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# EFFECT OF WATER CEMENT RATIO AND GGBFS SUBSTITUTION ON COMPRESSIVE STRENGTH AND WORKABILITY OF SCC

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**ABSTRACT**

Self-Compacting Concrete (SCC) is an innovation in concrete technology that is able to flow and solidify independently without the help of mechanical vibration. This study aims to analyze the effect of variations in water to cement ratio (w/c) and cement substitution with Ground Granulated Blast Furnace Slag (GGBFS) optimal value from mortar cube testing, with the optimal value at 30% substitution with a compressive strength of 28.40 MPa. The optimal GGBFS value will be used for the design of SCC specimens and will be tested for workability and compressive strength with variations of 0.35, 0.375, and 0.40. Mix design is made with reference to the recommended composition of the EFNARC standard (2005). The workability test includes slump flow, V-funnel, and L-box, while the compressive strength test will conduct at 7, 14, and 28 days using 15×30 cm cylindrical specimens. The test results showed that increasing the w/c from 0.35 to 0.40 improved the workability of the mix, slump flow increased from 540 mm to 660 mm, the V-funnel time decreased from 15 s to 7 s, and the L-box ratio increased from 0.84 to 0.97. In the compressive strength test, the concrete with w/c 0.40 showed a higher strength increase at 28 days (38.01 MPa) than the other mixes, although the initial value (7 days) was lower. Cost evaluation showed that the use of GGBFS provided an efficiency of Rp37,500 per m³ (±2.94% savings) compared to conventional SCC. Based on the test results and performance analysis, the mix variation with w/b 0.40 and 30% GGBFS substitution was declared as the most optimum composition in terms of workability, strength, and cost efficiency.

**Keywords** : SCC, compressive strength, GGBFS, workability, water cement ratio.

## 1. Introduction

Concrete plays an important role in construction, one of the most important stages in conventional concrete applications is the compaction process, which aims to remove trapped air and ensure proper placement of the concrete around the reinforcement. However, field practices often deviate from the proper procedure, resulting in reduced compressive strength and durability. According to Sulman and Suppa [1], inadequate compaction can lead to lower water tightness and increase the risk of reinforcement corrosion.

With the advancement of concrete technology, Self-Compacting Concrete (SCC) has been introduced to address these issues. SCC is a high-performance concrete that is capable of flowing under its own weight, filling formwork and encasing reinforcement without the need for mechanical vibration [2]. SCC is particularly beneficial in structures with dense reinforcement or complex formwork, offering increased durability, reduced porosity, and improved long-term performance [3].

To further improve the sustainability and performance of SCC, the use of additional cementitious materials such as Ground Granulated Blast Furnace Slag (GGBFS) has been explored. GGBFS is a by-product of the steel industry, rich in reactive silica that contributes to long-term strength development [4]. As reported by Ding et al. [5], incorporation of GGBFS into SCC not only enhances its novel properties but also improves the strength gain over time, thus making it a promising partial replacement for cement.

Another key factor affecting SCC performance is the water to cement ratio (w/c), which directly affects workability and compressive strength. According to ACI 237R-07, optimizing the w/c ratio is essential to achieve the performance of fresh and hardened concrete in SCC [6].

This research aims to investigate the effect of water-to-binder ratio variation (0.35, 0.375, and 0.40) in combination with optimal GGBFS substitution on the workability and compressive strength of SCC.

## 2. METHODOLOGY

The steps required in the research, namely starting from testing materials, finding the optimal Ground Granulated Blast Furnace Slag (GGBFS) substitution through mortar cube testing, Self-Compacting Concrete (SCC) mix design planning through trial and error, SCC sample manufacture, concrete testing, analyzing data, and cost analysis.

### Material Testing

The type of coarse aggregate material is Pasuruan gravel with a maximum size of 10 mm, the tests carried out are water content testing, gradation testing, specific gravity testing, absorption testing, and los angeles abrasion testing.

The type of fine aggregate material is Lumajang sand. the tests carried out are Water content testing, specific gravity testing, water absorption testing, and sand gradation testing.

GGBFS as cement substitute material obtained from PT Krakatau Steel Indonesia. The tests carried out were fineness testing, normal consistency testing, setting time testing, and X-Ray Fluorescence (XRF) testing.

### GGBFS Substituted Mortar Cube

The first stage to determine the strength of the percentage of GGBFS substitution to cement that has the best strength carried out in the form of 50 mm x 50 mm mortar cube with method based on SNI 03-6825-2002.

**Table 1.** GGBFS Substituted Mortar Cube Sample Needs

| Sample Code | Curing Day | Testing Type | GGBFS (%) | Sample Needs |
|---|---|---|---|---|
| C20 | 21 | Compressive Strength Test | 20 | 3 |
| C25 | 21 | | 25 | 3 |
| C30 | 21 | | 30 | 3 |
| C35 | 21 | | 35 | 3 |
| Total Needs | | | | 12 |

*Source: Research 2025*

### GGBFS Substituted SCC Trial and Error

The determination of mix design is obtained through the recommended material content obtained from the EFNARC standard in **Table 2**, while the superplasticizer dosage is determined from the catalog of the Sika Viscocrete 3115N.

The trial was conducted by finding the optimal material proportion for w/c ratio variations. Then the specimens will be tested for workability test according to EFNARC standards and compressive strength within a 7-day curing period. the right mix will be applied in workability testing and compressive strength testing [7].

**Table 2.** Typical Range of SCC Mix Composition

| Constituent | Weight Limit ($kg/m^3$) | Weight Limit ($liters/m^3$) |
|---|---|---|
| Powder | 380 - 600 | |
| Paste | | 300 - 380 |
| Water | 150 -210 | 150 - 210 |
| Coarse Aggregate | 750 - 1000 | 270 - 360 |
| Fine Aggregate | 48 - 55% from aggregate weight | |
| W/C Ratio | | 0,85 - 1,10 |

*Source: EFNARC,2005 [7]*

### Workability Testing

Workability testing was conducted to determine the flowability properties with Slump Flow testing, passing ability with L-box testing, and fill ability with V-funnel testing of SCC concrete with Optimal GGBFS substitution. Workability testing was carried out following the EFNARC (2005) standard [7].

### Compressive Strength Test

mix design that passes workability testing from tiral and error will be applied in compressive strength testing with Samples planning at **Table 3**. Compressive strength testing is carried out in reference to SNI 03-1974-1990, calculated based on the amount of load per unit area, in the following equation:

$$f'c = \frac{P}{A} \tag{1}$$

Description:

F'c = Concrete compressive strength (MPa)
P = Axial compression force (N)
A = Sample cross-sectional area ($mm^2$)

**Table 3.** GGBFS Substituted SCC Sample Needs

| Testing Age (Days) | GGBFS (%) | Water Cement Ratio (w/c) | | | Total |
|---|---|---|---|---|---|
| | | 0,30 | 0,375 | 0.40 | |
| 7 | GGBFS Optimum | 4 | 4 | 4 | 12 |
| 14 | | 4 | 4 | 4 | 12 |
| 28 | | 4 | 4 | 4 | 12 |
| Total Needs | | | | | 36 |

*Source: Research 2025*

## 3. RESULT AND DISCUSSION

The results obtained in this study include the physical properties of aggregates, physical properties of GGBFS as a substitute for cement, GGBFS substituted mortar cubes result, workability test results, compressive strength test results, and cost analysis.

**Aggregate Physical Properties**

The following are the results of testing coarse aggregate gravel pasuruan size 1-1, and fine aggregate sand lumajang:

**Table 4.** Coarse Aggregate Physical Test Result

| Type of Testing | Standards | Range | Result |
|---|---|---|---|
| Water Content | SNI 1971 2011 | 0%-10% | 1.25% |
| Bulk Specific Gravity (Oven Dry) | SNI 1970 2008 | 2.5-2.8 | 2.705 gr/cm$^3$ |
| Bulk Specific Gravity (SSD) | SNI 1970 2008 | 2.4-2.8 | 2.754 gr/cm$^3$ |
| Apparent Specific Gravity | SNI 1970 2008 | 2.4-2.8 | 2.843 gr/cm$^3$ |
| Water Absorption | SNI 1970 2008 | 1%-2% | 1.74% |
| Los Angeles Abrasion | SNI 2417 2008 | <40% | 16% |
| Sieve Analysis | EFNARC 2005 | >20 mm | Dominant 9.5 mm |

*Source: Research 2025*

**Table 5.** Fine Aggregae Physical Test Result

| Type of Testing | Standards | Range | Result |
|---|---|---|---|
| Water Content | SNI 1971 2011 | 0%-10% | 8.29% |
| Bulk Specific Gravity (Oven Dry) | SNI 1970 2008 | 2.5-2.8 | 2.703 gr/cm3 |
| Bulk Specific Gravity (SSD) | SNI 1970 2008 | 2.4-2.8 | 2.723 gr/cm3 |
| Apparent Specific Gravity | SNI 1970 2008 | 2.4-2.8 | 2.758 gr/cm3 |
| Water Absorption | SNI 1970 2008 | 0%-5% | 0.75% |
| Sieve Analysis (Zone) | SNI 03 1968 1990 | Zone 1 -4 | Zone 2 |
| Fine Modulus | SNI 03 1968 1990 | 1.5-3.5 | 2.51 |

*Source: Research 2025*

**GGBFS Subtituted Setting Time and Normal Consistency Test**

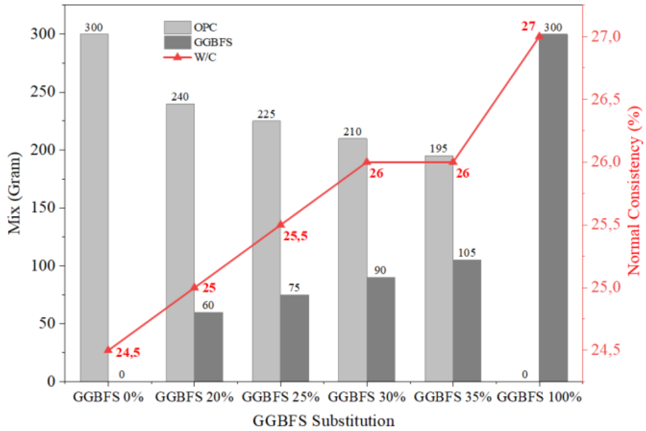


**Figure 1.** Normal Consistency Result
*Source: Research 2025*

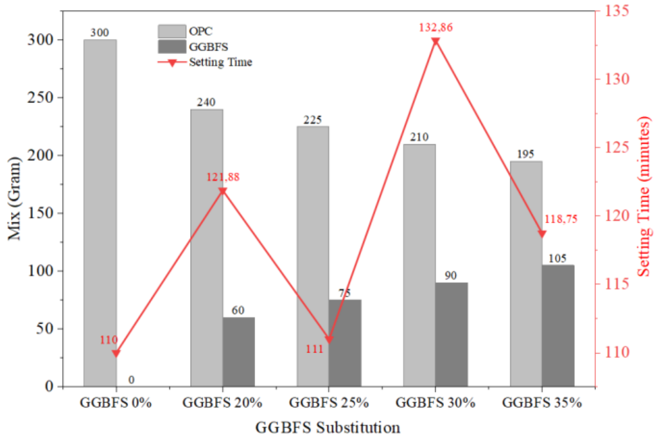


**Figure 2.** Setting Timr Result
*Source: Research 2025*

Based on the normal consistency test, with the addition of GGBFS the w/c ratio value in the mixture increases. While the results of the Setting Time test show non-linear results, with the highest value at 30% variation with a setting time of 132.86 minutes.

**GGBFS Sieve Analysis Test**

**Table 6.** GGBFS Sieve Analysis Testing

| Sieve Number | Retained Weight | | | |
|---|---|---|---|---|
| | Gram | Percentage (%) | Cumulative (%) | Range (%) |
| 100 | 1.5 | 2.9 | 2.9 | < 0 |
| 200 | 44.3 | 88.4 | 91.4 | < 22 |
| Pan | 4.3 | 8.6 | 100.0 | |
| Total | 50 | 100 | | |

*Source: Research 2025*

The sieve test results show that the GGBFS used does not meet the fineness requirements according to SNI 15-2530-1991.

**GGBFS X-Ray Fluorescence Test**

Based on the XRF test results at **Figure 2**, the GGBFS used shows significant chemical composition similarities with OPC cement, especially in the main contents such as CaO and $SiO_2$ which are in the range of 63% and 22% respectively.

**Table 7.** GGBFS and OPC XRF Result Comparison

| Oxide | | GGBFS Used | OPC |
|---|---|---|---|
| Fe2O3 | Calcium Oxide | 3,3 | 0,913 |
| Al2O3 | Silicon Dioxide | 5,69 | 8.00 |
| CaO | Aluminum Oxide | 63,3 | 63,14 |
| MgO | Magnesium Oxide | 0,67 | 0.00 |
| SiO2 | Iron (III) Oxide | 22,18 | 22,2 |
| SO3 | Titanium Dioxide | 1,86 | 1.00 |

*****All Units in (%Wt)

*Source: FMIPA UM XRF & Yulizar et al. (2018)*

**GGBFS Substituted Mortar Cube**

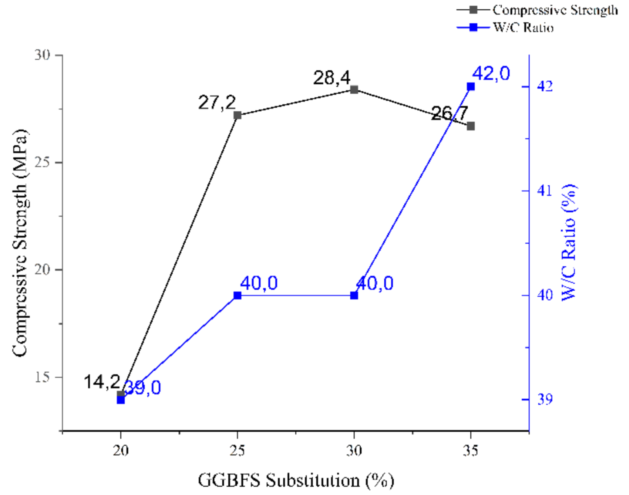


**Figure 3.** GGBFS Substituted Mortar Cube Result

*Source: Research 2025*

Significant increase in average compressive strength was obtained at 25-30% substitution, with the highest value of 28.4 MPa at 30% substitution. This increase indicates that GGBFS provides optimum pozzolanic contribution within this range.

**GGBFS Substituted SCC Mix Design Determination**

After trial and error, the mix design with the optimum 30% GGBFS substitution was obtained as follows

**Table 8.** GGBFS Substitued SCC Mix Design

| Material Needs | W/C Variation 0.350 | 0.375 | 0.400 |
|---|---|---|---|
| GGBFS | 150 | 150 | 150 |
| OPC | 350 | 350 | 350 |
| Gravel | 776.25 | 770.63 | 765 |
| Sand | 948.75 | 941.88 | 935 |
| Water | 175 | 187.5 | 200 |
| SP | 6 | 5 | 4 |

*Material Units in Kg/m$^3$

*Source: Research 2025*

**GGBFS Substituted SCC Workabilty Test**

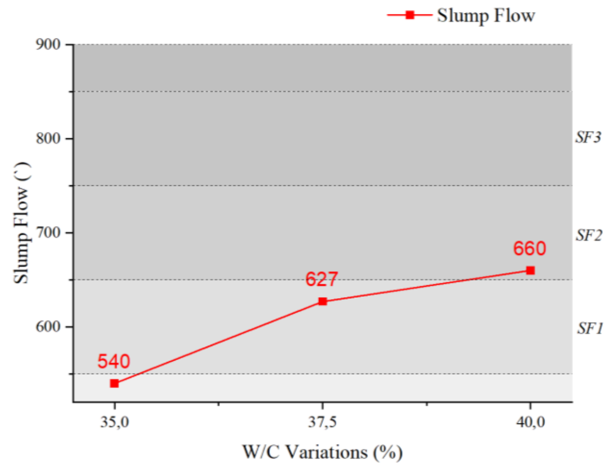


**Figure 4.** Slump Flow Test Result

*Source: Research 2025*

Based on the slump flow test results, there was an increase in the diameter of spread from 540 mm in the mixture with w/c 0.35 to 660 mm at w/c 0.40. This increase indicates an increased level of flowability. This increase also affected the slump flow classification, from SF1 at w/c 0.35 and 0.375 to SF2 at w/c 0.40.

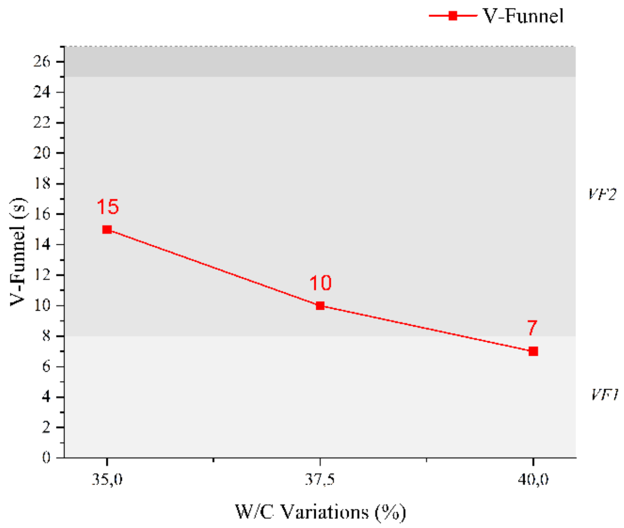

**Figure 5.** V-Funnel Test Result
*Source: Research 2025*

In the V-Funnel test, the flow time decreased significantly from 15 seconds to 7 seconds as the w/c ratio increased, this indicates a reduction in the viscosity of the concrete and a smoother flow of the mixture through the narrow gap.

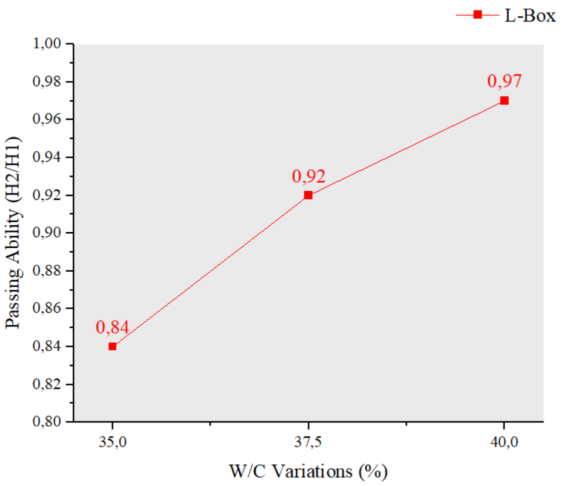


**Figure 6.** L-Box Test Result
*Source: Research 2025*

Based on the results, all mixtures achieved the PA2 classification, which indicates a good level of passing ability suitable for reinforced concrete elements. This trend reflects the reduced viscosity and improved flow characteristics as more water is introduced into the mix.

**GGBFS Substituted SCC Compressive Strength Test**

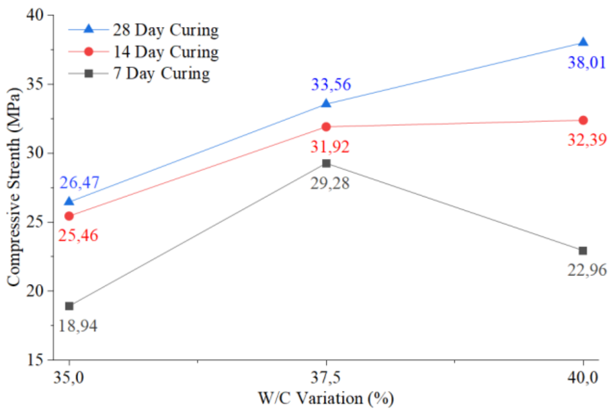


**Figure 7.** Compressive Strength Result
*Source: Research 2025*

Results showed a general increase in strength with both curing time and higher w/c ratios. At 28 days, the compressive strength increased from 26.47 MPa (w/c 0.35) to 33.56 MPa (w/c 0.375) and reached 38.01 MPa (w/c 0.40). Although the 7-day strength of the w/c 0.40 mix was lower than that of the w/c 0.375 mix, the long-term gain surpassed others. This confirms that GGBFS needs more time to react but can help concrete become stronger over time, especially when the w/c ratio is higher.

**Cost Analysis**

**Table 9.** Material Unit Cost

| Description | Units | Unit Price |
|---|---|---|
| Portland Cement | In Kg | Rp 1,508.00 |
| GGBFS | Kg | Rp 1,258.00 |
| Coarse Aggregate | Kg | Rp 232.00 |
| Fine Aggregate | Kg | Rp 219.00 |
| Water | Ltr | Rp 14.00 |
| Superplasticizer | Kg | Rp 33,649.00 |

*Source: Research 2025*

**Table 10.** Conventional SCC Cost Analysis in $m^3$

| Description | Coeff | Total Price |
|---|---|---|
| Portland Cement | 500.00 Kg | Rp 754,000.00 |
| Coarse Aggregate | 765.00 Kg | Rp 177,480.00 |
| Fine Aggregate | 935.00 Kg | Rp 204,765.00 |
| Water | 200.00 Ltr | Rp 2,800.00 |
| Superplasticizer | 4.00 Kg | Rp 134,596.00 |
| **Total Price of Materials** | | **Rp 1,273,641.00** |

*Source: Research 2025*

**Table 9.** GGBFS Substituted SCC Cost Analysis in $m^3$

| Description | Coeff | Total Price |
|---|---|---|
| Portland Cement | 300.00 Kg | Rp 527,800.00 |
| GGBFS | 150.00 Kg | Rp 188,700.00 |
| Coarse Aggregate | 765.00 Kg | Rp 177,480.00 |
| Fine Aggregate | 935.00 Kg | Rp 204,765.00 |
| Water | 200.00 Ltr | Rp 2,800.00 |
| Superplasticizer | 4.00 Kg | Rp 134,596.00 |
| **Total Price of Materials** | | **Rp 1,236,141.00** |

cost for the GGBFS-substituted mix is Rp 1,236,141 per $m^3$, while the cost for the control mix is Rp 1,273,641 per $m^3$. This yields a cost savings of Rp 37,500 per $m^3$, or approximately 3% cheaper than the mix without GGBFS. This reduction in cost supports its use not only as a sustainable material but also as a cost-effective alternative in SCC production.

## 4. CONCLUTION

Based on the results of the study, the following conclusions can be obtained:

a. The SCC mix design applied in this study was based on EFNARC recommendations, which include the proportion of fine aggregate between 48% to 55% of total aggregate weight. A fixed ratio of 55% fine aggregate and 45% coarse aggregate was adopted. Additionally, the dosage of superplasticizer was determined using the recommended range from the Sika Viscocrete 3115N catalogue, set between 0.8% and 2.0% of the total binder weight to ensure adequate flowability without segregation

b. The variation of water to cement (w/c) ratio and the substitution of 30% GGBFS significantly affected the fresh properties of SCC. As the w/c ratio increased from 0.35 to 0.40, the concrete exhibited consistent improvements in workability. The slump flow diameter increased from 540 mm to 660 mm, indicating better filling ability. The V-funnel time decreased from 15 seconds to 7 seconds, showing reduced viscosity and easier flow. The L-box passing ability also improved from a ratio of 0.84 to 0.97, demonstrating better capacity of the concrete to pass through narrow reinforcement gaps. These results confirm that higher w/c ratios improve the flowability and passing ability of GGBFS Substituted SCC.

c. The compressive strength results showed that increasing the water-to-binder (w/c) ratio led to higher strength at 28 days, despite slower early-age strength gain. The mix with a w/c ratio of 0.40 achieved the highest 28-day compressive strength at 38.01 MPa, followed by 33.56 MPa for w/c 0.375 and 26.47 MPa for w/c 0.35. This confirms the contribution of GGBFS to long-term strength development, as it reacts more slowly than OPC but enhances hydration over time.

d. Based on the tests that have been carried out, the optimal GGBFS substitution value is obtained at 30%, which is obtained through testing mortar cubes with a compressive strength of 28.4 MPa at the age of 21 days. The best w/c ratio variation value with optimal GGBFS substitution (30%) was obtained at a value of 0.40 with a compressive strength value of 38.01 MPa at 28 days curing age and the best workability value in all three tests, including Slump Flow testing reaching 660 mm with SF2 classification, V-Funnel testing as fast as 7 seconds with VF1 classification, and L-Box testing with a value of 0.97. Thus, the best w/c ratio variation value with optimal substitution of GGBFS (30%) is at 0.40.

e. In terms of economic performance, the use of GGBFS provides measurable cost advantages. With a 0.40 w/c ratio, SCC containing 30% GGBFS had a total material cost of Rp 1,236,141 per cubic meter, while the conventional SCC (with 100% OPC) cost Rp 1,273,641 per cubic meter. This indicates a cost saving of Rp 37,500 per $m^3$, or approximately 2.94%. The cost reduction is primarily due to the lower unit price of GGBFS (Rp 1,258/kg) compared to OPC (Rp 1,508/kg). Therefore, the substitution of GGBFS in SCC not only improves fresh properties but also enhances cost efficiency, making it a viable and sustainable option in concrete mix design.

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