nickel slag powder on Split tensile strength

The actual slumps obtained were 210 mm, 230 mm, 230 mm, 240 mm, 250 mm, 250 mm and 250 mm (Table 3) for each percentage substitute of cement while the value of split tensile strength increases to 14-day concrete. The 28-day samples with 5% and 10% NSP produce higher split tensile strength compared to OPC type 1 (Figure 2). Furthermore, the use of copper slag increases the split tensile strength of

concrete by 5.76% (Karimah, 2016). Higher-strength of the NSP substitution concrete is due to the pozzolanic reaction. This result is supported by research conducted by Ashad (2008) which states that nickel waste is a pozzolanic material. The average split tensile strength according to SNI 2491: 2014 is 2.8 MPa (405 psi).

## CONCLUSION

The conclusions of this study are:

Nickel slag powder has the ability to be used as alternative construction or Supplementary Cementitious Materials (SCMs) and appears as an eco-friendly material.

Slag waste powder increases split tensile strength. This result is supported by Karimah (2016) which states that the shape and texture of slag affect the density of concrete to increase split tensile strength. The average split tensile strength specimens were  $5 \pm 1.2$  MPa in any NSP substitution. It means that NSP has the ability to be used as a substitute for OPC Type 1.

The value of split tensile strength on 28-day concrete reaches  $\geq 5\%$  of the compressive strength testing results conducted by the researchers with successive substitutions of 5%, 10%, 15%, 20%, 25% and 30%, namely 80.49 MPa, 82.94 MPa, 82.28 MPa, 79.98 MPa, 77.89 MPa, 77.26 MPa and 73.80 MPa.

## ACKNOWLEDGMENTS

The authors wish to express their gratitude to PT. Jaya Beton Indonesia-Bitung; PT Indocement Tunggal Prakarsa Tbk and PT. Growth Java for the support provided during the administering of this research.

## REFERENCES

- Al-Jabri, K. S., Hisada, M., Al-Saidy, A. H., & Al-Oraimi, S. K. (2009). Construction and Building Materials. *Performance of High Strength Concrete Made with Copper Slag as a Fine Aggregate.*, 23(6), 2132–2140. <https://doi.org/https://doi.org/10.1016/j.conbuildmat.2008.12.013>
- Ashad, H. (2008). Kontribusi Bubuk Slag Nikel di dalam Meminimalkan Dampak Intrusi Mikroorganisme terhadap Perilaku Fisik Material Beton (Contribution of nickel slag powder in minimizing the impact of microorganism intrusion on the physical behavior concrete materials. *Jurnal Teoritis Dan Terapan Bidang Rekayasa Sipil*, 15, (1), 1–14.
- Astutiningsih, S., Suharno, B. (2019). Ni Slag Valorisation in Indonesia: A case study slag characterization. In *6th International Slag Valorisation Symposium*. Mechelen.
- Berndt, M. L. (2009). Properties of sustainable concrete containing fly ash, slag and recycled concrete aggregate. *Construction and Building Materials*, 23(7), 2606–2613. <https://doi.org/https://doi.org/10.1016/j.conbuildmat.2009.02.011>
- Karimah, R. (2016). Kajian Penggunaan Copper Slag sebagai agregat halus beton (Study of Copper Slag as Fine Aggregate Concrete), 14 (2). <https://doi.org/https://doi.org/10.22219/jmts.v14i2.3710>
- Oksri-Nelfia, L., AKbar, R and Astutiningsih, S. (2019). Pemanfaatan terak nikel dalam bentuk bubuk sebagai substitusi parsial semen pada beton normal (Utilization of nickel slag powder as a partial substitution of cement in normal concrete). In *KonTeks Proceeding*. Aceh (To be Published).
- Oksri-Nelfia, L., Mahieux, P. Y., Amiri, O., Turcry, P., Lux, J. (2016). Reuse of recycled crushed concrete fines as mineral addition in cementitious materials. *Materials and Structures/Materiaux et Constructions*, 49(8), 3239–3251. <https://doi.org/https://doi.org/10.1617/s11527-015-0716-1>
- SNI 2491:2014. (2014). *Metode Uji Kekuatan Tarik Belah Spesimen Beton Silinder (Tensile strength test method for cylinder concrete specimens)*.
- Sudarsana, K. (2015). Mechanical properties of concrete using nickel slag as coarse aggregate. In *The 5th Environmental Technology and Management Conference "Green Technology towards Sustainable Environment*. Bandung, Indonesia.

Sugiri, S. (2005). Penggunaan Terak Nikel Sebagai Agregat Dan Campuran Semen untuk Beton Mutu Tinggi (Use of Nickel Slag as An Aggregate and Cement Mixture for High-Quality Concrete. *Infrastructure and Built Environment Journal*, 1(1).

Sun, L., Zhao, Q., Xiang, J., Shi, J., Wang, L., Hu, S., Su, S. (2007). Effect of Anions on Preparation of Ultrafine Alpha-Al<sub>2</sub>O<sub>3</sub> Powder. *J. Cent. South Univ. Technol*, 14(6), 773–778. <https://doi.org/https://doi.org/10.1007/s11771>

Wang, W. H., Li, H., Ge, L. J., Yang, D. Y., Yue, H. (2014). Research on Nickel Slag Powder as Concrete Mineral Admixture. *Advanced Materials Research*, 1065–1069; 1825–1832. <https://doi.org/https://doi.org/10.4028/www.scientific.net/amr.1065-1069.1825>