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Designing of Flow Mortar Design Mix for Self Compacting Concrete (SCC) with FWC = 0.4

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ABSTRACT Self Compacting Concrete (SCC) is an innovation to produce concrete that could flow independently without being compacted. One of the practical methods is by making the mortar mix design first. The purpose of this research was to find optimum value of the flow mortar which will be base in the design of self-compacting concrete; and to find the optimum ratio of the mortar's absolute volume to the volume of coarse aggregate cavity. The mortar material used type I cement, silica fume content 10% of cement weight, ratio of cement and grade III cement was of 1:1.25; water-cement factor of 0.4; and superplasticizer content of 0.3%, 0.4%, 0.5%, and 0.6% of cement weight. In this design of self-compacting concrete, the ratio of mortar absolute volume to coarse aggregate cavity were of 1.4, 1.6, and 1.8 with size of coarse aggregate of 10-20 mm. This research showed the optimum content of superplasticizer on mortar was of 0.6% which resulted slump flow of 260 mm, and compressive strength of 57.44 MPa. The testing result of SCC showed optimum value on ratio of mortar absolute-volume to coarse aggregate cavity was of 1.8 resulted slump flow of 280 mm, and compressive strength of 65.76 MPa.

KEYWORDS Flow; mortar; concrete; self compacting; compressive strength

1 INTRODUCTION

On the field of construction industry, concrete work holds a very important role. It could be said that almost on all built construction, such as high rise buildings, housings, roads, bridges, dams and irrigation channel, as well as other constructions always need concrete work, both as the primary need or as the supporting material element.

In concrete work for conventional reinforced concrete structures works, the most important job that needs to be done is compacting or concrete vibration. The purpose of compacting is to minimalize air voids in fresh concrete, so homogenous concrete would be obtained and there are no cavities occur in the concrete (honey-comb) (Widodo, 2003). If the concrete is not perfectly compacted, it could reduce compressive strength and the water-proof element of the concrete, which then could lead to rust formed in the steel reinforcement. Conventional concrete casting on beam-column joint, in which a lot of reinforcement is installed, faces the difficulties to reach optimal density even if it already has been compacted with vibrator. One of solution to overcome this problem is with self-compacting concrete (SCC) technology.

Self-compacting concrete (SCC) is an innovative concept to produce concrete that could flow yet stays homogenous, so it could be easily and quickly casted, without compacting/vibrating, and the concrete could even easily flow through the tight reinforcement without being segregated or experiencing bleeding (Widodo, 2003). This type of concrete is commonly used for concrete work on structure part that is hard to be reached and it also could create structure with good quality. The basic principal concept on self-compacting concrete production is the relation between superplasticizer utilization and fresh concrete characteristic, as shown in Figure 1.

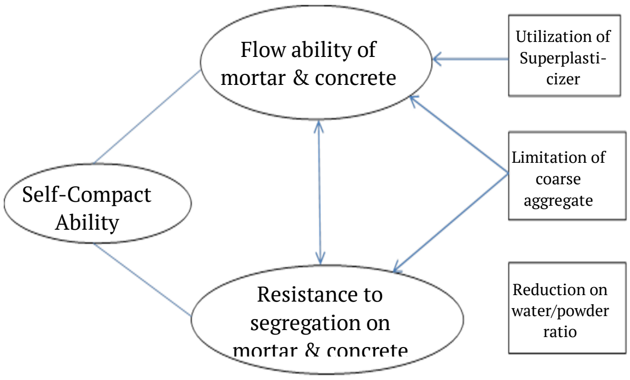

Figure 1. Basic principal concept on self-compacting concrete production (Dehn, et al., 2000).

SCC could be produced if using superplasticizer that is needed to disperse cement particles to be evenly distributed and separate it into fine particles; therefore the C-S-H (*tobermorite*) formation reaction would be more even and more active. The coarse aggregate and fine aggregate also should be considered in the production process of self-compacting concrete. It should be considered that the greater proportion of fine aggregate, the more flow ability of fresh concrete would be increased. If too much fine aggregate is being used, the compressive strength of the produced concrete would be decreased; vice versa, if too much coarse aggregate is being used, the segregation risk of the concrete would be increased. Whereas filler material is needed to increase the concrete's viscosity in order to avoid bleeding and segregation, therefore fly ash, limestone powder, silica fume, or other filler, is being used for this purpose (Persson, 2000).

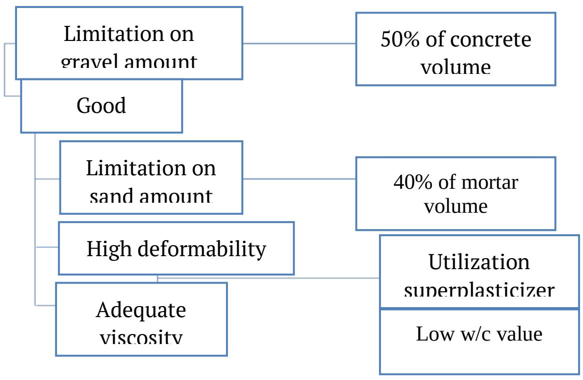

Figure 2. Self-compacting concrete mix ingredients (Okamura & Ouchi, 2003).

One of the methods being used to design SCC mix proportion is by designing the flow mortar design mix first (Okamura & Ouchi, 2003). The design method of SCC mix proportion by first designing flow mortar design mix aims to make a more practical and more economical SCC designing. The proportion of Okamura SCC mix is shown in Figure 2.

The coarse aggregate composition in conventional concrete is 70-75% of total concrete volume. Whereas in self-compacting concrete, the amount of coarse aggregate is being limited to less than 50% of total concrete volume, as shown in Figure 2. This aggregate limitation is used to make the concrete could be flow and self-compact without compacting machine. In this research, the coarse aggregate that being used was gap graded aggregate. Gap graded is a condition in which there is one or more intermediate size of the aggregate is being neglected. A study conducted by Shacklock (1959) showed that in the case of (the same) ratio of cement/aggregate and water/cement, the higher workability was obtained on gap graded aggregate, compared with concrete with fine gradation aggregate.

In this research, the self-compacting concrete was firstly designed by determining the optimum flow mortar, as the base to determining the self-compacting concrete (SCC) design mix. The additional elements that being used were superplasticizer type viscocrete-1003 and powder material of silica fume. The reason of using silica fume was because it is easy to obtain, it is in powder form, and it is quite high in silica. Besides its function as powder and prevents segregation and bleeding, the silica fume in concrete mix was expected to give pozzolanic reaction, therefore would increase the compressive strength of the concrete. This pozzolanic reaction is commonly referred as secondary reaction. This reaction cause faster increase of compressive strength on the concrete early age compared with normal concrete. As for the Viscocrete-1003, it was chosen because it is a chemical additional that functions as range water reducer that has high viscosity characteristic.

Referring to several abovementioned problems, it is necessary to conduct a research to find the right composition of self-compacting concrete (SCC) with silica fume powder and superplasticizer type viscocrete-1003 as addictive materials. This research aims to know : the optimum value of flow mortar that would be base in designing the self-compacting concrete, the optimum dosage of superplasticizer, to find optimum value of mortar absolute volume to coarse aggregate cavity volume, and to find optimum concrete compressive strength.

2 METHOD

The research materials needed to conduct various tests in this study consist of: (1) OPC (*Ordinary Portland*

Cement) type I brand of Semen Gresik, (2) Split stone aggregate with diameter of 10 – 20 mm, which originated from Nanggulan Kulon Progo, (3) fine aggregate with gradation intermediate value III which originated from Cangkringan Sleman, (4) clean water from Construction Material Laboratory, Faculty of Engineering, Universitas Gadjah Mada, (5) Superplasticizer with brand of SIKA VISCOCRETE 1003, (6) Silica Fume with brand of SIKA FUME. The tools used in this laboratory works are: sieve,mortar and concrete mold,Universal Testing Machine, Concrete and Mortar Mixer, Mortar cone, Abrams cone, scales, Los Angeles testing machine, Rudeloff vessel, steel plates,V-funnel, L-Box, Oven,water bath,conical cone,and pycnometer.

The variables using in this research consist of:(1) the water-cement ratio was 0,4; (2) the weight ratio of cement to sand was 1:1.25; and (3) the weight ratio of silicafume to cement was 10%. The optimum flow mortar was achieved by varying the superplasticizer contents, namely 0.3%, 0.4%, 0.5%, and 0.6% of cement weight.Subsequently, the SCC mix design was based on variables, namely the ratio of absolute-volume of coarse aggregate cavities of 1.4, 1.6, and 1.8.

Result of initial testing on SCC aggregate characteristic is shown in Table 1, as for the specific weight of the cement was known of 3.15, silica fume was of 2.2, andsuperplasticizer was of 1.06. Sand gradation used in this research was medium-fine gradation or of area III (Badan Standardisasi Nasional, 2002). Table and percentage graph from sieve screening on area III are shown in Table 2 and Figure 3.

Table 1. Aggregate characteristic

Characteristic	Sand	Gravel
Specific weight SSD	2.79	2.6
Unit weight	1,604	1,500
Cavity volume (%)	-	43.4
Abrasion (%)	-	17.06
Rudellof (%)	-	11.25
Mud content (%)	3.21	-

Table 2. Sand gradation area III

Sieve size (mm)	Percentage limit of passing	Percentage of retained	Percentage weight of retained
4.8	90-100	100	0
2.4	85-100	92.5	7.5
1.2	75-100	87.5	5
0.6	60-79	69.5	18
0.3	12-40	26	43.5
0.15	0-10	5	21
0.075	pan	0	5

Design for concrete and mortar design mix could be calculated based on the absolute-volume or weight proportion of each material, such as cement, water,silica fume, superplasticizer, sand, and gravel (Satyarno, 2015). The base for design mix that was used in designing mixture of 1 m^3 mortar and concrete based on materials weight is shown in Equation 1.

$$\frac{W_c}{SW_cUW_w}+\frac{W_s}{SW_sUW_w}+\frac{W_w}{SW_wUW_w}+\frac{W_{sp}}{SW_{sp}UW_w}+\frac{W_{sf}}{SW_{sf}UW_w}=1 \qquad (1)$$

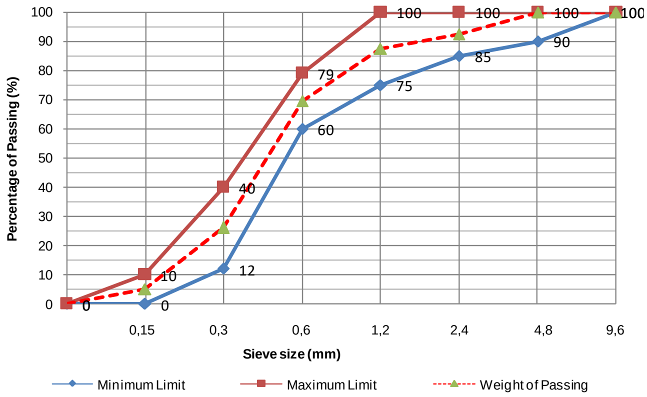

Figure 3. Sand gradation area III

Where W_c is cement weight (kg), W_s is fine aggregate weight (kg), W_w is water weight (liter), W_{sp} is superplasticizer weight (kg), W_{sf} is silica fume weight (kg), SW_c is cement specific weight, SW_w is water specific weight, SW_s is fine aggregate specific weight, SW_{sp} is superplasticizer specific weight, SW_{sf} is silica fume specific weight, and UW_w is water unit weight.

Steps in designing mortar based on materials weight are as follow:

a) Determine silica fume weight (W_{sf}) from cement weight (W_c) that would be used; therefore resulted to Equation 2.

$$W_{sf} = D_{sf} \times W_c \qquad (2)$$

D_{sf} is silica fume dosage.

b) Determine water weight based on water/cement factor (f_{wc}) that would be used by using Equation 3; which would result to Equation 4.

$$f_{wc} = \frac{W_w}{W_{sf}+W_c} \qquad (3)$$

$$W_a = f_{as} \times (D_{sf} + 1) \times W_s \qquad (4)$$

c) Determine sand weight based on the comparison of sand: cement that would be used (*s/c*), which would result to Equation 5.

$$W_s = W_c \times \frac{s}{c} \quad (5)$$

d) Determine superplasticizer weight (W_{sp}) from superplasticizer content to cement that would be used, which would result Equation 6.

$$W_{sp} = D_{sp} \times W_c \quad (6)$$

D_{sp} is dosage of superplasticizer.

e) From abovementioned material weight equations, the initial step in determining material compositions is the cement weight. Therefore, cement weight is acquired with Equation 7 based on Equation 1.

$$\frac{W_c}{SW_cUW_w} + \frac{W_c\,(s/c)}{SW_sUW_w} + \frac{fwc(D_{sf}+1)W_c}{SW_wUW_w} + \frac{D_{sp}W_c}{SW_{sp}UW_w} + \frac{D_{sf}W_c}{SW_{sf}UW_w} = 1 \quad (7)$$

f) Equation 7 then resulted to mortar design mix which is shown in Table 3.

Table 3. Mortar mix composition

SP Dosage	Cement (kg)	SF (kg)	Water (kg)	Sand (kg)	SP (kg)
0.3%	797.6	79.8	350.9	996.9	2.4
0.4%	796.9	79.7	350.7	996.2	3.2
0.5%	796.4	79.6	350.4	995.5	3.9
0.6%	795.8	79.6	350.2	994.7	4.8

g) Weight of each concrete material (W_{cr}) was obtained by multiplying weight of each mortar composers' weight (W_m) to aggregate cavity volume (V_{cv}) and ratio of mortar absolute-volume to coarse aggregate cavity volume (R_m) as in Equation 8.

$$W_{cr} = W_{mx} \times V_{cv} \times R_m \quad (8)$$

h) Absolute-volume of the gravel was residue of mortar volume on 1 m^3 concrete, so the gravel weight (W_k) could be found with Equation 9.

$$W_g = (1 - V_{cv} \times R_m) \times SW_{ca} \times UW_w \quad (9)$$

SW_{ca} iscoarse aggregate specific weight.

The abovementioned equations yielded concrete composition which was shown in Table 4.

Table 4. Concrete mix composition

R_m	Cement (kg)	SF (kg)	Water (kg)	Sand (kg)	SP (kg)	Gravel (kg)
1.4	483.53	48.35	212.75	604.41	2.90	1,020.24
1.6	552.60	55.26	243.14	690.75	3.32	794.56
1.8	621.68	62.17	273.54	777.09	3.73	568.88

3 RESULT AND DISCUSSION

3.1 Fresh Mortar Testing

Testing that conducted on fresh mortar was the slump flow testing. The result of slump flow testing for mortar is shown in Table 5 and Figure 4.

Table 5. Mortar slump flow mortar and SP content

Mortar Code	SP Content (%)	Ø Average Slump Flow (cm)
M04SP0.3	0.3	12.7
M04SP0.4	0.4	14.1
M04SP0.5	0.5	25.3
M04SP0.6	0.6	26.0

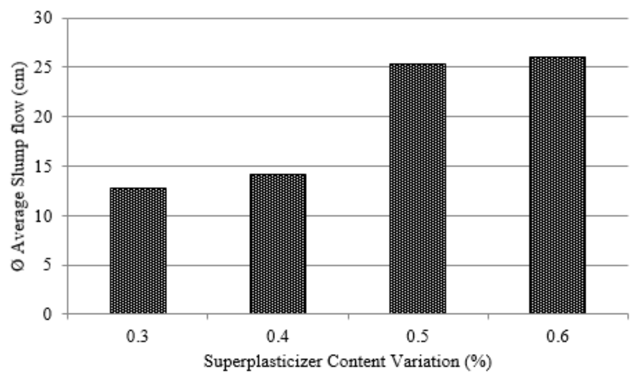

Figure 4. Flow mortar and SP content.

From the conducted tests, which are shown in Table 5 and Figure 4, the addition of superplasticizer affected flow characteristic on mortar. The higher the superplasticizer content, the slump flow value would increase, such shown in diameter distance from the flow table testing with mortar cone. According to EFNARC (2005) the target slump flow is 24 – 26 cm. The test result showed that the highest diameter slump flow value was 26 cm on mortar with superplasticizer with content of 0.6%. The superplasticizer content of 0.6% would then be used for self-compacting concrete designing, because the main requirement on self-compacting concrete designing is slump flow.

3.2 Mortar Compressive Strength Test

The result of mortar compressive strength test is shown in Table 6 and Figure 5.

Table 6. Compressive strength and SP content

Mortar Code	SP Content (%)	f'c (MPa) 1 day	f'c (MPa) 7 days	f'c (MPa) 28 days
M04SP0.3	0.3	23.49	50.42	53.31
M04SP0.4	0.4	25.53	52.99	63.11
M04SP0.5	0.5	27.46	58.06	75.34
M04SP0.6	0.6	30.80	54.39	57.44

The result test on mortar average compressive strength is shown in Table 6 and Figure 5. It could be seen that the mortar compressive strength increases as the concrete ages; but the addition of superplasticizer concentration was not followed with compressive strength increase trend. The highest mortar compressive strength was seen in superplasticizer content of 0.5%, which was 75.34 MPa. The research result also showed the same constant increase of strength on f_{wc} value, yet also showed that the trend on compressive strength increase was tend to be insignificant when the percentage of superplasticizer addition was more than 0.5. The 1 day compressive strength test conducted to find initialy compressive strength based on previous research.

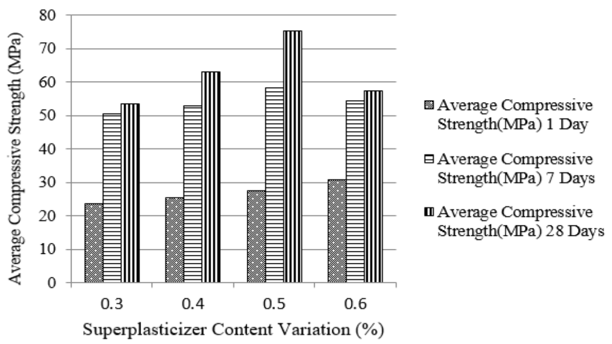

Figure 5. Mortar Compressive strength and SP content.

3.3 Slump Flow Test

Result on slump flow testing on concrete is shown in Table 7 and Figure 6.

Table 7. Concrete slump flow

ConcreteCode	R_m	Ø AverageSlump Flow(mm)
B04R1,4	1.4	430
B04R1,6	1.6	660
B04R1,8	1.8	680

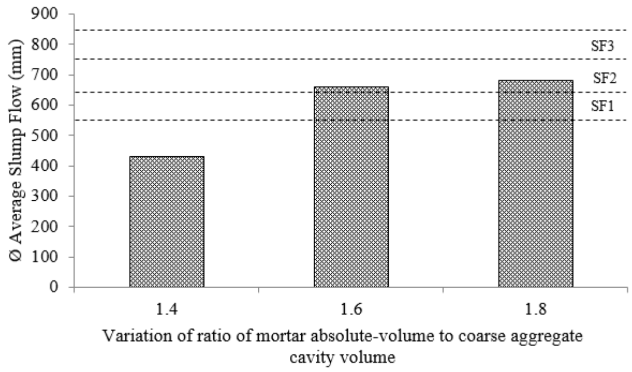

Figure 6. Concrete slump flow and R_m.

Figure 6 shows the decrease of fresh SCC slump flow at ratio of mortar absolute-volume to coarse aggregate cavity volume was reduced. Fresh SCC slump flow that meets the standard according to EFNARC (2005) is of 550-650 mm for class SF1, 660-750 mm for class SF2 and diameter of 760-850 mm for class SF3.

The decrease of fresh SCC slump flow along the decrease of c is because the lower the ratio of mortar absolute-volume to coarse aggregate cavity volume, the higher coarse aggregate that absorb the water. Absorption by the coarse aggregate then caused the free water content on the fresh SCC mixture to decrease. This is in accordance with the research of Zardi, et al.,(2014) and Widodo (2003) that showed the same trend in flow increase for constant f_{wc} value.

3.4 V-funnel Test

Testing with V-funnel was conducted by testing the needed time for fresh SCC to flow through V-funnel. The result of testing with V-funnel is shown in Table 8 and Figure 7.

Table 8. V-funnel test result

Concrete Code	R_m	V-funnel(seconds)
B04R1.4	1.4	16
B04R1.6	1.6	14
B04R1.8	1.8	5

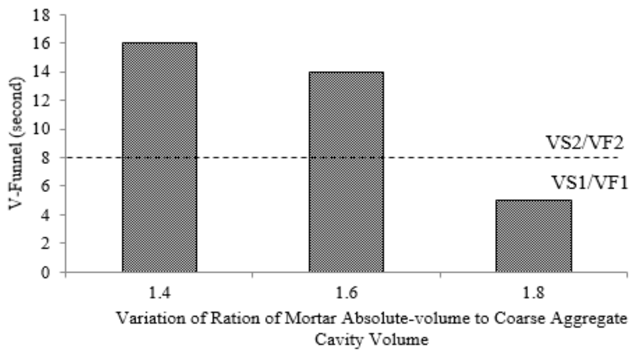

Figure 7. Graph ofV-funnel and R_m.

Result on V-funnel test for ratio of mortar absolute-volume to coarse aggregate cavity volume of 1.4 and 1.6 was 16 and 14 seconds respectively. While for the ratio of 1.8, the result was 5 seconds. According to the EFNARC (2005), the V-funnel value should be⩽ 8 seconds for class VS1/VF1, and V-funnel ranges on 9-25 seconds for class VS2/VF2. The test result showed that variation of ratio of mortar absolute-volume to coarse aggregate cavity volume of 1.8 complied to time standard (i.e. ⩽ 8 seconds) needed for fresh SCC to go through the funnel on V-funnel testing. This test result showed trend such as in the slump flow testing of fresh SCC, which is the lower the ratio of mortar absolute-volume to coarse aggregate cavity volume, the longer time needed for fresh SCC to flow.

3.5 L-Box Test

Testing with L-Box was conducted in order to measure the passing ability. The result of testing with L-Box is shown in Table 9 and Figure 8.

Table 9. Result of L-Box Test

Concretecode	R_m	L-Box
B04R1.4	1.4	0.71
B04R1.6	1.6	0.93
B04R1.8	1.8	0.94

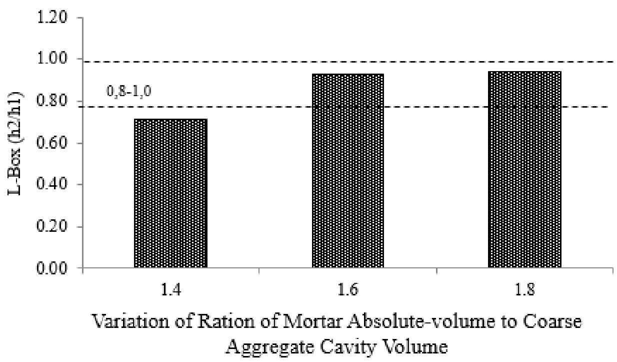

Figure 8. Graph of L-Box andR_m.

Test result showed that ratio of mortar absolute-volume to coarse aggregate cavity volume of 1.8 and 1.6 meet the value standard on L-Box test. This result showed trend such as in fresh SCC slump flow test and V-funnel test, which is the lower the ratio of mortar absolute-volume to coarse aggregate cavity volume, the lower the L-Box value needed for fresh SCC to flow.

3.6 Concrete compressive strength test

Compressive strength test was conducted at 1 and 28 days old for each ratio of mortar absolute-volume to coarse aggregate cavity volume. The test result on self-compacting concrete compressive strength on this research is shown in Table 10 and Figure 9.

Table 10. Concrete compressive strength test result

ConcreteCode	R_m	$f'c$ (MPa) 1 Day	$f'c$ (MPa) 28 Days
B04R1.6	1.6	17.64	45.53
B04R1.8	1.8	26.03	65.76

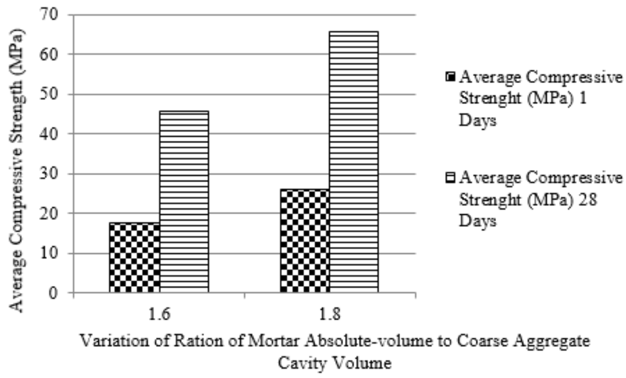

Figure 9. Graph on SCC compressive strength and R_m.

As shown in Figure 9, result on 28 days old concrete indicated that in order to produce self-compacting concrete, fine aggregate fraction that is used was of 58% on ratio of mortar absolute-volume to coarse aggregate cavity volume of 1.8. This is in accordance of the research from Nan Su and others (2001) that suggested using fine aggregate between 50% up to 57%. Using 58% fine aggregate fraction showed a maximal result, due to the easy flow characteristic of fresh concrete that is reached and variation of aggregate size would fill each other, therefore it resulted to concrete that would compact itself using its own weight, and with a quite good compact level.

On the compressive strength test, the ratio of mortar absolute-volume to coarse aggregate cavity volume of 1.6 with fine aggregate fraction of 47% resulted a generated compressive strength of 45.53MPa; this was because of the segregation. Segregation is the event of the separation of material components in fresh concrete mixture due to inhomogeneous mixture. In this test, segregation wasoccurredbecause the concrete mixture was too wet, thus creating separation of cement and water with concrete mixture.

Compared with compressive strength on normal concrete based on SNI-03-2834-2002, the result of self-compacting concrete was higher. Regarding to Figure 10 on the graph on relation of water/cement factor with normal concrete compressive strength, the compressive strength value ranged in 43 MPa, while on the SCC design, compressive strength was 65.76 MPa.

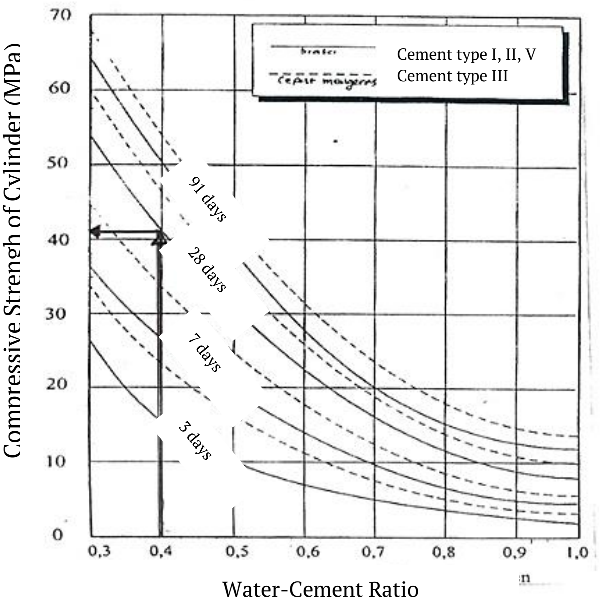

Figure 10. Graph on relation of water/cement factor with normal concrete compressive strength.

4 CONCLUSIONS

Several conclusions that can be drawn from the research are as follows:

a) Result on flow mortar mix design designing with f_{wc} value of 0.4 showed optimum value of superplasticizer content of 0.6%. The designing of flow mortar design mix with content of 0.6% resulted to slump flow value of 26 cm and compressive strength of 57.44 MPa.
b) Result on flow mortar mix design designing with f_{wc} value of 0.4 showed optimum value of ratio of mortar absolute-volume to coarse aggregate cavity volume of 1.8. The design of self-compacting concrete design mix with ratio of mortar absolute-volume to coarse aggregate cavity volume of 1.8 resulted to slump flow value of 680 mm and compressive strength of 65.76 MPa.This was higher compared with estimated value of normal concrete compressive strebthbased on SNI-03-2834-2002 (i.e. 43 MPa for the same water cement ratio).

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