International Journal of GEOMATE, Oct., 2021, Vol.21, Issue 86, pp.9-16
ISSN: 2186-2982 (P), 2186-2990 (O), Japan, DOI: https://doi.org/10.21660/2021.86.Gx282
Geotechnique, Construction Materials and Environment

UTILIZATION OF GGBFS AS CEMENT SUBSTITUTE TO REDUCE PRODUCTION COST OF CONSTRUCTION PROJECT

*Ranti Hidayawanti[1], Yusuf Latief[2], Yusnita Rahayu[1], Fahdun Ibnu Wachid[3], and Rony Panca Adi Widodo[4]

[1]Department of Civil Engineering, Faculty of Territorial Science Engineering, Institut Teknologi PLN, Indonesia; [2]Department of Civil Engineering, Faculty of Engineering, Universitas Indonesia, Indonesia; [3]PT PJB, Indonesia; [4]Adhimix RMC, Indonesia

*Corresponding Author, Received: 30 Nov. 2020, Revised: 12 Aug. 2021, Accepted: 23 Sept. 2021

ABSTRACT: The rapid advancement in construction development is associated with numerous positive and negative impacts. One of the negative impacts is the decrease in natural resources used in cement production, such as limestone. Over the past few years, several kinds of preliminary studies and experiments have been carried out to improve the quality of concrete in terms of additives additions, treatments, improving quality of materials, and use of industrial waste as a reinforcement mixture. However, this study uses waste from burning iron, namely Grand Granulated Blast Furnace Slag (GGBFS) or cement slag, as a substitute because it has similar properties as cement, C_3S_2, increases elasticity, and reduces the heat of hydration. The substitution of fine aggregate with GGBFS is 0%, 25%, 50%, and 75% of the volume cement. From these variations, the most optimal is used to reduce the production cost of construction projects in accordance with initial setting time, compressive strength, linear regression, and slag activity index. The result showed that initial setting time increases with a variation of 75% for the optimum compressive strength test GGBFS. Furthermore, linear regression reaches a value of 0.9781, with a categorized strong relationship and applicable slag index activity values of grades 80, 100, and 120 approaching OPC 100. GGBFS does not only have a significant substitute for cement in concrete rather, it also reduces production cost by 3% and environmentally friendly.

Keywords: GGBFS, Cement, Concrete, Compressive Strength, Production Cost

1. INTRODUCTION

The most common material used in the construction of roads and buildings is concrete. This material is very popular because it is easy to use and naturally obtained from the surrounding environment. Along with the significant use of concrete in construction, cement, which is becoming scarce and expensive, is needed to improve the quality. This led to the use of GGBFS, according to ACI 233R-95 [1], which is a slag furnace of metal or iron with a temperature of approximately 1500° C. GGBFS is used to make strong and durable concrete structures that can be combined with ordinary Portland or other pozzolan materials. When cement is blended with slag, it modifies mineralogical distribution and surface electrical properties, increases tortuosity, and reduces porosity and threshold pore size to show high chloride resistance and better durability performance[2]. GGBFS has been used as a cement substitute in developed countries. However, this is in contrast to Indonesia, where not all constructions have implemented concrete slag waste. Industrial waste is used in the construction sector to improve the quality and compressive strength of concrete because it reduces natural resources. Approximately 70% of construction materials are concrete [3]. Therefore, with the utilization of GGBFS, potential losses are reduced, and money is saved [4]. The purpose of this research is to measure the utilization of GGBFS and determine the optimal percentage from variations of 0%, 25%, 50%, and 75% in the quality of K200 - K700. This research was carried out at Tokyo Apartment construction. From the laboratory test results, it is recommended to utilize GGBFS with a variation of 25% with the quality of the K400.

Figure 1 shows The Tokyo Tower Apartment construction project owned by PT Agung Sedayu Group (ASG) and carried out by PT Multikon, PT Rekaguna Teknik, and PT Pulau Intan implementation time of 356 (three hundred and fifty-six) calendar days starting on 1 August 2019. The Tokyo Tower Apartment construction project comprises 6 towers with 2 from each contractor, of which 5 towers were constructed after the 3rd quarter of 2020. This tower which occupied a land area of 35,000 m^2, a total concrete volume of 300,000 m^3, and foundation work of 56,000 m^3, cost 1.5 trillion rupiahs. Therefore, to minimize the need for cement that is more expensive, it is necessary to innovate and substitute this material with others of the same quality.

In designing concrete used for high-rise buildings, good quality is needed to meet the specifications, including the K200 - K700 concrete quality. This compressive strength calculation is supported by other formulations such as initial setting time (w/c), slag index activity, and linear regression.

Fig.1 Tokyo Apartment Project using GGBFS

2. RESEARCH SIGNIFICANCE

The purpose of this research is to map the GGBFS research on high-strength concrete by considering the calculation of the compressive strength reinforced on the slag index activity and linear regression. It is important to be analyzed because it affects the strength of concrete, for example the results of linear regression analysis if it is close to one means that it can be applied and accounted for in the use of high-level concrete.

3. MATERIALS AND METHODS

Support the fulfillment of concrete are as follows:

a. GGBFS Slag : ex. PT. KSI
b. Natural Sand : Ex Belitung
c. Coarse aggregaten10-25mm : ex. Purwakarta
d. Admixture Type F: Standard Adhimix
e. Cement: Type 1 (OPC) and water: Concrete Standard

Fig. 2a GGBFS

Fig. 2b Natural Sand

Fig. 2c Coarse

Fig. 2d Admix

Fig. 2e Cement

Tools needed are as follows:

a. Mortar Mixer: 1 Unit
b. Mortar Cube Mold 5x5x5 cm : 12 set @ 3 ea
c. Mortar Flow Test: 1 Set
d. Cylindrical Mold D15 X h30 cm : 40 ea
e. Compressive Strength equipment

The unit weight of Mortar and Concrete, specific gravity of cement, GGBFS, sand, gravel, and gradations are determined before the mix design.

Fig. 3a Mortar

Fig. 3b Mortar Cube

Fig. 3c Mortar Flow

Fig. 3d Cylindrical

Fig. 3e Compressive Strength

4. METHODOLOGY

Experiments carried out at the laboratory scale include mortar cube and concrete experiments using a small mixer with a capacity of 100 liters. Variations in mortar experiments are with a mixture of GGBFS 0%, 25%, 50% and 75%. Meanwhile, the concrete experiment was conducted by determining the correlation w/c (cement water factor) to the percentage of GGBFS within the range of w/c K200 – K700.

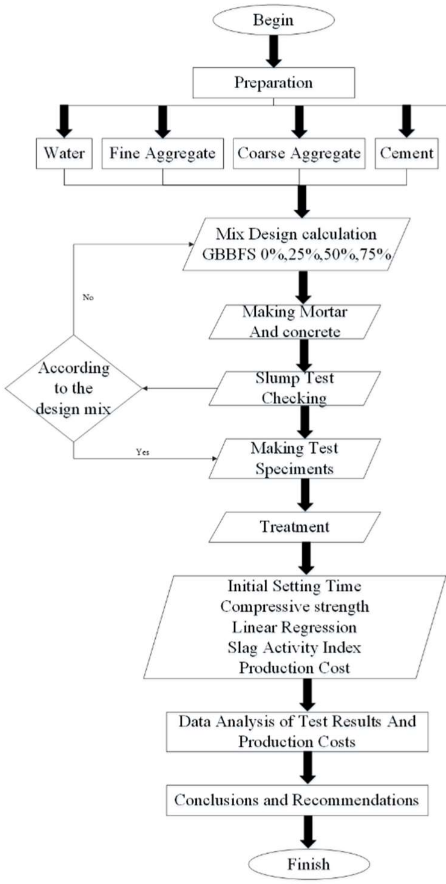

Fig. 4 Research Methodology

To determine the quality of GBFS in addition to direct physical and chemical testing of the slag material, a comparison method is also performed. This is also carried out by determining the laboratory-scale experiments on cube compressive strength of 5x5x5 cm, which refers to the ASTM-C 109 Standard Test Method for Compressive Strength of Hydraulic Cement Mortars [5]. Furthermore, the compressive strength of concrete cylinders 15 x height 30 cm, which refers to ASTM-C39 [6] Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens, is also determined by applying Slag index activity and linear regression.

5. RESULT

5.1 Mortar Experiment

The mortar experiments result conducted 3 (three) times obtained the following average data:

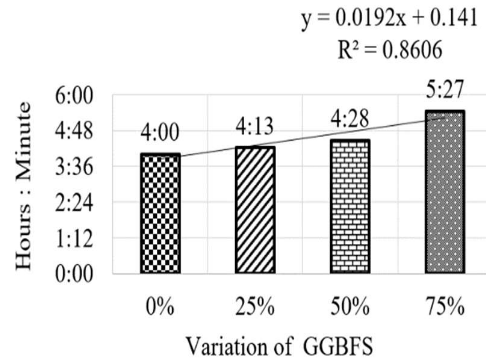

Fig. 5 Initial setting Time of Mortar

Figure 5 shows that the greater use of GGBFS, the longer the initial setting time.

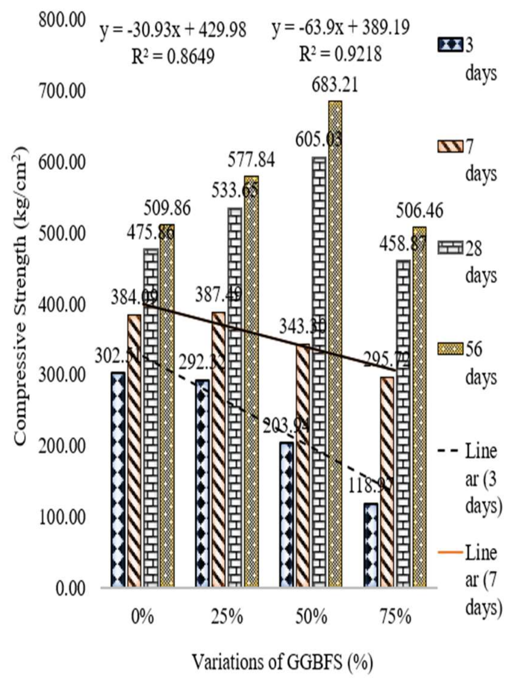

Fig. 6 Mortar Strength Mortar Comparison Number

Figure 6 shows that the greater the use of GGBFS, the lower the compressive strength at the age of 3 and 7 days. However, at the age of 28 days, there was a significant increase capable of exceeding 100% OPC, thereby influencing linear regression value. At the age of 28 and 56 days, the need for water is greater, therefore it is not recommended to use slag.

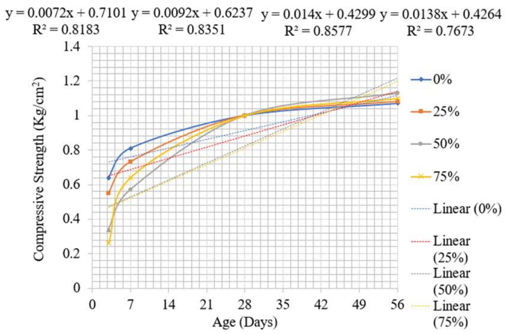

Fig. 7 Development of Mortar Strength

Figure 7 shows that the development of compressive strength using GGBFS at the age of 3 and 7 days is very slow compared to 100% OPC. Therefore, with the development of a 50% variation, the regression value reached 0.8577, meaning that there is a strong relationship between mortar age and compressive strength. The linear regression formulation is as follows:

$$Y = a+bx \quad (1)$$

a = water requirement (ltr/m^3)
b = w/c

Determination coefficient of the correlation relationship is formulated as follows:

$$r^2 = \frac{a(\sum y) + b\,(xy) - n\,(\bar{y})^2}{(\sum y^2) - n(\bar{y})^2} \quad (2)$$

coefficient value of relations
0 = no relation
1 = perfect relation

5.2 Concrete Experiment

The concrete experiments results using variations of GGBFS compared to 100% OPC are as follows:

$$\text{Compressive strength} = \frac{P}{A} \quad (3)$$

f'c = Concrete compressive strength (Mpa)
P = maximum load (N)
A = press area of test object (mm^2)

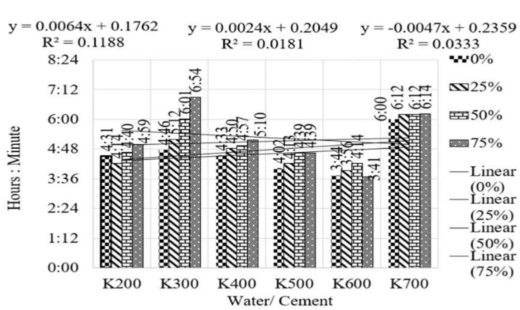

Fig. 8: Initial setting time of concrete

Figure 8 shows the use of GGBFS tends to increase the initial concrete setting time by an average of 30 minutes. The data does not show a clear pattern, and some show the opposite, such as K200 and K600 for GGBFS 25% and 75%, respectively. The greater the use of GGBS, the smaller the air needed to obtain the same working/slump ability. The figure shows that the greater the quality of concrete, the smaller the initial setting time. The increase in the achievement of GGBFS with a decrease in the requisite for cement leads to a decrease in the binding time of concrete.

Fig. 8 shows that the water per cement (W/C) is not too significant because the addition of water for each constant quality is between 10-20 liters.

Before making a testing sample on a cylindrical mold, a slump test is needed for the author to determine the amount of water needed in a concrete mixture. The combination effects of mineral admixtures in concrete on the performance-related properties under different aspect ratios are compared to conventional concrete [7]. The results of water needs and slump tests are as follows:

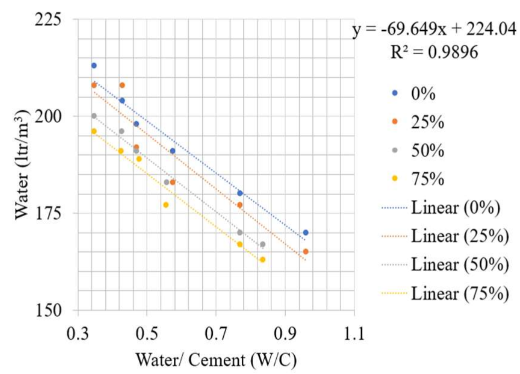

Fig. 9 Water requirements perm^3, slump 12cm, size 25mm

Figure 9 shows that with the utilization of 50% GGBFS, the lower the water used with a linear regression value of 0.9896 [8].

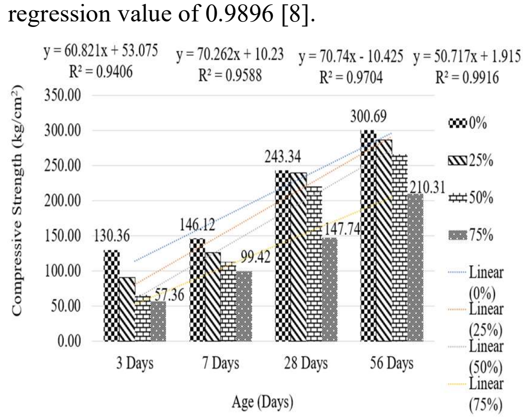

Fig.10 Quality of Compressive Strength (K200)

The greater the use of GGBFS, the lower the compressive strength produced at an early age. However, this leads to a rise in compressive strength development, as shown in the graph above. For K200 quality, GGBFS is used with varying Slag mixture of 0%, 25%, and 50%. Meanwhile, a variation of 75% does not meet the required compressive strength.

Figure 11 shows that the percentage achievement of 28 days of age varies from 0% to 75% in accordance with the requirements for compressive strength. However, the 75% variation using slag is not recommended because the compressive strength does not meet the specifics even though the percentage is 100%.

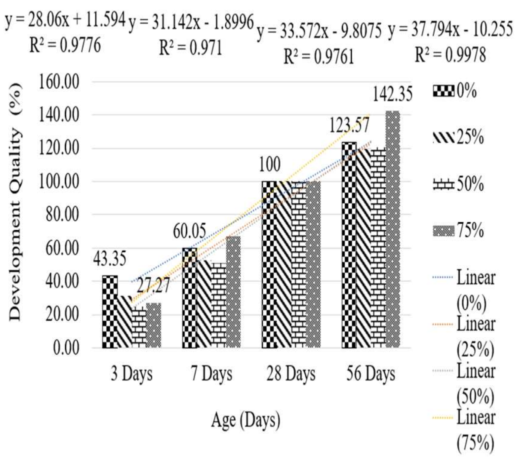

Fig. 11 Development of Quality Concrete (K-200)

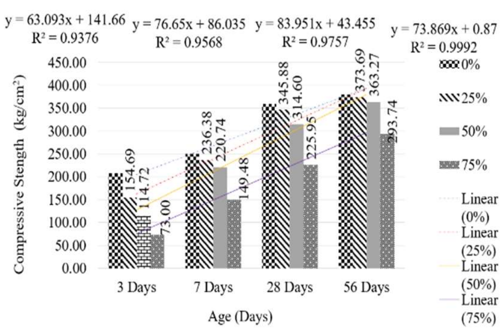

Fig.12 Quality of Compressive Strength (K300)

The compressive strength results of K-300 concrete quality show that each test takes 3, 7, 28, and 56 days for the compressive strength to decrease every additional variation in substituting GGBFS for cement. At the age of 28 days, the quality of K300 using GGBFS uses a mixture of slag with a variation of 0%, 25%, and 50%. The variation of 75% does not meet the required compressive strength.

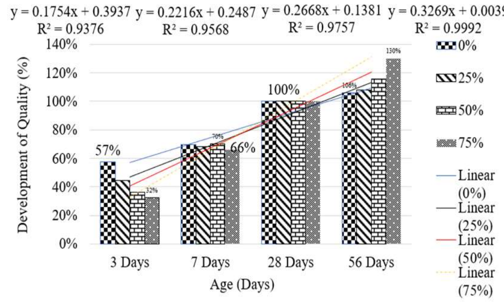

Fig.13 Development of Quality Concrete (K-300)

Figure 13 shows that the development of compressive strength increases every continuously. The percentage achieved at 28 days of varying from 0% to 50% meets the requirements for compressive strength. However, a 75% variation is not recommended because the compressive strength does not meet the specifications.

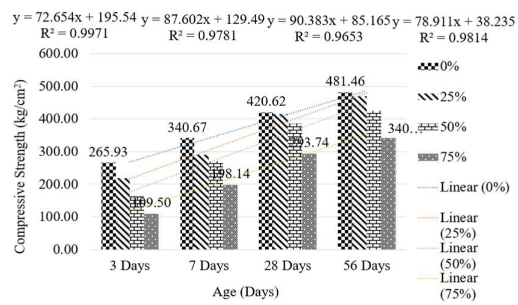

Fig. 14 Quality of Compressive Strength (K400)

Figure 14 shows the results of the compressive strength test of K-400 concrete quality at 28 days. The incoming variations are 0% and 25% with compressive strengths of 420.62kg / cm^2 and 415.41kg/cm^2

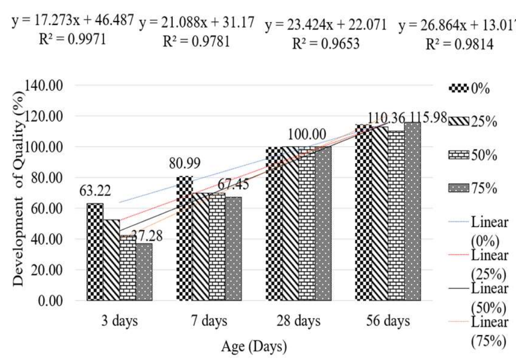

Fig. 15 Development of Quality Concrete (K400)

Figure 15 shows that the compressive strength increases every time. The achievement of the percentage of 28 days of variation 0%-25% meets the requirements. However, 50% and 75% variations are not recommended because the compressive strength does not meet specifications.

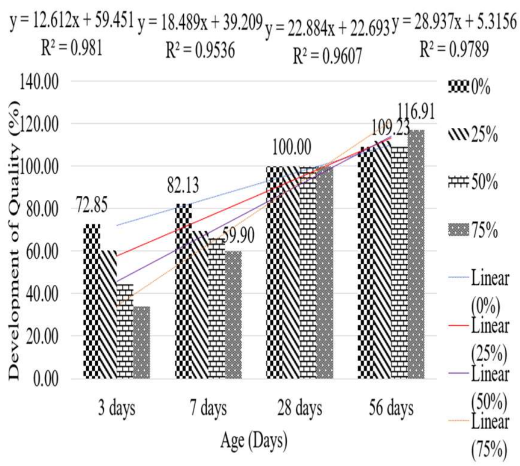

Fig. 16 Quality of Compressive Strength (K500)

Figure 16 shows the compressive strength test of the K-500 concrete quality. The figure shows that GGBFS is not needed because, from the point of view of compressive strength, it does not meet the requirements.

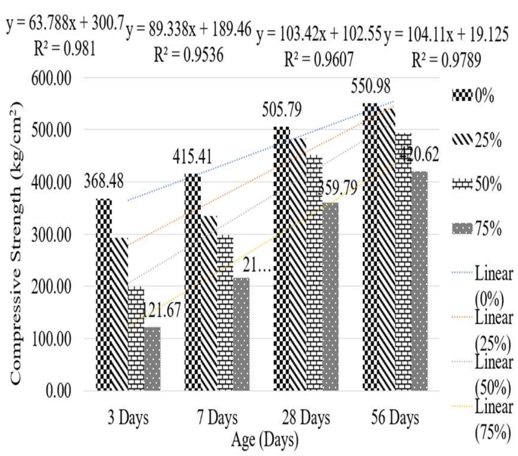

Fig. 17 Development of Quality Concrete (K500)

Figure 17 shows a continuous increase in compressive strength. The percentage of K 500 quality development increases every time. For example, at 3 and 28 days, it increases by 72.85% and 100%.

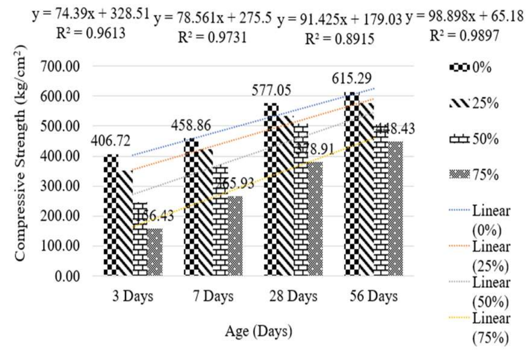

Fig. 18 Quality of Compressive Strength (K600)

Figure 18 shows, the compressive strength test results of K-600 concrete quality, at 3, 7, 28 and 56 days. The result showed that the compressive strength decreased with each variation of the GGBFS substitution percentage for cement. For K600 quality is not needed because the compressive strength for variation 0% = 577.05 kg / cm^2, 25% = 535.34 kg / cm^2, 50% = 451.91kg / cm^2 and 75% = 359.79 kg / cm^2. The variations results are below the standard even though the percentage values reaches 100% and the linear regression approaches 1.

The higher the quality of the concrete, the more cement is needed for GGBFS to achieve the compressive strength is not optimal since it is influenced by the quality of the materials asides from cement.

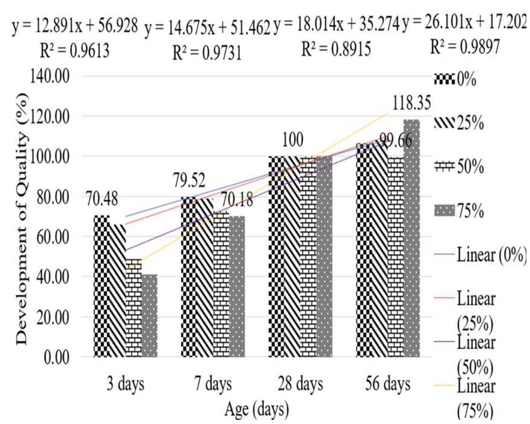

Fig. 19 Development of Quality Concrete (K600)

Figure 19 shows, the percentage of K 600 quality development increases continuously. For example, it increased for 7 days with a variation of 41.28% to 50%, while at 28 days the quality of development rises to 100%. Therefore, the use of the K600 is not recommended because it does not comply with the required standards.

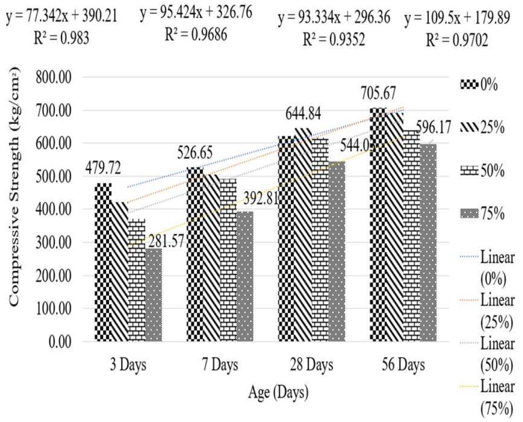

Fig.20 Quality of Compressive Strength (K700)

Figure 20 shows, the compressive strength testing results of K-700 concrete quality. It shows that each test at the age of 28 days does not meet the specifications due to the inability of the compressive strength to meet the needed standards.

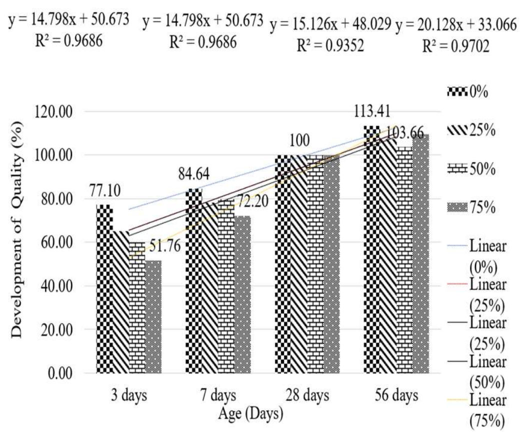

Fig. 21 Development of Compressive Strength (K700)

Figure 21 shows that the percentage of K 700 quality development increases continuously, and at 28 days, it rises to 100%.

5.3 Linear Regression Experiment

Quality samples taken from the compressive strength of K200 to K400 for linear regression calculations are higher than the age of the concrete produced with increased compressive strength. From the results of linear regression analysis, R = 0.9781 on the variation of 25% with K400 quality value of 1 [8].

5.4 Slag Activity Index Experiment

$$\text{Slag Activity Index, \%} = \frac{SP}{P} \times 100\% \qquad (4)$$

SP = average compressive strength of the slag-reference cement cubes

P = average compressive strength of the reference cement cubes

100% OPC is the same as 0% GGBFS usage. In this test, the compressive strength values of 7 and 28 days [9] were compared with a 25%, 50%, 75% GBFS mixture and divided by OPC cement with a 100% cement mixture. The following are the results of slag activity index testing:

Table 1 Slag Index Activity

Variation of GGBFS	Compressive Strength(kg/cm²)		Slag Index Activity			
	7 days	28 days	7 days		28 days	
0%	384.09	475.86	100.89	Grade 120	112.14	Grade 120
25%	387.49	533.65				
0%	384.09	475.86	89.38	Grade 100	127.14	Grade 120
50%	343.30	605.03				
0%	384.09	475.86	76.99	Grade 80	96.43	Grade 100
75%	295.72	458.87				

5.5 Production Cost

Production cost is the total amount needed to manufacture a good, such as cost for raw material costs, direct labor, and overhead. Based on research carried out by [10], it is necessary to determine alternative solutions for the mix of raw materials for concrete production due to the increase in production costs. Prices for concrete for K200 - K700 concrete for 2020 are shown in Table 2.

The following is used to implement the Tokyo Apartment construction project using the K 400 concrete quality and GGBFS:

$$\text{Cost} = \text{Volume x Selling Price} \qquad (5)$$

Table 2 Price of Concrete Quality 2020

Concrete Quality	Price per m³ (IDR)	
	GGBFS Concrete	Conventional Concrete
K200	700.000	720.000
K300	750.000	775.000
K400	800.000	830.000
K500	900.000	930.000
K600	1.000.000	1.030.000
K700	1.200.000	1.230.000

Therefore, it is calculated as follows:

1. Utilization of Slag 300.000m^3 x 900k = 270 billion.
2. With Conventional Concrete 300.000m^3 x 930k = 279 billion.

The difference generated for the sale price with the use of slag is 9 billion. The construction value of the construction can reduce the efficiency of materials or the cost of production by 3%. The utilization of this slag improves a friendly environment without reducing the quality of concrete.

6. CONCLUSION

In conclusion, the more levels of GGBFS content, the longer the initial time of concrete production by 30 minutes. Furthermore, the development of K200 to K700 concrete compression strength at the age of 3, 7, 28, and 56 days tends to decrease in value. The use of GGBFS for over K500 quality is not recommended because it does not meet specifications and the linear regression percentage at 100% is close to one. Slag index activity is categorized in grades 80, 100, and 120 according to ASTM C989. The utilization of GGBFS reduces the cost of production by 9 billion or 3%, and it can also improve a healthy environment without reducing the quality of high-quality concrete.

7. ACKNOWLEDGMENTS

The authors are grateful to the Rector and the Institute for Community Service Research in internal grants for the Superior Research of the Civil Department of the PLN Institute of Technology No. SK: 0094.SK/2/A0/2020.

8. REFERENCES

[1] ACI(American Concrete Institute), ACI 233R-03. Slag Cement in Concrete and Mortar. in ; American Concrete Institute, 2003, pp. 1–19.

[2] Yogarajah E, Nawa T, Igarashi T, Physical, chemical, and mineralogical characteristics of blast furnace slag on durability of concrete. MATEC Web Conf., vol. 147, p. 01007, 2018.

[3] Hidayawanti R, Legino S, Harjanto D. Optimizing the Utilization Cement Slag and Fly Ash of Concrete Quality. in The IIER International Conference, 2018, March, pp. 14–18.

[4] Hidayawanti R, Legino S, Sangadji I, Panca Adi Widodo R. The Efficiency of Fly Ash and Cement Slag to Development Building. Geomate, vol. 16, no. 57, 2019, pp. 95–100.

[5] ASTM Committee. ASTM C109/C109M-02. Standard Test Method for Compressive Strength of Hydraulic Cement Mortars. in Annual Book of ASTM Standards. vol. 04, 2002, pp. 1–6.

[6] ASTM C-39International, Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens. no. C. 2010. p 1-7.

[7] Cleetus A, Shibu R, Paul VK, Jacob. B. Analysis and Study of the Effect of Ggbfs on Concrete Structures. Irjet, vol. 5, no. 3, 2018, pp. 3033–3037.

[8] Hidayawanti R, Purnama DD, Iduwin T, Legino S, Wachid FI. The Impact Aggregate Quality Material as a Linear Regression. GEOMATE, vol. 18, no. 70, 2020, pp. 23–29.

[9] ASTM C989. Standard Specification for Slag Cement for Use in Concrete and Mortars. in : ASTM Standards, vol. 44, no. 0, 2013, pp. 1–8.

[10]Pourmahmoud N, Sadeghifar H, Torkavannejad A. International Journal of Heat and Mass Transfer A novel , state-of-the-art tubular architecture for polymer electrolyte membrane fuel cells : Performance enhancement , size and cost reduction. Int. J. Heat Mass Transf., vol. 108, 2017, pp. 577–584.