MIX DESIGN OF HIGH STRENGTH SCC WITH POLYPROPYLENE FIBER BASED ON FLOW MORTAR MIX

Kristyan Hari Subangkit[1], Iman Satyarno[2], Andreas Triwiyono[3]
[1, 2, 3]Department of Civil and Environmental Engineering, Gadjah Mada University, Jl. Grafika No. 2, Yogyakarta, Indonesia
christyanhs01@gmail.com[1]

ABSTRACT

Mix design process of Self-Compacting Concrete or SCC is not a simple as normal concrete. The process becomes more complicated if high compressive and tensile strength are required that involves the application of fiber such as polypropylene. This paper discusses the process of such SCC mix design which is based on the mix design of high strength flow mortar with targeted content of absolute volume of polypropylene fiber to be 0.15% of that SCC volume. The mortar was made of Type I cement, 15% of cement weight silica fume, weight ratio of cement and curve No. IV sand was 1 : 0.50. The water-cementious ratio was 0.25 and the amount of plasticizer was 1.6% of the cement weight. Then the SCC mix design is taken by taking the absolute volume of mortar mix per cubic meter SCC was 1.4 and 1.6of the aggregate void, where the aggregate size was 4.8 mm - 9.6 mm. Using this approach the need of absolute volume of aggregate shall one minus that absolute volume of mortar and the need of polypropylene fiber will be 0.21% and 0.19% of the mortar absolute volume. The test results show that the flow of mortar was 276.7 mm and 280 mm, the compressive strength was 100.48 MPa and 106.2 MPa, and the tensile strength was 5.43 MPa and 4.22 MPa for the fiber content of 0.21% and 0.19% respectively. Meanwhile the test results of the SCC show that the slump-flowwas 670 mm and 705 mm, the *V-funnel* time was 20.1 seconds and 12.1 seconds, the *L-box* ratio was 0.82 and 0.89, the compressive strength was 86.65 MPa and 102.76 MPa, and the tensile strength was 6.24 MPa and 7.96 MPa for the mortar absolute volume of 1.4 and 1.6 of aggregate void respectively.

Keywords:flow, mortar,polypropylene fiber, strength, self-compacting concrete

A. INTRODUCTION

Construction world today demands the use of concrete with very high quality and ease of implementation. High compressive strength of concrete is correlated with the nature of brittleand easy to crack. Therefore, it needs to be modified by the addition of fiber in order to improve tensile strength, ductility, resistance to cracking and resistance to shock loads of concrete matrix (Tjokrodimuljo, 2012). Side effects of the addition of fibers into the concrete mix is the changing nature of the fresh concrete into the concrete more difficult to work (Mindess, et al., 2003). When the performance of high strength concrete is achieved then the achievement of economically often not achieved.

In concrete construction work, the concrete compaction or vibration is a job that absolutely must be done for a conventional reinforced concrete structure work. Conventional concrete casting on *beamjoint column* a solidreinforcementby means of *a vibrator* not ensure the achievement of optimal density. The discovery *superplasticizer* based *polycarboxylate* been possible to obtain the fresh concrete that are *high-flowable* and *self-compactable*,where fresh concrete is able to flow and solidified by utilizing its own weight so as to produce concrete hard really dense or compact without any compaction or *vibration*, Flowable concrete itself by using its own weight withoutcompaction *vibration* now known as the *Self-Compating Concrete* (SCC).

There are two basic requirements that it appears to SCC in designing the conflicting namely high fluidity and compactness, SCC mix design was very important and not fully recognized. The relationship between the flow properties or rheology is one of the main issues for designing SCC. However, the measurement of the rheological properties of SCC is often not practical for complex equipment needs. (Okamura & Ouchi, 2003) states that to perform the design *mix design* of self compacting concrete (SCC) then it should start from the mortar, so that in the plan is more practical and economical.

Therefore need a comprehensive assessment of the design *mix design*flow mortarto manufacture *high strength - self-compacting concrete* (SCC) with*polypropylene fiber.* This study was conducted as to how*mix design*flow mortarto manufacture *high strength - self-compacting concrete* (SCC) and how the effect of the addition ofpolypropylene fiber and *superplasticizer* on the ability to flow and rheological properties of mortar and concrete.

B. RESEARCH OBJECTIVES

This study aims to determine the effect of the use of *superplasticizer*(Tue, et al., 2008)(Dubey & Kumar, 2013) andpolypropylene fiber on the rheological properties of mortar and concrete SCC (EFNARC, 2005). This study also wan't investigation how *mix design self* compacted concrete(SCC) based on the *mix design flow* mortar(Satyarno, 2015).

C. STUDY LITERARTUR

1. Mortar

Self-compacting mortar(SCM) can serve as the basis for designing the concrete for the measurement of the rheological properties of SCC is often not practical for complex equipment needs (Dubey & Kumar, 2013). To achieve compaction properties of its own in a mortar, fresh properties of mortar tested using a spread diameter *slump flow table.*

Moderate viscosity and deformability of the mortar phase are needed so that the resistance that occurs when the relative displacement between the coarse aggregate particles can reduce the resistance that occurs when the concrete is flowing(Okamura & Ouchi, 2003).

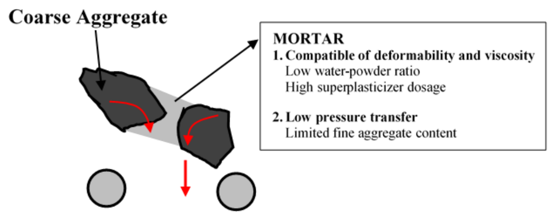

Figure 2. Mechanism between Mortar and Aggregate Coarse to achieve *Self-Compactibility*
(Source: Okamura and Oichi, 2003)

2. *Self-Compacting Concrete* (SCC)

Concrete solidifies itself was generally similar to conventional concrete, but the high use of *superplasticizer* to the reduction of water usage and restrictions fraction thereby increasing workability coarse aggregate concrete. The basic principle of the concrete solidifies itself (SCC) can be seen in Figure 2. SCC specification of EFNARC 2015 states that a concrete SCC said if eligible *filling ability, passing ability* and *segregation*resistance.SCC concrete must remain homogeneous, cohesive, resistant to segregation,does not *blocking*occur,and no bleeding.

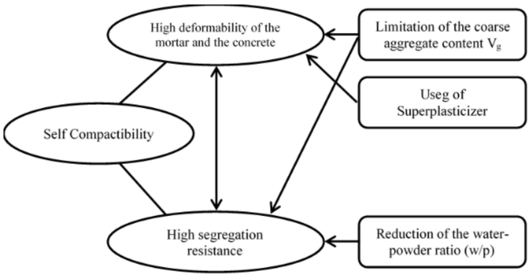

Figure 1. Basic Principles of *Self Compacting Concrete*
(Source: Dhen, et al., 2000)

3. Fiber

In EFNARC (2005) metallic and polymer fibers have been used in the production of SCC, but can reduce the ability flowability and passing ability. Polymer fibers can be used to improve the stability of SCC, as it helps prevent cracking due to shrinkage of concrete. Steel fiber or polymer fibers used to modify the ductility/toughness of the hardened concrete. The length and quantity is selected depending on the maximum size of aggregate and structural requirements. If used as a substitute for normal reinforcement, the risk of blockage is no longer valid but it must be emphasized that using SCC with fibers in structures with normal reinforcement significantly increases the risk of blockage (EFNARC, 2005).

D. METHODOLOGY

1. Material

This researchusing local aggregates, sands from Kuning river and gravel from Nanggulan, Yogyakarta, Indonesia. Cement used Type I (OPC) of Gresik with a specific gravity of 3.15 and a *silica fume* specific gravity of 2.2.Sand and gravel with a specific gravity of 2.81 and 2.53.

Polypropylene fiber hasa length of 12 mm and a diameter of 18 μm with a specific gravity of 0.91. *Superplasticizer* are used manifold *polycarboxylate copolymers* form *liquid* with a specific gravity of 1.065 ± 0.01.

Gradation of sand used in this study is smooth gradation or zone IV (Raju, 1983). Graph the percentage of passes in zone IV sieve can be seen in Figure 3.

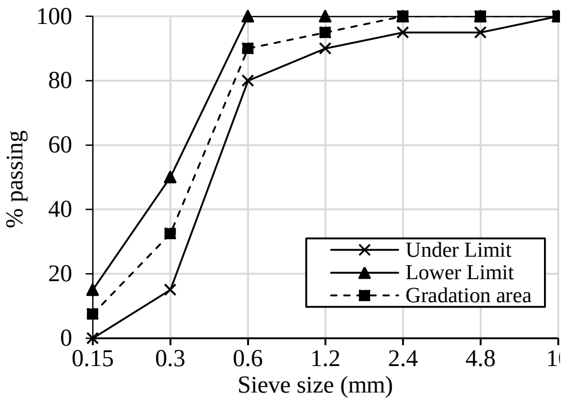

Figure 3. Gradation of sand in the zone IV (Source: Raju, 1983)

2. *Mix Design*

Design mix design mortar and concrete can be calculated based on absolute volume or the proportion of the weight of each material, such as cement, water, *silica*fume, *superplasticizer*,sand and gravel (Satyarno, 2015). This study uses a water-cementitious factor*(w/*c)0.25 (Toutanji & El-Korchi, 1995),content *superplasticizer* 1.6by weight of cement andcontent of *silica fume* 15% by weight of cement (Rao, 2003). Comparison of cement: sand used in this study is around 1: 0.5 (Satyarno, et al., 2014). Mortar mix use a variation coefficient of void volume (C_{vv})1.4 and 1.6, content *Polypropylene fiber* for variation are respectively 0.21% and 0.19% of the volume mortar.

Concrete mixture using coefficient of void volume variation of 1.4 and 1.6 tocontent *superplasticizer* 1.6%by weight of cement (Tue, et al., 2008). Levels ofpolypropylene fiberused in concrete of 0.15% of the volume of concrete (Zhang, et al., 2016)(Akca, et al., 2015)(Widodo, 2012). Basic design of *mix design* that is used in mortar and concrete mix design based on the weight of materials, which can be seen in Equation 1.

$$1m^3 = \left(\frac{W_w}{G_w.\gamma_w}\right) + \left(\frac{W_c}{G_c.\gamma_w}\right) + \left(\frac{W_s}{G_s.\gamma_w}\right) + \left(\frac{W_{sf}}{G_{sf}.\gamma_w}\right) + \left(\frac{W_{sp}}{G_{sp}.\gamma_w}\right) + \left(\frac{W_{pp}}{G_{pp}.\gamma_w}\right) \quad (1)$$

Step in the design of heavy mortar based materials can be seen as follows.

a. Determining levels *silica fume*by weight ofcement (W_c)to be used, so we get the equation 2.

$$W_{sf} = D_{sf}.\ W_c \quad (2)$$

b. Determine the weight of water based on water cementitious factors *(w/*c)used by using Equation 3, so we get the equation 4.

$$w/c = \frac{W_w}{(W_{sf}+W_C)} \quad (3)$$

$$W_w = w/c\ (D_{sf} + 1)\ W_c \quad (4)$$

c. Determine the weight of the sand based on the ratio of cement: sand (c / s) used, so we get the equation 5.

$$W_s = W_c\ (s/c) \quad (5)$$

d. Determine the weight *superplasticizer* of a content*superplasticizer* against the weight of the cement used, obtained equation 6.

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

e. Weight*of polypropylene fiber* (W_{pp})based on the weight of fiber concrete (W_{ppc}),the aggregate void volume (V_r)and coefficient of void volume (C_{vv}),in order to get the equation 8.

$$W_{ppc} = D_{pp}.\ G_{pp}.\ \gamma_w \quad (7)$$

$$W_{pp} = W_{ppc}.\left(\frac{1}{V_r.C_{vv}}\right) \quad (8)$$

f. From the equation above material weight, the first step in determining the composition of the material is the weight of the cement. So we get the weight of cement to the equation 9 by equation 1

$$W_c = \frac{1-\left(\frac{W_{pp}}{G_{pp}.\gamma_w}\right)}{\left(\frac{w/c(D_{sf}+1)}{G_w.\gamma_w}\right)+\left(\frac{1}{G_c.\gamma_w}\right)+\left(\frac{s/c}{G_{sf}.\gamma_w}\right)+\left(\frac{D_{sf}}{G_{sf}.\gamma_w}\right)+\left(\frac{D_{sp}}{G_{sp}.\gamma_w}\right)} \quad (9)$$

g. By equation 9 is obtained mortar mix design that can be seen in Table 1.

h. The weight of each ingredient (W_{ic})concrete sought by multiplying the weight of each mortar (W_{im})of the aggregate void volume (V_r)and coefficient of void volume (C_{vv})as in equation 10.

$W_{ic} = W_{im}.V_r.C_{vv}$ (10)

i. The absolute volume of gravel is the remainder of the mortar on the concrete volume of 1 m^3,so that the weight of gravel (W_g)can be found using the equation 11.

$W_g = (1 - V_r.C_{vv}).G_g.\gamma_w$ (11)

j. From the above equation, the obtained concrete composition which can be seen in Table 2.

Table 1. Composition of mortar mix

Code	Material Weight (kg/m³)					
	Cement	*Silica Fume*	Water	Sand	*superplasticizer*	*Polypropylene*
MS025R1.4	1154.8	173.2	332.0	577.4	18.5	2.0
MS025R1.6	1154.8	173.2	332.0	577.4	18.5	1.7

Table 2. Composition ofconcrete mix

Code	Material Weight (kg/ m³)						
	Cement	*Silica Fume*	Water	Sand	*superplasticizer*	*Polypropylene*	Gravel
BS025R1.4	808.39	121.26	232.41	404.19	12.93	1.37	755.21
BS025R1.6	923.87	138.58	265.61	461.94	14.78	1.37	502.21

E. RESULTS AND DISCUSSION

1. *Flow Table Test*Mortar

Testing fresh mortar properties using the *flow table*test.The test results *of flow table test* is shown in Table 3. and Figure 4.

Table 3. The test results of flow table test

Code	C_{vv}	*Polypropylene* (%)	*Flow* (mm)
BS025R1.4	1.4	0.21	276.7
BS025R1.6	1.6	0.19	280.0

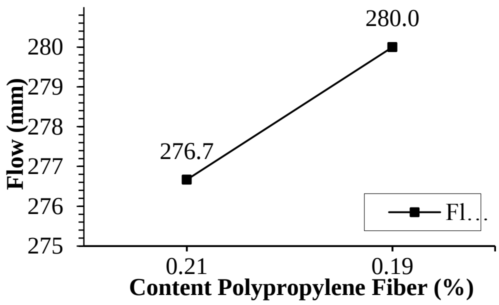

Figure 4. Graph relation to the coefficient of void volume *flow* mortar withpolypropylene fiber

In the coefficient of void volume 1.4 usingcontent *polypropylene fiber* of 0.21% and coefficient of void volume 1.6 usingcontent *polypropylene fiber* of 0.19% by volume of mortar. The effect of addingfiber *polypropylene*will reduce the flow of fresh mortar. This is due to the addition of the fiber surface area to be lubricated by the pasta will increase, so the pasta will decrease the flow properties. At the same time, polypropylene fiber also reduces the potential energy needed by the fresh mortar in order to be able to flow with its own weight because of the increased friction between the aggregate and fibers in the mortar mix (Widodo, 2012).

2. Compressive Strength Mortar

Test specimen size used in mortar 50x50x50 mm^3 and a compressive strength testing is done at the age of 1, 7 and 28 days. The results of compressive strength testing can be seen in Table 4. and Figure 5.

Table 4. Results of testing the compressive strength of mortar

Kode	C_{vv}	Compressive Strength (MPa)		
		1 Days	7 Days	28 Days
BS025R1.4	1.4	57.66	86.16	100.48
BS025R1.6	1.6	58.52	90.21	106.20

Compressive strength value generated in tcoefficient of void volume variation of 1.4 and 1.6 at 28 days amounted to 100.48 MPa and 106.2 MPa. From the test results can be seen that with the addition ofpolypropylene fiber will decrease the compressive strength of mortar. The highest compressive strength at 1.6 with a variation of*polypropylene fiber* 0.19% is 106.2 MPa.

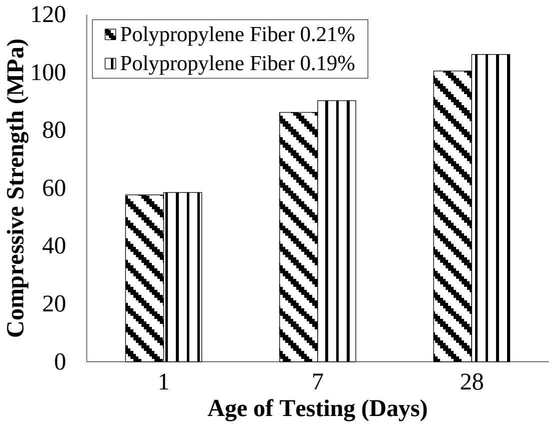

Figure 5. The graph of compressive strength according to agemortar

3. Tensile Strength Mortar

Mortar tensile strength testing done at the age of 1, 7 and 28 days with the test object paint form bone. Results of testing the tensile strength of the mortar can be seen in Figure 6.

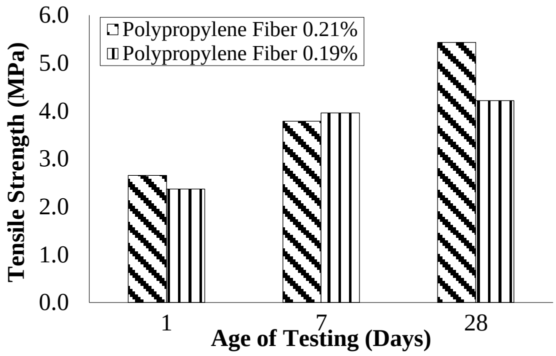

Figure 6. Graph tensile strengthbased on age mortar

From the test results can be seen that with increasing addition ofpolypropylene fiber in mortar will increase the tensile strength of the mortar. Results of testing the tensile strength at 28 days with a variation ofC_{vv} 1.4 and 1.6is 5.43 MPa and 4.22 MPa.

4. PropertiesConcrete Rheology

Rheological properties of self compacting concrete (SCC) is done by testing *the slump-flow test, the L-box test*, and *V-funnel*test. *Slump-flow test* to review the *filling*ability, *the L-box test* for reviewing *filling ability* and *V-funnel test* for reviewing the viscosity of fresh concrete mixture SCC. Terms and conditions are used to review testing based EFNARC (2005). The test results of the rheological properties of fresh concrete SCC can be seen in Table 5.

Table 5. Personality Testing ResultsRheology of Fresh ConcreteSCC

Code	*Slump-Flow* (mm)	*L-box*	*V-funnel* (sec)
BS025R1.4	670.00	0.82	20.08
BS025R1.6	705.00	0.89	12.10

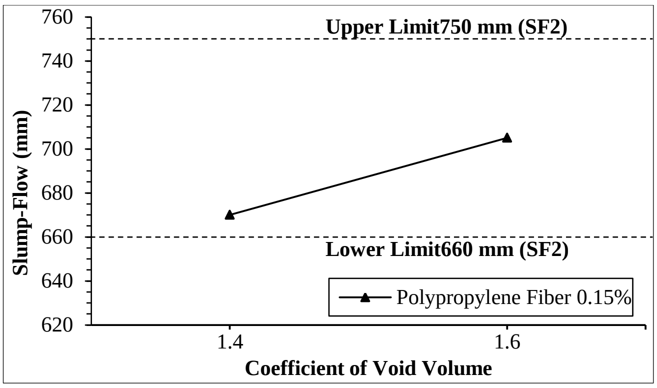

Figure 7. Relations coefficient of void volume(C_{vv})against the value *Slump-flow test*

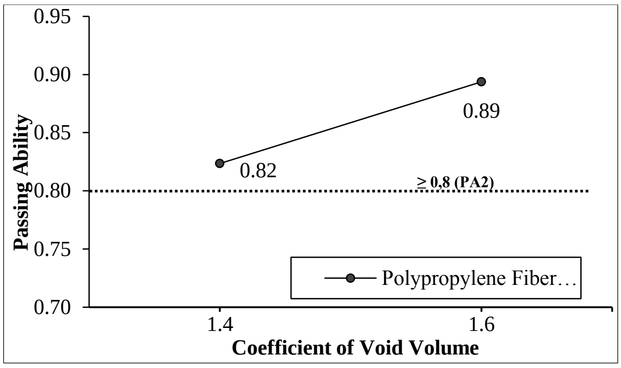

Figure 8. The relationship coefficient of void volume (C_{vv})to the value of *the L-box test (passing ability)*

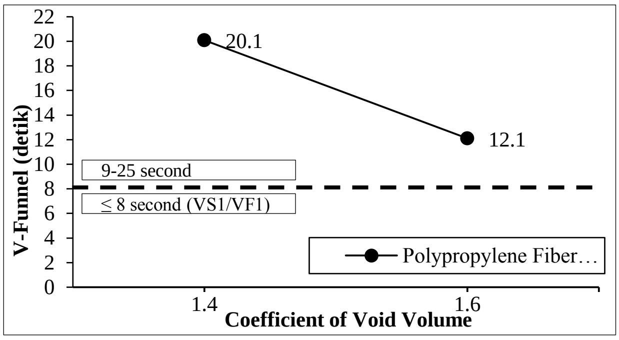

Figure 9. The relationship coefficient void of volume (C_{vv})to the value of *the V-funneltest*

The ratio of the absolute volume of mortarto give effect to *a slump flow* fresh concreteSCC, the greater the ratio the higher the value of *slump*flow.Testing *slump flow* on coefficient of void volume variation of 1.4 and 1.6 belonging to the class with the proviso SF2 660-750 (EFNARC, 2005).

Aggrawal, et al., (2008) looks at the characteristics of self compacting concrete with the comparison between the fine and coarse aggregates. The test results with a ratio of sand: gravel = 53.1%: 46.9% gainvalue of *slump-flow* 670 mm and in this study using a comparison of sand:gravel = 34.9%: 65.1% hadvalue *a slump-flow* 670 mm.

In research Widodo (2012), the addition offibers *of polypropylene* 0.15%in concrete solidified itself with *w/c* 0.44 showsvalue *Slump-flow* of 428.33 mm. In this study, the addition ofpolypropylene fiber0.15%and *w/c* 0.25 showsvalue *Slump-flow* of 670.

V-funnel tests showed increasing ratio of the absolute w of fresh concrete. Th

From the results of testing the rheological properties of fresh concrete SCC is the *slump-flow*, *L-box*,V-funnel,it can be concluded that the concrete is eligible EFNARC (2005) and it can be said *self-compacting concrete* (SCC)

5. Compressive strength concrete

Testing compressive strength of concrete in this study conducted at the concrete age 1 and 28 days. The test object used cylinder with Ø100 x 200 mm size. The test results of concrete strength can be seen in Table 6.

Table 6. Concrete compressive strength test results 1 and 28 days

Code	Compressive Strength (MPa)	
	1 Day	28 Day
BS025R1.4	39.78	86.65
BS025R1.6	54.68	102.76

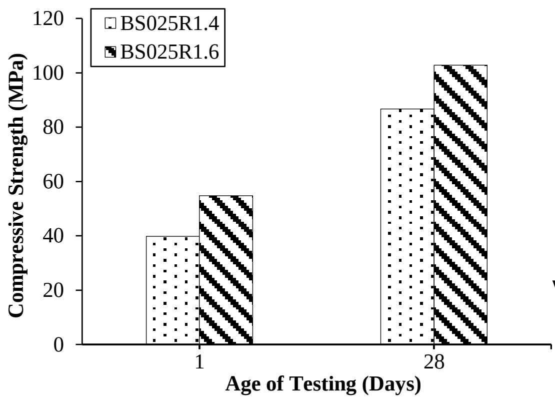

Figure 10. Comparison chart compressive strength of concrete without fiber and concrete with fiber

Figure above shows that with increasing coefficient of void volume will increase the compressive strength of concrete. This is because, at a ratio of 1.4 concrete with fibers more difficult to flow, so that the fresh concrete does not fill the space throughout the concrete and leaving the void resulting in a weak spot at the time of compressive strength testing. The highest compressive strength of the research is in the coefficient of void volume variation of 1.6 to 102.76 MPa compressive strength.

In research Vaitkevicius and Serelis (2014) usingcontent of *silica fume* 15% by themethod *heat treatment* obtained maximum compressive strength of 113 MPa and with methods of *heat* treatment-7D-T80T20-1D obtained compressive strength of 124 MPa. In this study usingcontent of *silica fume* 15% obtained the maximum compressive strength of 102.76 MPa.

6. Tensile Strength Concrete

Tensile strengthtests performed on concrete age 1 and 28 days for each mixture. Results of testing the tensile strength of sides can be seen in Table 7.

Table 7. Results of testing the tensile strength of concrete

Code	*Polypropylene* (%)	Tensile Strength (MPa)	
		1 Day	28 Day
BS025R1.4	0.15	4.42	6.24
BS025R1.6	0.15	5.02	7.96

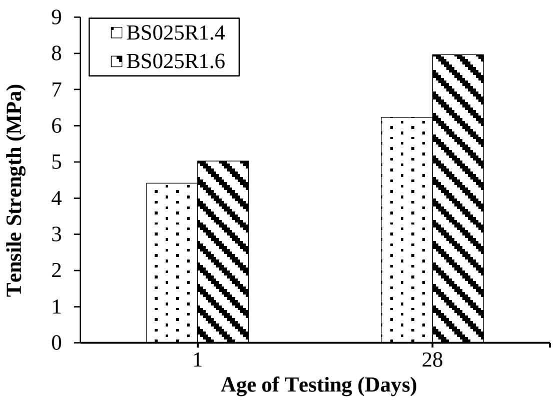

Figure 11. Graph strong relationship attractiveness of coefficient of void volume on the concrete 28 days

Based on the above chart we can see that the highest tensile strength is in the variation coefficients of 1.6 void volume that is equal to 7.96 MPa. The results of this research also showed that the addition ofpolypropylene fiber in concrete will increase the tensile strength of concrete. This is becausepolypropylene fiber microbridging the gap where the crack growth can be controlled. This causes higher the composite strength in terms of tensile strength.

F. CONCLUSIONS

1. The addition ofcontent *polypropylene*fiber will decrease flow mortar and compressive strength. However, an increase in tensile strength mortar. Centipede compressive strength is at a variation coefficient of void volumeof 1.6 at 106.2 Mpa.
2. From the results of testing the rheological properties of the self compacting concrete (SCC) is the *slump-flow*, *L-box*,V-funnel,this concrete qualify said *self-compacting concrete* (SCC) based EFNARC (2005).
3. The highest compressive strength in this study are in the coefficient of void volume variation of 1.6 to the value reached 102.76 MPa compressive strength. Increasing the coefficient of void volume in the concrete will increase the compressive strength in the SCC.
4. The addition ofpolypropylene fiber in SCC will increase the tensile strength of the concrete. The highest tensile strength at SCC is at coefficient of void volume 1.6 is 7.96 MPa.
5. From the results of tensile strength and compressive strength values obtained optimum coefficient of void volume variation of 1.6.

G. APPENDIX

C_{vv} = coefficient of void volume
D_{pp} = dosage of polypropylene fibers (%)
D_{sf} = dosage of silica fume (%)
D_{sp} = dosage of superplasticizer (%)
G_c = density of cement
G_g = density gravel
G_{pp} = density polypropylene fibers
G_s = density of sand
G_{sf} = density silica fume
G_{sp} = density superplasticizer
G_w = density of water
V_r = void volume aggregate (m3)
W_c = weight of cement (kg)
W_g = weight of gravel (kg)
W_{ic} = weight of i on the concrete (kg)
W_{im} = weight of i in mortar (kg)
W_{pp} = weight of fiber mortar (kg)
W_{ppc} = weight of fiber concrete (kg)
W_s = weight of sand (kg)

W_{sf} = weight of silica fume (kg)
W_{sp} = weight of superplasticizer (kg)
W_w = weight of water (liters)
w / c = cement water factor
γ_w = unit weight of water (kg / m^3)

REFERENCES

Aggrawal, P., Siddique, R., Aggarwal, Y. & Gupta, S. M., (2008). Self-Compacting Concrete - Procedure for Mix Design. *Leonardo Electronic Journal of Practices and Technologies*, Issue 12, pp. 25-24.

Akca, K. R., Cakir, O. & Ipek, M., (2015). Properties of polypropylene fiber reinforced concrete using recycled aggregates. *Construction and Building Materials*, Issue 98, p. 620–630.

Dehn, F., Holschemacher, K. & Weiße, D., (2000). Self-Compacting Concrete (SCC) Time Development of the Material Properties and the Bond Behaviour. *LACER*, Volume 5, pp. 115-124.

Dubey, R. & Kumar, P., (2013). Effect of Fly Ash on Water/Powder Ratio and Superplasticizer Dosage in Self-Compacting Mortars. *International Journal of Architecture, Engineering and Construction*, II(1), pp. 55-62.

EFNARC, (2005). *the European Guidelines for Self-Compacting Concrete: Specification Production and Use.* Norfolk United Kingdom: European Federation for Specialist Construction.

Gambhir, M. L., (2006). *Concrete Technology*. 3th ed. New Delhi: Tata McGraw - Hill Publishing Company Limited.

Mindess, S., Young, J. F. & Darwin, D., (2003). *Conrete Second Edition.* 2nd ed. New Jersey: Prentice Hall.

Okamura, H. & Ouchi, M., (2003). Self-Compacting Concrete. *Journal of Advanced Concrete Technology* , 1(1), pp. 5-14.

Raju, K. N., (1983). *Design of Concrete Mixes.* India: CBS Publisher & Distributors.

Rao, G. A., (2003). Investigations on the performance of silica fume-incorporated cement pastes and mortars. *Cement and Concrete Research* , Volume 33, p. 1765–1770.

Satyarno, I., (2015). *Perancangan Praktis Campuran Beton dengan Pengerjaan dan Persyaratan Khusus.* Yogyakarta: s.n.

Satyarno, I. et al., (2014). Practical method for mix design of cement-based grout. *2nd International Conference on Sustainable Civil Engineering Structures and Construction Materials 2014 (SCESCM 2014),* II(95), p. 356 – 365.

Tjokrodimuljo, K., (2012). *Teknologi Beton.* 3rd ed. Yogyakarta: Biro Penerbit.

Toutanji, H. A. & El-Korchi, T., (1995). The Influence of Silica Fume on the Compressive Strength of Cement Paste and Mortar. *Cement and Concrete Research,*, 25(7), pp. 1591-1602.

Tue, N. V., Orgass, M. & Ma, J., (2008). Influence of addition method of Superplasticizer on the Properties of Fresh UHPC. *Second International Symposium on Ultra High Performance Concrete*, II(10), pp. 93-100.

Vaitkevicius, V. & Serelis, E., (2014). Influence of Silica Fume on Ultrahigh Performance Concrete. *International Journal of Civil, Environmental, Structural, Construction and Architectural Engineering*, 8(1), pp. 37-42.

Widodo, S., (2012). Fresh and hardened properties of Polypropylene fiber added Self-Consolidating Concrete. *International Journal Of Civil And Structural Engineering*, III(1), pp. 85-93.

Zhang, H., Liu, Y., Sun, H. & Wu, S., (2016). Transient dynamic behavior of polypropylene fiber reinforced mortar under compressive impact loading. *Construction and Building Materials*, Issue 111, pp. 30-42.