Performance of Workability and Compressive Strength on Self-Compacting Geopolymer Concrete Based on High-Calcium Fly Ash with Additive Admixture

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***Abstract*—Geopolymer concrete has been developed to replace conventional concrete with other pozzolan materials with a high silicate alumina content. Fly ash is a material that contains a high silicate alumina of 22%. The high content of Al and Si increases the compressive strength of concrete. High-calcium fly ash is abundantly found in Indonesia. However, it has not been widely used for industry or research, and this is due to the fast-hardening time of concrete. Therefore, it has the potential to be developed. High-quality concrete has a low cement water factor that causes low workability in concrete. Self-compacting geopolymer concrete (SCGC) has been developed as a high-quality, workable concrete innovation. Concrete is produced using gravel, sand, fly ash, alkaline activator, and water materials. This study used 14 Molar levels of NaOH. The variations used were 0%, 3%, 5%, and 7% superplasticizers (SP) made from polycarboxylate. This study used a dry mixing method to overcome the setting time on concrete. The results show that the workability achieved is 645mm, and the compressive strength achieved is 41.7 MPa.**

***Keywords*—Compressive strength, Dry mixing, High-calcium fly ash, Self-compacting geopolymer concrete, Workability**

I. Introduction

Along with the improvement of construction technology advances, revolutionary developments related to new eco-green materials as an alternative to Portland cement have been founded. The use of Portland cement needs to be reduced because cement production as a concrete binding material contributes as much as 7% to global CO_2 emission, which is poorly related to the environment [1], [2]. Geopolymer cement is a synthesis of non-organic natural materials that is gained through the polymerization process. The main raw materials required to manufacture geopolymer cement are materials that contain a lot of silica (SiO_2) and alumina (Al_2O_3) [1]. One of the most commonly found aluminosilicate materials is fly ash with a total of 2260 million tons per year or 12 times the availability of Portland cement in its use. Fly ash is divided into 2 types: high-calcium fly ash (Type C) and low-calcium fly ash (Type F). The availability of class C fly ash in Indonesia is abundant, yet it has not been widely used as a geopolymer concrete material because it has a faster binding time [3]. Therefore, to overcome these problems and to support technological developments, innovation through Self Compacting Geopolymer Concrete (SCGC), which uses class C fly ash is needed [4], [5]. SCGC is a concrete with a high fluidity that can compact itself and does not require a compactor [6], [7]. This can reduce the amount of labor, shorten the casting time, and also decrease the noise caused by the use of compactors. In other words, SCGC performance will save the energy of pumping and compaction, and this means the concrete has been designed to be more eco-friendly [8], [9]. Apart from what have been discussed above, SCGC also has many advantages as it can reduce the permeability of concrete, which causes the concrete surface to be smoother and more homogeneous. In terms of material use, SCGC is eco-friendly because it reduces waste. SCGC does not use Portland cement, which is currently considered responsible for carbon gas emissions [6], [10]. Further, SCGC's performance can be compared even better to that of Portland cement concrete. Hence, SCGC can act as a replacement for concrete material which has been the most widely used material in the world of infrastructure as a sustainable material.

II. Method

A. Materials characterization

Material characterization testing is used to determine the material to be used in accordance with material test standards. All materials such as fine aggregate (sand), coarse aggregate (gravel), fly ash from PLTU Paiton, alkali (NaOH and Na_2SiO_3) are tested based on their respective standards. The detail of material characterization are shown in Table 1.

TABLE 1.
MATERIAL CHARACTERIZATION DETAIL

Material	Characterization	Standar
Fly Ash	Specific Gravity	ASTM C 188-78
Coarse Aggregate	Gradation Analysis	ASTM C 136-01
	Specific Gravity	ASTM C 127-01
	Abrasion Test	ASTM D4060
Fine Aggregate	Gradation Analysis	ASTM C 136-01
	Specific Gravity	ASTM C 128-01
	Volume Weight	ASTM C 29 M-97

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B. Mix Proportion

Mixed composition planning (mix design) refers to journals related to high-calcium fly ash-based geopolymer concrete [1], [11], [12]. 4 values of polycarboxylate SP levels were determined, including 0%, 3%, 5%, and 7% levels, using 2 variations of the Sika-Visconcrete 3115N brand SP and Consol P100 ESP. The determination of SP level values was based on previous studies from [13] which applied a range of SP content values from 3% to 7%. In this previous study, an increasing trend of workability was found along with the addition of SP levels. This is in line with its increasing compressive strength. However, the increase was not significant at a rate of 7%. The study used low-calcium fly ash, whereas this study used high-calcium fly ash. The mix proportion used are presented in Table 2.

TABLE 2.
SCGC MIX COMPOSITION KG/M^3

Composition	Mix-1	Mix-2	Mix-3	Mix-4
Fly Ash	595.8	595.8	595.8	595.8
Fine Aggregate	679.7	679.7	679.7	679.7
Coarse Aggregate	989.4	989.4	989.42	989.42
Na2SiO3	55.4	55.4	55.4	55.4
NaOH	48.6	48.6	48.60	48.60
Superplasticizer	17.8	29.7	41.7	-
Water	134.3	134.3	134.3	134.3

C. Materials

1) Fly Ash

Fly ash is one of the pozzolan materials derived from coal combustion residues at the PLTU Steam Power Plant with an availability volume of 2260 million tons per year [14]. Some countries have differences in fly ash specifications. The American standard [15] categorizes coal combustion-making fly ash into 2 classes, namely class F and C. Fly ash class C contains more than 18% CaO, whereas F-type fly ash generally contains less than 18% [3]. Fly ash has a spherical morphology that facilitates binding [16]. Fly ash can improve workability and reduce internal temperature. Fly ash improves the gradation in the mixture by smoothing the fine particle size distribution. The round particles of Fly ash allow fly ash to have better flowability when compared to other pozzolans [14]. Fly ash has a round microstructure, while GGBFS and sandblasting's microstructures are pointed [2]. Chemically fly ash is an inorganic oxide material that contains silica and active alumina because it has been combustion at high temperatures [2]. Differences in fly ash types affect the performance of geopolymer concrete [12], [17]. Type C fly ash has a faster hardening time than F-type fly ash, which has a relatively slow binding time. The length of time of hardening concrete is influenced by the magnitude of the CaO content in fly ash [17]. The high content of CaO in type C fly ash stimulates an increase in the amorphous phase of fly ash. This causes the concrete binding process to be faster [18].

2) Sodium hydroxide

Alkaline activators serve to help the polymeration reaction of geopolymer concrete. One of the activators used in this study is NaOH. The NaOH material in geopolymer concrete serves to react Si and Al contained in fly ash so that it can produce strong polymer bonds. The high concentrations of NaOH release more of Si and Al ions in fly ash [19]. Thus, it produces a better polycondensation reaction and makes a high long-term compressive strength of geopolymer concrete [18]. Polycondensation is a hardening process on concrete 9 geopolymers. The high concentration of NaOH also has the potential to inhibit the release of Si and Al from fly ash. This happens because the increase in NaOH molarity results in high viscosity and low workability [20].

3) Sodium silicate

The second activator alkaline material is Sodium Pentahydric Metasilica. This material is applied to accelerate the polymerization reaction of geopolymer concrete [21]. In general, researchers use Sodium Silica (Na_2SiO_3) as an activator [2], [22]. Sodium Metasilica Pentahydrate is a solid form of Sodium Silica. This study used Sodium Metasilica Pentahydrate for the application of the dry mixing method of geopolymer concrete.

4) Fine aggregate

This study employed sand materials from Lumajang. From the results of the gradation of fine aggregates, the sand used in this study was included in the classification of zone 3 (rather fine sand). The sand gradation analysis chart is shown in Figure 1.

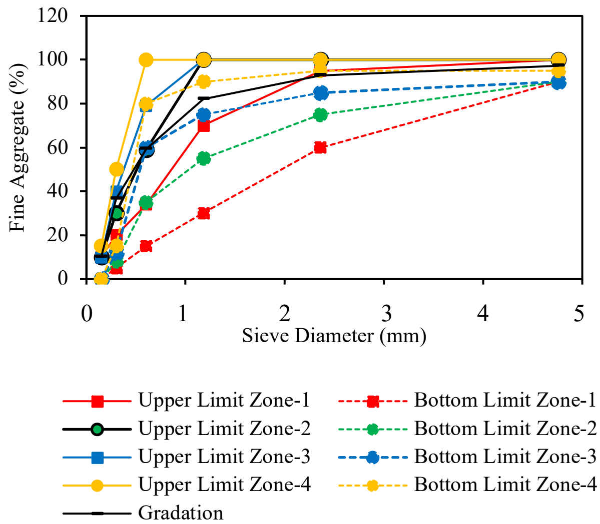

Figure 1. Fine aggregate sieve analysis

The sand properties obtained from the test are presented in Table 3.

TABLE 3.
FINE AGGREGATE MATERIAL PROPERTIES

No	Parameter	Value	Unit
1	Spesific Gravity (SSD)	2.77	
2	Weight Volume	1604	Kg/m^3
3	Moisture	0.57	%
4	Absorbsion	0.68	%
7	Fine Modulus	2.23	

5) Coarse aggregate

This research applied gravel materials from PT Calvary, Mojokerto. The results of the analysis of the gravel sieve are shown by Figure 2. The gravel sieve analysis chart shows that the gravel employed for this study has a maximum aggregate size of 2 cm.

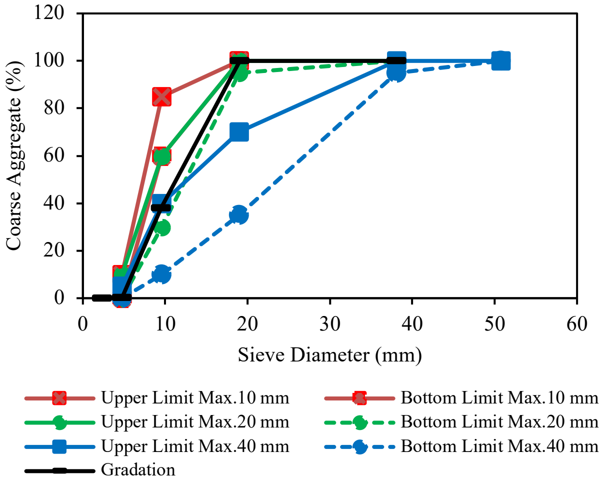

Figure 2. Coarse aggregate sieve analysis

The gravel material properties obtained from the test is shown in Table 4.

TABLE 4.
GRAVEL MATERIAL PROPERTIES

No	Parameter	Value	Unit
1	Spesific Gravity (SSD)	2.74	
2	Weight Volume	1297	Kg/m^3
3	Moisture	0.52	%
4	Absorption	2.18	%
5	Abrasion	15.82	%
7	Coarse Modulus	3.59	

6) Superplasticizer

An F-type admixture is a superplasticizer (SP) that modifies concrete properties according to the planner's needs. Based on ASTM C494-82 classification "Standard Specification for Chemical Admixture for Concrete", this study used SP type sika visconcrete 3115N and Consol P100 ESP with levels of 3%, 5%, and 7%.

D. Mixing and Curing

Self-Compacting Geopolymer Concrete (SCGC) has three tests to evaluate the workability of concrete: Slump Flow, V-funnel, and L-box testing. In addition, to achieve the compressive strength according to the plan of 42 MPa, a compressive strength test of concrete age of 7.14, and 28 days was carried out. Before the compressive strength test conducted, concrete was stolen or treated at room temperature (Ambient Curing). It was carried out by putting concrete into plastic, the aim is to inhibit the evaporation process in concrete.

E. Specimen Testing

SCGC specimen testing uses 3 workability test parameters, namely slump flow, v-funnel and l-box, and 1 concrete quality test, namely compressive strength test. Workability testing complies with ERNARC and ACI 237R standards. Meanwhile, the testing of compressive strength of concrete is in accordance with ASTM C39.

III. RESULTS AND DISCUSSION

A. Fly Ash Characterization

Table 4 shows the chemical composition of the fly ash, which has been tested using X-Ray Fluorescence (XRF) that is applied in this study. The conducted XRF testing shows that the fly ash used for this study is classified as type C fly ash. This type C fly ash is High-Calcium Fly Ash as its CaO levels is greater than 18%, based on ASTM C618-19 the level is 27.2%. The fly ash also contains $SiO_2+Al_2O_3+Fe_2O_3$.

TABLE 5.
CHEMICAL COMPOSITION OF FLY ASH

Compound	Al_2O_3	SiO_2	P_2O_5	SO_3	K_2O	CaO	$Fe2O_3$
(%)	9.4	24.8	0.44	0.3	1.27	27.2	30.6

Some researchers argue that the use of type C fly ash is not recommended for research. This is due to its high calcium content which can interfere with the polymerization process, and change the microstructure of geopolymer tissues. Therefore, type C fly ash has the potential to be further researched and developed to maximize its utilization properly.

B. Slump Flow Test

Slump flow testing is one of the tests in concrete workability. The test is used to determine the ability of concrete to flow. The slump flow test examines the diameter of the flowing concrete and classifies it according to the ERNARC. The workability value achieved indicates the ease of concrete to flow during the casting process. Scgc slump flow test results are presented in Figure 3.

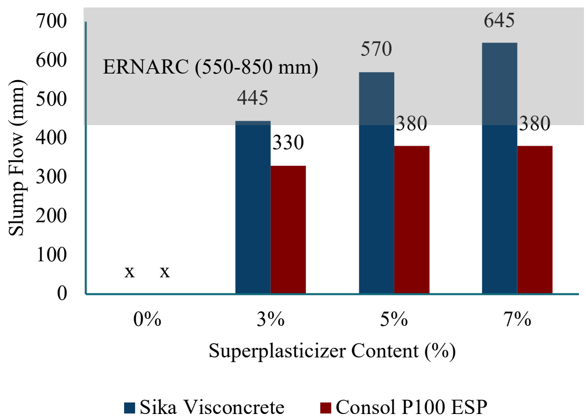

Figure 3. Slump Flow Test Result

Based on these data, it is known that the composition of concrete without the use of SP cannot flow so it cannot be measured for slump flow testing. The increased of SP levels in SCGC can significantly increase slump flow. The increase in SP content from 3% to 5% and 7% shows an increase in workability that occurs in concrete, namely 445 mm, 570 mm, and 645 mm. Mixed composition using SP Visconcrete 31115N with a content of 5% and 7% has met the slump flow testing standards based on EFNARC, which requires 550-850 mm [23]. Meanwhile, the composition of the mixture using SP Consol P100 ESP does not meet concrete testing standards with slump flow values for a base of 3%, 5%, and 7% are 330 mm, 380 mm, and 380 mm.

C. V-funnel Test

V-funnel testing is used to determine the viscosity of concrete. ERNARF requires a 9-25 second v-funnel test [23]. A graph of the v-funnel test results is presented in Figure 4.

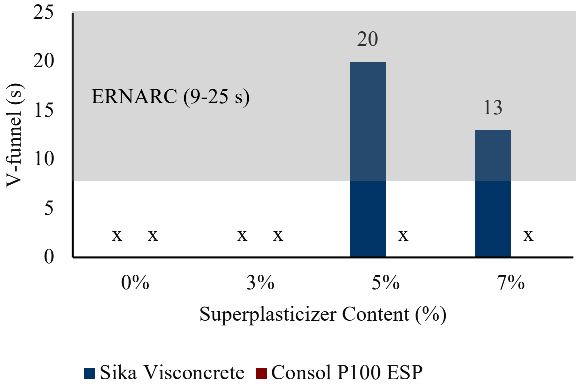

Figure 4. V-funnel Test Result

The v-funnel test results showed that adding SP Sika-visconcrete 3115N with a rate of 5% and 7% met the v-funnel testing standards of 20 seconds and 13 seconds. The faster the time it takes for the concrete to fall indicates that the viscosity of the concrete is low. And, this shows that the concrete has good flowability. The test with the addition of SP content of 3% sika visconcrete 3115N cannot flow to the end. The same thing happens to the addition of SP Consol P100 ESP 3%, 5%, and 7% . Therefore, the test has to be stopped. The composition of the mixture without the use of SP cannot flow caused by the agglomeration, hence, the concrete cannot be tested for V-funnel.

D. L-box Test

L-box testing is used to determine the ability of concrete to pass through reinforcement. EFNARC requires a concrete height ratio of 0,8-1 [23]. The L-box test results align with the v-funnel test results, where the test can be measured in composition with the addition of SP Sika-visconcrete 3115N with a content of 5% and 7%. The values obtained were 0.66 and 0.81. Based on the results of the carried out test, the composition of the addition of SP Sika-visconcrete 3115N with a content of 7% meets the EFNARC standard with a value of 0.81. The ratio of comparison, which was close to 1, shows that concrete has high workability, and this enables it to pass the concrete reinforcement without segregation (separation of aggregates with geopolymer cement). A graph of the L-box test results can be seen in Figure 5.

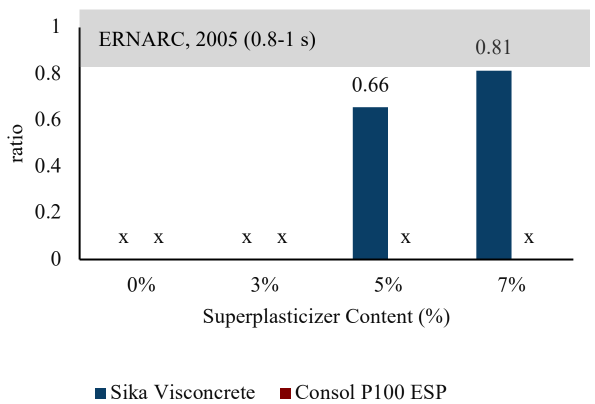

Figure 5. L-box Test Result

Based on the three workability test parameters, namely slump flow, v-funnel, and L-box, it can be seen that the composition of SCGC concrete that meets all SCGC concrete workability test standards is the addition of SP Sika-visconcrete 3115N 7% grade. This is in line with research [5] stating that an increase in SP levels will increase workability in SCGC concrete. Although it is made from the same base as Sika-visconcrete 3115N, modified polycarboxylate, Consol P100 ESP does not meet the standard of Self-Compacting Concrete (SCC) concrete when applied to geopolymer concrete.

E. Compressive Strength Test

Compressive strength testing is carried out to test the quality of concrete. The concrete compressive strength testing graph is shown by Figure 6.

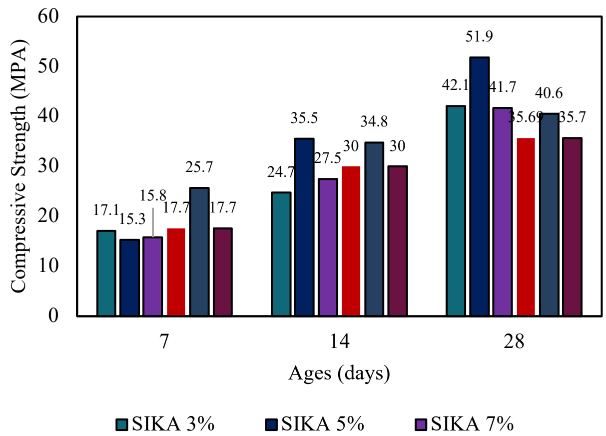

Figure 6. Compressive Strength Test Result

The compressive strength performance of concrete at the age of 7 days shows the strength of concrete achieved, which is about 30%. As the age of the concrete increases, the results of the compressive strength test of concrete also increase. The composition of mixture with the addition of SP sika visconcrete 3115N with levels of 3% and 5% showed a significant increase at the age of 7, 14, and 28 days with the highest compressive strength at the age of 28 days of 42.1 MPa and 51.9 MPa, respectively. However, the retention of SP Sika-visconcrete 3115N content of 7% caused a decrease in concrete quality, with the result of concrete compressive strength in the 28-day concrete test of 41.7 MPa. The three test results are included in the category of high-quality concrete with a standard of >41.2 MPa. On the other hand, the addition of the SP Consol P100 ESP showed better performance in the 7-day test. However, there was no significant improvement in concrete testing of 14 and 28 days of age. The test results for 28 consecutive days were 35.7; 40,6; and 35.7 MPa. These three results have not met the high quality concrete standards.

F. The Relationship of Workability to SCGC Compressive Strength

The increased workability in SCGC is inversely proportional to the result of compressive strength of concrete. This is proven by the increase in SP levels from 5% to 7% affecting the quality of concrete, namely for 5% at 51.9 MPa and 7% at 41.7 MPa.

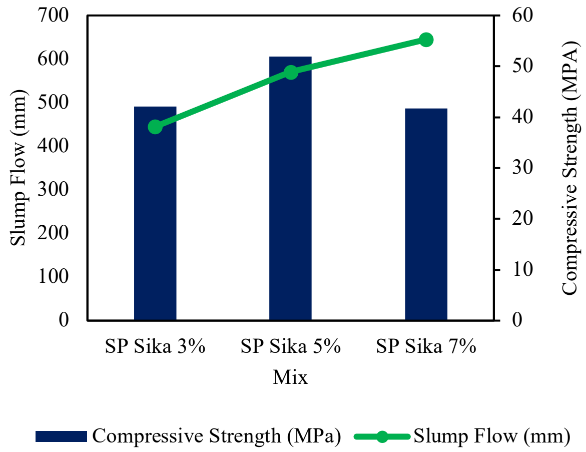

Figure 7. Relationship within workability and compressive strength

Figure 7 shows the relationship between workability and SCGC compressive strength. The addition of superplasticizer (SP) levels with a range of 2% improves the workability of SCGC concrete. This can be viewed from the graph of the relationship between the compressive strength and the workability. The graph in Figure 8 shows that an increase in SP levels with a range of 2% increases SCGC workability. Meanwhile, an increase in SP with a level of 7% decreases the compressive strength by 10 MPa. The compressive strength results of concrete with the addition of SP content of 7% shows that it meets the standards of high quality concrete compressive strength test and the requirements to be used as SCGC concrete.

Overall, the analysis results indicate that an increase in SP levels can improve the workability of concrete. However, the addition of SP beyond its optimum level can lower the concrete compressive causation. The optimum level that can be inferred from the results of the analysis is conducted by applying SP Sika Visconcrete 3115N with a level of 7%, which has good flowing ability and has a high compressive strength at a testing age of 28 days.

IV. Conclusion

The SCGC concrete based on high-calcium fly ash with SP type, namely Sika Visconcrete 3115N, shows a trend of increasing workability along with the SP increase. The composition of SCGC, with the addition other SP of 7% Sika Visconcrete 3115N, obtained optimum results, deriving in a compressive strength of 28 days of 41.7 MPA, and these results are included in the high-quality concrete standard. SCGC workability tests for slump flow, v-funnel, and L-box tests are 645 mm, 13 seconds, and 0.81, respectively. Meanwhile, the composition of the SCGC with the addition of Consol P100 ESP does not meet the self-compacted concrete workability test (SCC) standard because the concrete cannot flow during the test. The highest compressive strength test for the addition of SP Consol P100 ESP is 40.6 MPa at a rate of 5%. Based on the results of this research, it can be seen that performance of SCGC concrete has the same quality as normal concrete. This occurs in variations with the addition of 7% Sika-Visconcrete 3115N. Therefore, high-calcium fly ash-based SCGC concrete has great potential to be implemented as a large-scale construction material.

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