TEKNIKA: JURNAL SAINS DAN TEKNOLOGI

Homepage journal: http://jurnal.untirta.ac.id/index.php/ju-tek/

The effect of composition and shape variations on compressive strength slag depressant

Bening Nurul Hidayah Kambuna [a,1], *Soesaptri Oediyani* [a,2], *Della Izzaty Salman* [a], *Kusnadi* [a]

[a]*Department of Metallurgical Engineering, Faculty of Engineering, Universitas Sultan Ageng Tirtayasa, Jl. Jenderal Sudirman KM. 03, Cilegon City 42435, Indonesia*

[1]*E-mail: bening.kambuna@untirta.ac.id*
[2]*E-mail: s_oediyani@untirta.ac.id*

ARTICLE INFO

Article history:
Submitted 12 September 2021
Reviewed 12 September 2021
Received 20 October 2021
Accepted 25 October 2021
Available online on 1 November 2021

Keywords:
Slag foam, slag, blast furnace, porositas kuat tekan.

Kata kunci:
Slag foam, slag, blast furnace, porosity, compressive strength.

ABSTRACT

The steel-making process begins with a reduction process carried out in a blast furnace (BF) then continues with the refining process in the converter. In the refining process, there is a slag foam that is formed from the reaction of oxygen with hot metal. To reduce the formation of foam in the slag, an additive called a slag depressant is needed. Slag depressants are made using paper mill waste, limestone, and slag blast furnaces. This study aims to increase the compressive strength of the slag depressant by varying the composition and shape variations. Variations in the composition used were with and without the addition of BF slag, while variations in the shapes used were cylinder, round, and cube. The process of making slag depressants begins with the stages of mixing, compacting, and drying. Slag depressant drying is carried out in the sun for ± 8 days. The slag depressant raw material was analyzed using the XRF method to see the chemical composition of the raw material. The resulting slag depressant was then analyzed for proximate analysis, compression test, drop test, and porosity test. In this study, the best quality slag depressant with high compressive strength and low porosity values is the slag depressant in a cylindrical shape and the ratio of paper waste to limestone is 80:20%. The resulting compressive strength value is 1207.5 N/cm^2 and has a porosity of 34.7%. The addition of BF slag in this study was proven to affect the compressive strength of the slag depressant. The highest compressive strength value was achieved in the addition of 10% slag blast furnace to 10%, which was 862.08 N/cm^2.

ABSTRAK

Proses pembuatan baja diawali dengan proses reduksi yang dilakukan dalam *blast furnace* (BF) kemudian dilanjutkan dengan proses pemurnian dalam *converter*. Dalam proses pemurnian, terdapat gelembung/busa *slag* (*slag foam*) yang terbentuk dari reaksi oksigen dengan *hot metal*. Untuk mengurangi pembentukan busa pada *slag* maka diperlukan bahan aditif yang disebut dengan *slag depressant*. *Slag depressant* dibuat dengan menggunakan limbah pabrik kertas, batu kapur, dan *slag blast furnace*. Penelitian ini bertujuan untuk meningkatkan kekuatan tekan *slag depressant* dengan melakukan variasi komposisi dan variasi bentuk. Variasi komposisi yang digunakan yaitu dengan dan tanpa penambahan *slag* BF sedangkan variasi bentuk yang digunakan yaitu silinder, bulat, dan kubus. Proses pembuatan *slag depressant* diawali dengan tahapan *mixing*, kompaksi dan pengeringan. Pengeringan *slag depressant* dilakukan di bawah sinar matahari ± 8 hari. Bahan baku *slag depressant* dianalisis dengan metode XRF untuk melihat komposisi kimia bahan baku tersebut. *Slag depressant* yang dihasilkan kemudian dilakukan analisis proksimat, uji tekan, uji jatuh dan uji porositas. Pada penelitian ini didapatkan *slag depressant* dengan kualitas paling baik dengan nilai kuat tekan tinggi dan porositas rendah yaitu pada *slag depressant* bentuk silinder dan perbandingan limbah kertas dengan batu kapur sebesar 80: 20 %. Nilai kuat tekan yang dihasilkan sebesar 1207,5 N/cm^2 dan porositas sebesar 34,7%. Penambahan *slag* BF dalam penelitian ini terbukti mempengaruhi kuat tekan *slag depressant*. Nilai kuat tekan tertinggi dicapai pada penambahan 10% slag blast furnace 10% yaitu sebesar 862,08 N/cm^2.

Available online at http://dx.doi.org/10.36055/tjst.v17i2.12371

1. Introduction

In refining iron using a converter, there are slag bubbles (slag foam) formed from the reaction of oxygen with hot metal. Slag foam formed can spill so that it can cause loss of molten metal and reduce productivity. A substance known as a slag depressant is required to minimize foam production in the slag. Slag depressant serves to break down slag foam that arises during the purification process. Slag foam is broken down to release the gas trapped in the bubble so that the gas can be released out [1]. If the compressive strength of the steel is too high, a slag depressant is used. The sample observed for this study still has a compressive strength of 700-800 N/cm^2. If the value is below 1500 N/cm^2, it will cause problems, including the material being not optimal in breaking slag bubbles, easily crushed, and easily agglomerated due to the humidity of the air contained in the storage container or hopper [2].

Slag depressant, which has a compressive strength value below 1500 N/cm^2, is easily destroyed because it is difficult to withstand pile loads. In some cases, slag depressant is very susceptible to agglomeration in the hopper because of its high moisture content and compressive strength below 1500 N/cm^2. As a result, the slag depressant is easily destroyed and causes blockages in the hopper. As a result of these issues, research was done to increase the quality of the slag depressant's strength so that it is not readily damaged. The methods used in this research are the compression test, the drop test, and the porosity test. The expected target with this research is to produce a slag depressant with compressive strength, density, volatile matter values following the standard slag depressant to avoid clumping in the hopper and slag foaming problems.

2. Research Methodology

The research was conducted by mixing raw materials in organic materials (paper mill waste), limestone, blast furnace slag. At the initial stage, the characterization of raw materials was carried out using the x-ray fluorescence (XRF) method to determine the chemical composition of the raw materials. Furthermore, the formation of slag depressants with variations in cylinders, rounds, and cubes with different composition ratios has been determined. Then it is dried in the sun.

Furthermore, proximate analysis, compression tests, porosity tests, and slag depressant drop tests were carried out. The slag depressant porosity test was carried out using the water boiling method. This research is divided into two stages. Waste paper and limestone composition were varied in the first stage, namely 3:2; 2:3; 1:1; 4:1; 1:4. The second stage is the blast furnace slag, which is added as much as 10%, 20%, and 30%. The addition of blast furnace slag is carried out along with reducing the limestone composition. Then the formation of slag depressants with round, cube, and cylindrical shapes was carried out on each variation of the slag depressant composition.

3. Results and Discussion

The slag depressant is first characterized for raw materials and then several variations to obtain a higher compressive strength value. Raw materials are paper sludge, slag blast furnace, and limestone as the main component of slag depressant.

3.1. Raw Material Characteristics

At this characterization stage, raw materials are divided based on their shape into two types, namely solid and liquid. The results of the characterization of the two types of raw materials can be seen in Table 1.

Table 1. Raw material composition

No.	Component	Result (%mass)		
		Paper sludge	Slag blast furnace	Limestone
1.	Al	ND	3.5300	2.5400
2.	Si	0.5150	7.2200	1.7400
3.	P	0.2950	0.9590	1.3900
4.	S	0.0899	0.4380	0.1960
5.	Cl	0.0512	0.0534	0.0468
6.	K	0.0971	0.5470	0.4190
7.	Ca	6.5300	24.8000	47.5000
8.	Ti	0.0368	0.2390	0.0715
9.	V	0.0053	0.0083	0.0219
10.	Cr	0.0065	0.0501	0.0326
11.	Mn	0.0056	0.1320	0.0514
12.	Fe	0.1150	0.7300	1.0800
13.	Co	0.0020	0.0093	0.0145
14.	Ni	0.0019	0.0125	0.0098
15.	Cu	0.0039	0.0051	0.0077
16.	Zn	0.0161	0.0022	0.0072

In Table 1, the main composition of the paper mill waste used is calcium (Ca), with a content of 6.53%, while the other elements are impurities. The results of limestone characterization show that limestone has the main content of calcium (Ca) with a level of 47.5%. The analysis results using XRF show that the limestone used in this study is CaCO3 limestone. The results of slag blast furnace characterization showed that blast furnace slag has the main content of calcium (Ca) and silica (Si) with levels of 24.8% and 7.22%, respectively.

3.2. Slag Depressant Proximate Analysis

Proximate analysis was carried out to determine the value of ash, volatile matter, and inherent moisture of the slag depressant. Slag depressant is declared to be of good quality if it follows predetermined conditions. The proximate analysis carried out in this study uses the ASTM D 3172 standard regarding Standard Practice for Proximate Analysis of Coal and Coke [3]. There are five samples written 1d to 5d based on differences in composition.

Table 2. Composition of sample slag depressant

No.	Sample	Composition (%)	
		Paper sludge	Limestone
1.	1d (3:2)	60	40
2.	2d (2:3)	40	60
3.	3d (1:1)	50	50
4.	4d (4:1)	80	20
5.	5d (1:4)	20	80

Table 3. Slag depressant proximate analysis result

No.	Name	Proximate analysis		
		Ash (%)	Moisture (%)	Volatile Matter (%)
1.	1d	52.40	2.36	48.25
2.	2d	54.99	2.59	45.70
3.	3d	53.32	2.15	47.29
4.	4d	46.29	4.17	54.56
5.	5d	56.95	1.10	43.32

Based on Table 3, the slag depressant that has been made in this study has good quality because the results of the proximate analysis show conformity with the specifications of the slag depressant. The value of volatile matter that is more than 20% will affect the combustion process so that the slag depressant can burn quickly and break the slag bubbles on the surface of the molten iron [4]. The result follows research conducted by Fernandez Anez in 2014 that showed the higher the volatile matter content, the easier it is for a material to burn [5]. Meanwhile, if the water content is more than 15%, it will also provide high resistance for slag depressants to be flammable (flammability) [6]. Therefore, the slag depressant must have the lowest possible moisture content, which is <15%, and the optimal moisture content for the slag depressant is 3%.

3.3. The Effect of Shape Variations on Slag Depressant Compressive Strength

Slag depressants used today have certain specifications, including having a compressive strength of around 1500 N/cm^2. Variations in the composition and form of the slag depressant were carried out in this research to get the value of compressive strength following the requirements of the slag depressant. The shape variation used is a cube using a wooden mold, a cylinder using a porcelain mold, and a round shape made manually with a weight of 20 grams. The slag depressant that has been made is then carried out in the drying stage. The drying process aims to reduce the moisture content contained in the slag depressant. Drying is done with the help of direct sunlight for ± eight days. The form of the slag depressant in this study is shown in Figure 1.

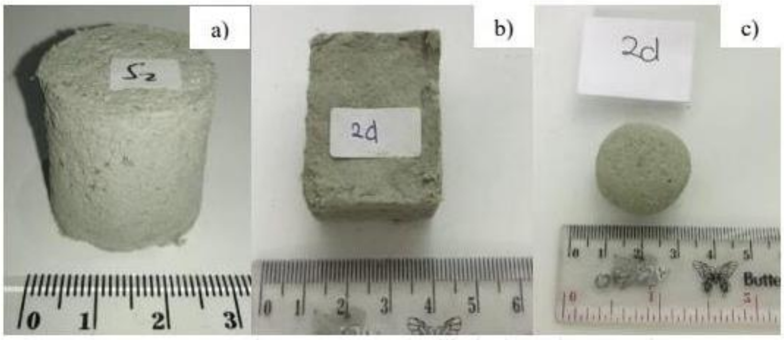

Figure 1. Slag Depressant a) Cylinder b) Cube c) Round.

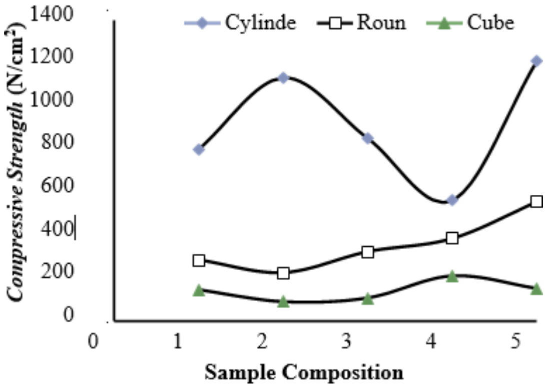

Figure 2. Graph of the effect of shape variations on slag depressant compressive strength.

The compressive strength of a material can decrease with an increase in the cross-sectional area of the specimen. Figure 2 shows that the cylindrical slag depressant has the highest compressive strength value compared to round and cube shapes. In this study, the cross-sectional area of the cube shape specimen has a value of 96 cm^2, the cylindrical shape specimen has a value of 86.51 cm^2, and the round shape specimen is 113.04 cm^2. The compressive strength of cube specimens is usually higher than that of cylindrical shapes [7].

The compressive strength of the spherical shape specimen has a low value because the cross-sectional area of the specimen has the highest value among cylindrical and cube specimens. Slag depressant with high compressive strength is owned by composition 5, which is a ratio of 20% paper mill waste and 80% limestone. The use of limestone with increasing amounts of 80% aims to increase the density of the slag depressant. Limestone can also increase the compressive strength of the slag depressant because limestone can increase the specific gravity so that the slag depressant is hard but brittle. This difference in strength indicates that the paper mill waste (sludge) is composed of 60% water, and the rest is in the form of solids so that the slag depressant produced does not have optimal strength to withstand a large enough load [8-9].

3.4. Effect of Addition of Slag Blast Furnace on Compressive Strength of Slag Depressant

The composition of slag depressant with variations in the addition of blast furnace slag in this study is shown in Table 4. The slag blast furnace in this study had the main content of calcium (Ca) and silica (Si) with levels of 24.8% and 7.22%, respectively. Theoretically, the silica element contained in the slag blast furnace has the property of increasing the flexural strength of the raw material and product strength. The results of the compressive strength test of slag depressant with and without the addition of blast furnace slag are shown in Figure 3.

Table 4. Slag depressant composition with and without addition of slag blast furnace

No.	Name	Proximate Analysis		
		Paper mill waste (sludge)	**Limestone**	**Slag blast furnace**
1.	S1	60	30	10
2.	S2	60	20	20
3.	S3	60	10	30
4.	T1	80	20	0
5.	T2	60	40	0
6.	T3	50	50	0

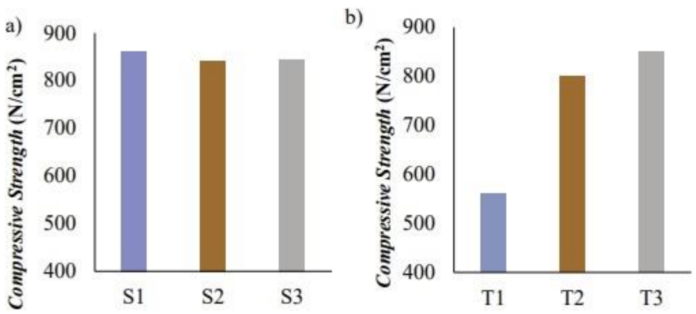

Figure 3. Graph of slag depressant compressive strength
a) with the addition of a slag blast furnace b) without the addition of a slag blast furnace

The composition of slag depressant with variations in the addition of blast furnace slag in this study is shown in Table 4. The slag blast furnace in this study had the main content of calcium (Ca) and silica (Si) with levels of 24.8% and 7.22%, respectively. Theoretically, the silica element contained in the slag blast furnace has the property of increasing the flexural strength of the raw material and product strength. The results of the compressive strength test of slag depressant with and without the addition of blast furnace slag are shown in Figure 3.

Based on Figure 3, the addition of blast furnace slag is proven to affect the compressive strength of the slag depressant. The addition of blast furnace slag can increase the compressive strength of slag depressant compared to slag depressant without the addition of blast furnace slag. The slag blast furnace will fill the pores formed in the slag depressant to increase the compressive strength. The compressive strength increases with increasing silica (Si) content [10]. Slag has a high content of SiO_2, Al_2O_3, and Fe_2O_3, which causes a material to have a tighter bond [11]. Silica particles can fill the space between the slag depressant, thereby reducing the porosity of the slag depressant [12].

3.5. Effect of Addition of Slag Blast Furnace on Compressive Strength of Slag Depressant

Slag depressant porosity testing was carried out to see its effect on compressive strength. Porosity is defined as the percentage ratio of the pore volume of a substance such as a rock layer or rock to the total volume mass [13]. The porosity value strongly influences the compressive strength of a material. If the porosity of a material increases, it will reduce the strength of the material. This is evidenced in Figure 4. The increasing value of porosity can lead to a decrease in the density of the slag depressant so that the strength of the slag depressant decreases. Increasing porosity can reduce the strength of a material, but this can depend on the pore size, shape, and distribution of the pores.

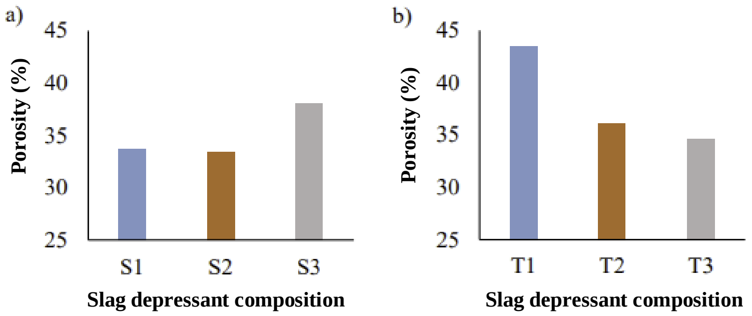

Figure 4. Slag depressant porosity graph
a) with the addition of slag blast furnace b) without the addition of slag blast furnace

3.6. Slag Depressant Shatter Index

Shatter index slag depressant is obtained by performing a drop test. This test is performed to assess the capacity of the slag depressant to sustain the load while fed. The slag depressant drop test results with and without the addition of blast furnace slag are shown in Figure 5.

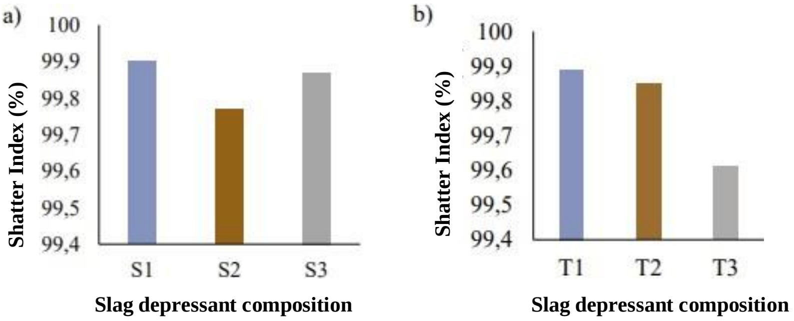

Figure 5. Graph of slag depressant drop test
a) with the addition of a slag blast furnace b) without the addition of a slag blast furnace.

4. Conclusions

The compressive strength of slag depressant increased compared to the initial sample from the industry, which was around 700-800 N/cm^2, although it had not met the target of 1500 N/cm^2. In this study, the maximum strength value is created in a cylindrical form with a value of 1207.5 N/cm^2 and comprises 20% paper waste and 80% limestone.

The addition of blast furnace slag is proven to increase the compressive strength of the slag depressant if done in the same condition. The compressive strength values with slag blast furnace additions of 10%, 20%, and 30% are 862.08, 842.08, and 41 N/cm^2, respectively. In this research, the size of the slag blast furnace is too large to cover the pores of the slag depressant, so it is best to reduce the size first. The slag depressant in the S1 composition has a low porosity value of 33.73%, and the shatter index in the S1 composition has a high value of 99.90%.

Acknowledgements

The authors would like to thank the Metallurgical Laboratory, Faculty of Engineering, University of Sultan Ageng Tirtayasa, which has facilitated the tools and places to conduct research.

REFERENCES

[1] Gugyeonghoe. (2007). *Matters for Depressing Slag Foaming and the Method for Adding It*. South Korea Patent No. 100946375B1.

[2] Kyun, K. M. (2013). *Deslopping Agent of Converter Having Sewage Sludge and Method for Manufacturing the Same*. Korea Patent No. 20130059757A.

[3] ASTM International. (1994). *Standard Test Methods for Proximate Analysis of the Analysis Sample of Coal and Coke by Instrumental Procedures (ASTM D5142-02)*. Society, pp. 1–6.

[4] Sunghyun, T. (2007). *Manufacturing Method of Converter Slag and Converter Slag Thereof*. Korea Patent No. 100880527B1.

[5] Fernandez-Anez, N., Garcia-Torrent, J., & Medic-Pejic, L. (2014). Flammability properties of thermally dried sewage sludge. *Fuel*, vol. 134, pp. 636-643.

[6] Erua, E. (2015). Impact of water content in hydrocarbons using consequence modelling. *Institution of Chemical Engineers Symposium Series*, no. 160, pp. 1-11.

[7] Che, Y., Ban, S. L., Cui, J. Y., Chen, G., & Song, Y. P. (2010). Effect of specimen shape and size on compressive strength of concrete. *Advanced Materials Research*, vol. 163, pp. 1375–1379.

[8] Akbar, Y. (2014). *Pengaruh Penggunaan Bubur Kertas sebagai Material Serat Terhadap Kuat Tekan Beton*. [Final Project]. Bogor: Institut Pertanian Bogor.

[9] Ishimoto, H., Origuchi, T., & Yasuda, M. (2000). Use of papermaking sludge as new material. *Journal of Materials In Civil Engineering*, vol. 12, no. 4, pp. 310-313.

[10] Mustofa, M., & Pintowantoro, S. (2017). The Effect of Si/Al Ratio to compressive strength and water absorption of ferronickel slag-based geopolymer. *IPTEK Journal of Proceedings Series*, vol. 3, no. 2, pp. 167-172.

[11] Karim, G. A., Susilowati, E., & Pratiwi, W. (2018). Pengaruh ground granulated blast furnace slag terhadap sifat fisika Semen Portland jenis-I. *Jurnal Teknologi Bahan dan Barang Teknik*, vol. 8, no. 2, pp. 47-52.

[12] Reddy, C. V., & Ramadasu, D. T. L. (2017). Effect of silica fume on the compressive strength of cement-silica fume mortars. *International Journal of Current Engineering And Scientific Research (IJCESR)*, vol. 4, no. 7, pp. 13-21.

[13] Wang, X., Yang, S., Wang, Y. et al. (2019). Improved permeability prediction based on the feature engineering of petrophysics and fuzzy logic analysis in low porosity–permeability reservoir. *J Petrol Explor Prod Technol*, vol. 9, no. 2, pp. 869–887.