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Characteristics of Self Compacting Concrete (SCC) by the Silica Fume as Portland Cement Substitute

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Abstract: *Self-compacting concrete (SCC) is a type of concrete that can flow by itself and can self-compact without using a compactor such as a vibrator. This study aims to observe the effect of cement substitution with silica fume on the compressive strength of concrete. The researchers expect a compressive strength of Self Compacting Concrete up to 500 kg/cm^2, although silica fume substituted some portland cement. In order to reduce water use while maintaining the slump flow value of 60±2 cm, a superplasticizer was added at the fixed composition of 1.2% (w/w). The experimental design of silica fume as a cement substitute with a variation of 0%, 5%, 10%, and 15% (w/w). The concrete compressive strength test is carried out under the ASTM C234 standard, while the slump flow value refers to the ASTM C494 standard and the British Standard 5075. Although there was no compressive strength of 500 kg/m^2 for all types of cement obtained, it shows that the highest compressive strength of SCC concrete was in the type of OPC cement at 28 days of age.*

Keywords: *Compressive Strength, OPC, PCC, PPC, Superplasticizer.*

INTRODUCTION

The developed concrete in the construction sector is Self Compacting Concrete (SCC). This concrete has the property of being able to flow by itself, and without compaction, with a compactor or vibrator, it can compact itself (Schutter, Bartos, Domone, & Gibbs, 2008). The advantages of SCC concrete technology are that it does not require a long time and saves investment costs because it does not require a compaction process and the purchase of a vibrator (Caijun, Wu, Lv, & Wu, 2015).

The focus of research is the effect of silica fume substitution on cement on the compressive strength of Self Compacting Concrete to reduce the amount of cement used without reducing the compressive strength of the concrete itself (Panjehpour, Ali, & Demirboga, 2011). Based on recommendations by (ASTM 2015), the silica fume specification used is not less than 85%. However, in this study, silica fume was used with a SiO_2 content of less than this requirement considering cheaper raw material costs without compromising quality. According to (Chouhan, Jamle, & Verma, 2017), the function of silica fume in concrete mixtures is to increase the compressive strength of concrete, fill voids in concrete, reduce permeability and reduce the heat of hydration. In addition, a superplasticizer is added to the concenrated mixture to reduce the amount of water use, increasing workability and increasing the slump flow value of the concrete itself (Benaichaa, Alaoui, & Jalbaud, 2019).

This study using three different types of cement, namely Ordinary Portland Cement (OPC), Portland Composite Cement (PCC), and Portland Pozzolana Cement (PPC). Thus it can be seen whether silica fume substitution effects increasing the compressive strength of the resulting concrete in the three types of cement. In addition, it can also observe which type of cement provides the most optimal compressive strength response as a mixture of Self Compacting Concrete. Companies PT. Indocement Tunggal Prakasa Tbk., continuously strives to improve production cost efficiency (Herliati, Asyha, & Nulhakim, 2020), then the cement substitution by some silica fume in order to reduce the need for cement raw materials becomes something interesting. However, the critical thing to note is to maintain the quality of the SCC produced.

This study's targeted concrete compressive strength was 500 kg/m^2 or K-500, observed at 3, 7, and 28 days. The variation of silica fume substitution on cement is 0%; 5%; 10%, and 15% (w/w), while the addition of superplasticizer at 1.2% based on the results of the research reported by (Benaichaa, Alaoui, & Jalbaud, 2019). The amount of water added produces a slump flow as targeted, which is 60±2cm based on the ASTM C494 standard and British Standard 5075. The composition of cement used in this study for each type of cement is the same, namely 488 kg/m^3.

RESEARCH METHODS

Materials and tools

The raw materials used consisted of Portland cement provided by PT Indocement Tunggal Prakasa Tbk., fine aggregate as sand, coarse aggregate, gravel measuring 5 - 10 mm supplied by PIONIR, silica fume (S.F.) from SIKA INDONESIA, and superplasticizer from BASF. The requirements for the physical properties of the cement used to refer to (SNI-2049, 2015) as presented in Table 1.

While the tools used in this study consisted of a concrete test mold (cubes are measuring 15x15x15), weighing capacity of 100 kg, concrete mixer (mixer), cement spoon, slump flow test tool, measuring instrument (meter), stopwatch, compressive strength testing tool.

Table 1. Cement Physics Requirements

Description	Unit	OPC	PPC	PCC
Setting time :				
- Initial Setting	- minute	- minimum 45	- minimum 45	- minimum 45
- Final Setting	- minute	- maximum. 375	- maximum 420	- maximum 375
compressive strength :				
- 3 days age	- kg/cm^2	- minimum 135	- minimum 130	- minimum 130
- 7 days age	- kg/cm^2	- minimum 215	- minimum 200	- minimum 200
- 28 days age	- kg/cm^2	- minimum 300	- minimum 280	- minimum 280

Source: (SNI-2049, 2015)

Test Sample Preparation

The materials needed in the form of coarse aggregate, gravel measuring 5-10 mm, fine aggregate, sand, portland cement (OPC, PPC, PCC), and silica fume with a certain weight. Then the raw materials are gradually fed into a mixer while adding water little by little until the mixture is all wetted. The materials were stirred for 3 minutes and then added with superplasticizer as much as 1.2 percent of the mixture. The next stage is the slump flow test on the fresh concrete produced using the slump flow test. If the results obtained have not reached the target of 60±2cm, then add water little by little until the slump flow target is achieved. The fresh concrete is only molded into cubes with 15cm × 15cm × 15cm, then stored for later testing.

The mixture of concrete ingredients using a mix design refers to the SNI Standard 03-2834-2000 and the British Standard, Department of Environment (DOE). Table 3 shows the types of concrete designs without S.F. and S.F.

Compressive Strength Test

Compressive strength is the ability of concrete to bear the load on the building structure. The compressive strength test was done after the cube-shaped specimen measuring 15cm × 15cm × 15cm reached the specified age, namely three days, seven days, and 28 days (Amhudo, Putu, & Tavio, 2018). The compressive strength of concrete testing uses a Compression Testing Machine referring to the ASTM C234 standard.

The procedure placed the test object on the pressing table of the Compression Testing Machine and turned on the Compression Testing Machine. The computer screen captures the movement of the test object from the beginning to breaking. The maximum value of the load that the test object can withstand is recorded when the test object begins to break.

Table 2. Typical Mix Design without Silica fume

	Typical Mix Design	**kg/m^3**
Cement Type	Ordinary Portland Cement (OPC)	488
	Portland Pozzolan Cement (PPC)	488
	Portland Composite Cement (PCC)	488
Fine Aggregate	Local sand prepared according to ASTM C136-06	880
Coarse Aggregate	Local gravel (5-10 mm), prepared according to ASTM C136-06	781
Superplasticizer	BAFS, 1.2 %	5.83
Water (Litre/m^3)		205
Slump Flow (60±2 cm)		60
Ratio design w/c		0.42

Source: (SNI-03-2834, 2000)

Table 3. Typical Mix Design with Variation of S.F.

Materials	**Total**			
Silica Fume (weight %)	0	5	10	15
Cement Content: OPC, PPC, PCC (kg/batch)	17.57	16.69	15.81	14.93
Fine Aggregate (kg/batch)	31.71	31.71	31.71	31.71
Coarse Aggregate, 5-10 mm (kg/batch)	28.12	28.12	28.12	28.12
Water design (liter/batch)	7.38	7.38	7.38	7.38
Target Slump flow (cm)	60±2	60±2	60±2	60±2
Silica Fume (kg/batch)	-	0.88	1.76	2.64
Superplaticizer (kg/batch)	0.21	0.21	0.21	0.21
Ratio design w/c	0.42	0.42	0.42	0.42
Curing Ages	3, 7, 28 days			

Source: (SNI-03-2834, 2000)

RESULTS AND DISCUSSION

Raw Material Test

First, an analysis of the raw materials for making concrete consists of coarse aggregate, fine aggregate, and silica fume is carried out. The physical and chemical tests of raw materials are shown in Table 4, Table 5, and Table 6. These results are very much in line with those reported by (Ketab & Nahhab, 2020).

Table 4. Aggregate Test Results

Analysis	Fine Aggregate	Coarse Aggregate
Zone	2	-
Fines Modulus (F.M.), %	2.53	6.20
Specific Gravity (SSD), g/cc	2.42	2.37
Absorption, %	4.81	3.49
Material Pass 75 µm, %	3.84	1.48
Sludge levels, %	14.63	0.95
Organic Level	2	-
Abrasion, %	-	47.56

Table 5. Cement Chemical Properties Test Results

	Component	PPC	PCC	OPC
XRD	C_3S (%)	51.73	52.40	53.06
	C_2S (%)	6.84	6.50	5.15
	C_3A (%)	8.96	8.61	8.89
	C_4AF (%)	6.15	6.45	5.84
XRF	CaO (%)	55.44	56.74	63.23
	MgO (%)	3.56	5.16	2.87
	SO_3 (%)	1.77	1.72	1.84

Tabel 6. Specifications of Silica Fume

Component	% in Silica Fume
SiO_2	80.35
Al_2O_3	0.27
Fe_2O_3	4.67
CaO	0.82
MgO	2.17
SO_3	0.83

Fresh Concrete Test

The purpose of testing fresh concrete is to measure the slump flow value resulting from the concrete mix. Because the desired concrete is Self Compacting Concrete, namely concrete that can flow by itself and without compaction with a vibrator it can solidify itself, it is necessary to pay attention to the viscosity of the concrete (Adi, Mousavi, ami, Danes, & Sarand, 2015). Slump flow test results are based on ASTM C494 standard and British Standard 5075, as shown in Table 7.

Table 7. Slump Flow Test Results

Silica Fume added (%)	PPC		PCC		OPC	
	Actual water (liter)	Slump Flow (cm)	Actual water (liter)	Slump Flow (cm)	Actual water (liter)	Slump Flow (cm)
0	6	60	5,9	60	5.8	61
5	6.35	58	5.04	61	5.64	60
10	6.56	60	5.38	58	5.85	58
15	6.90	59	6.36	60	6.35	60

Testing of Hardened Concrete

The compressive strength test was carried out on the hardened concrete at 3, 7, and 28 days. Table 8 shows the results of the compressive strength test. The procedure for testing the compressive strength of concrete refers to ASTM C234.

Table 8 Compressive Strength Test Data

Silica Fume added (%)	Compressive strength at PCC			Compressive strength at PPC			Compressive strength at OPC		
	3 days age	7 days age	28 days age	3 days age	7 days age	28 days age	3 days age	7 days age	28 days age
0	195	243	331	195	240	335	222	298	390
5	256	268	370	201	285	350	295	357	493
10	215	242	369	187	228	344	274	333	399
15	164	232	357	183	192	275	227	299	371

Effect of Silica Fume on Addition of Water and Slump Flow

Figure 2 showed that the higher the percentage of silica fume substitution, the more water is used. This is because the silica fume granules are very fine compared to cement so that the mixture becomes drier and absorbs much water. This result is following the results presented by (Shyam, Anwar, & Ahmad, 2017). For this reason, a superplasticizer is added so that the addition of water is not excessive but still maintains the slump flow value so that the compressive strength of the concrete remains high (Benaichaa, Alaoui, & Jalbaud, 2019).

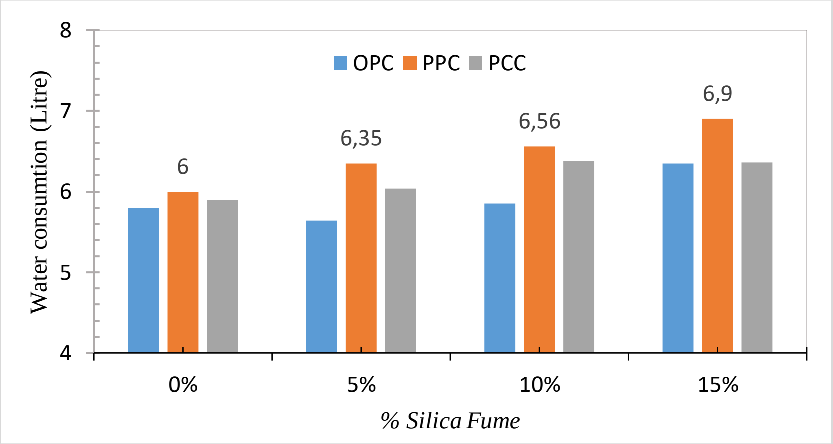

Figure 1. Effect of Silica Fume on the Water Consumption

From Figure 1, information is obtained that the highest slump flow value is obtained in concrete using OPC cement type without the addition of silica fume and PCC type with the addition of 5% silica fume. However, over all the slump flow value meets the standards for all types of cement.

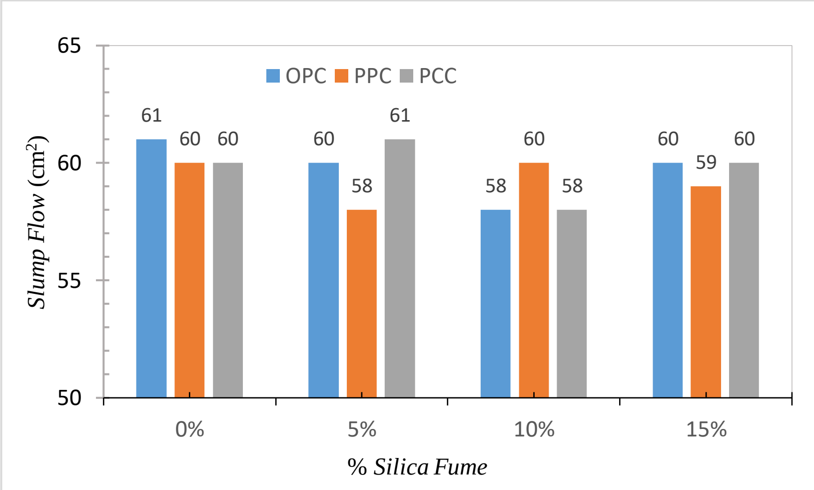

Figure 2. Effect of Silica Fume on Slump Flow

Effect of Silica Fume on Compressive Strength of Concrete

Figure 2 shows the compressive strength test results observed at the age of 3,7and 28 days using silica fume at 0%, 5%, 10% and 15% of the cement weight. At 0% silica fume obtained a compressive strength of 271 kg/m^2, 355 kg/m^2 and 430 kg/m^2. The use of 5% silica fume obtained a compressive strength of 201 kg/m^2, 285 kg/m^2 and 483 kg/m^2. The use of 10% silica fume obtained a compressive strength of 187 kg/m^2, 228 kg/m^2 and 344 kg/m^2. While the use of 15% obtained a compressive strength of 183 kg/m^2, 192 kg/m^2 and 275 kg/m^2.

It can be seen that the more use of silica fume, the lower the compressive strength of the concrete, which is similar to that reported by previous researchers (Singh, Khan, & Kumar, 2016). The highest compressive strength value of concrete was obtained with 5% silica fume as a substitute for OPC-type cement, 383 kg/m^2 at the age of 28 days. Overall, no concrete reaches the compressive strength of 500 kg/m^2. The quality of the aggregate used and the content of the aggregate SiO_2 in silica fume may cause the compressive strength has not to be achieved. Table 7 shows that the SiO_2 content in silica fume is only 80.35%, while based on ASTM C 1240-05, the minimum SiO_2 content is 85%. So that SiO_2 in silica fume has not been able to react with Ca $(OH)_2$ to form CSH optimally. The CSH produces the compressive strength of the concrete (Singh & Bansal, 2015).

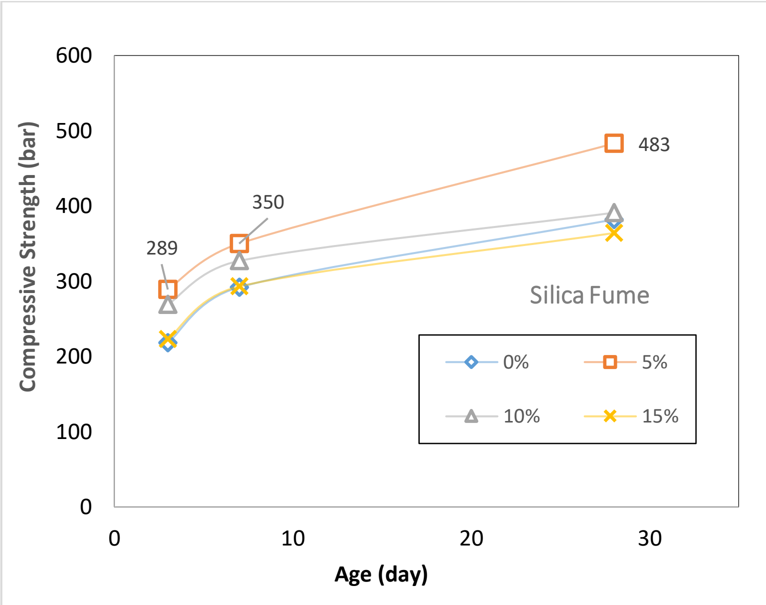

Figure 3. Effect of Addition of S.F. on Compressive Strength of OPC Type Cement

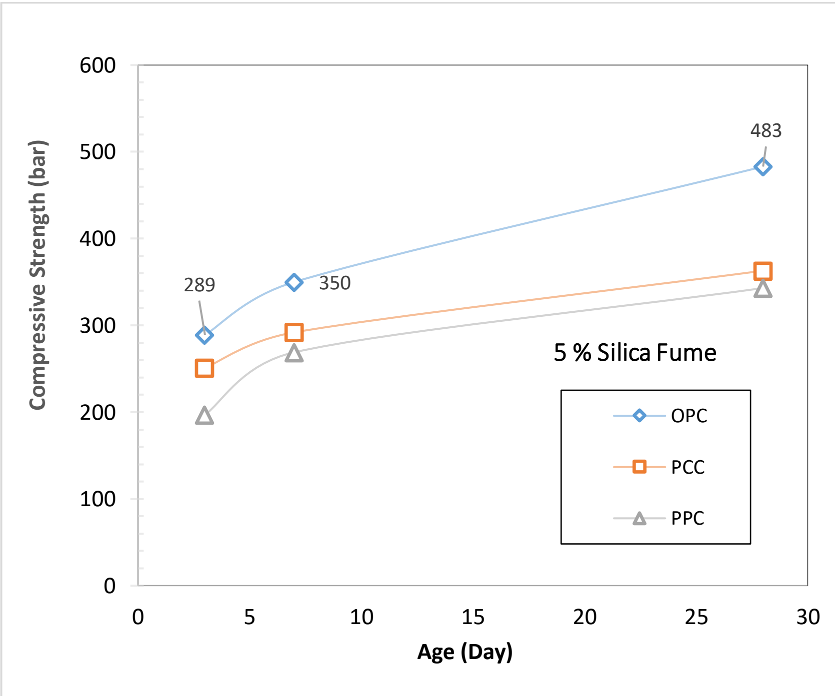

Figure 4. The effect of adding 5% S.F. on the Compressive Strength of Concrete with various types of cement

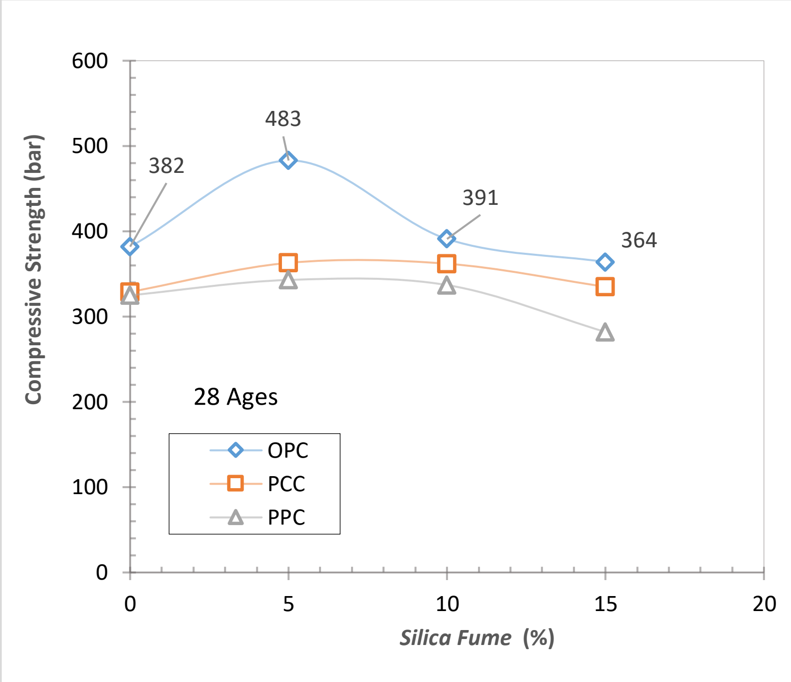

Figure 5. Effect of S.F. variation on Compressive Strength at 28 Days Concrete Age

Figure 5 shows the compressive strength test results from the age of 3, 7, and 28 days with a silica fume substitution of 5% for OPC, PPC, and PCC cement types. The highest compressive strength was found for the OPC cement type, which was 483 kg/m^2 at the age of 28 days and almost met the compressive strength of the design concrete. While Figure 6 is the result of observations on the effect of S.F. substitution with variations of 0%, 5%, 10%, and 15% on the compressive strength of concrete in OPC, PPC, and PCC cement types. Here it can be seen that the highest compressive strength is produced in the OPC cement type. This result because the C3S and CaO content of OPC is higher than others, while the MgO content of OPC is much lower than that of PPC and PCC. The content of C3S and CaO affects the compressive strength of concrete. Meanwhile, the high MgO content causes the concrete to expand, which causes the compressive strength of the concrete to decrease so that it is easy to crack.

CONCLUSION

A series of observations and tests have been carried out. The optimum compressive strength for all types of cement used is the silica fume substitution of 5%. The resulting compressive strength is 350 kg/m^2 for PPC, 370 kg/m^2 for PCC and 483 kg/m^2 for OPC. For further research, it is necessary to research using silica fume with a SiO_2 minimum of 85% as cement substitution in self-compacting concrete as standard ASTM C1240-05.

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