Journal of Thailand Concrete Association

วารสารวิชาการสมาคมคอนกรีตแห่งประเทศไทย

EFFECT OF TAPIOCA STRACH ON PROPERTIES OF SELF-COMPACTING CONCRETE

Samita chaikasatsin[1] Chalermchai Wanishlamlert[2] Parnthep Julnipitawong[3] Somnuk Tangtermsirikul[4]

[1]Graduate student, School of Civil Engineering and Technology, Sirindhorn International Institute of Technology (SIIT) , Thammasat University, Thailand, samitachaikasatsin@gmail.com

[2]Former research faculty, Construction and Maintenance Technology Research Center (CONTEC), School of Civil Engineering and Technology,Sirindhorn International Institute of Technology (SIIT), Thammasat University, Thailand, Chalermchai.wanich@gmail.com

[3]Research faculty, Construction and Maintenance Technology Research Center (CONTEC), School of Civil Engineering and Technology, Sirindhorn International Institute of Technology (SIIT), Thammasat University, Thailand, parnthep@siit.tu.ac.th

[4]Professor, School of Civil Engineering and Technology, Sirindhorn International Institute of Technology (SIIT), Thammasat University, Thailand, Thailand,somnuk@siit.tu.ac.th

ARTICLE INFO:

Received: November 23, 2017.

Received Revised Form:

November 27, 2017.

Accepted: November 30, 2017.

**Corresponding Author,*

Email address: parnthep@siit.tu.ac.th

ABSTRACT:

This project is aimed to be a preliminary study of using tapioca starch as a viscosity modifying agent (VMA) for self-compacting concrete (SCC). The effect of tapioca starch on viscosity of SCCwas investigated from the workability of corresponding mortars. Cement-only mortars with water to cement ratio (w/c) of 0.25 to 0.48, superplasticizer dosage of 1% to 2.5%, starch concentration of 0%, 0.25% and 0.5%, were tested for workability. Mortar mixes that had equivalent workability (flow diameter of 250 mm, and funnel flow time of 5 seconds) for each starch concentration were identified and checked for concrete properties. SCC mixtures were then tested for initial slump flow, slump flow loss, bleeding, setting times, and compressive strength. The results show that all tested concrete mixes provide same initial workability, however the mixes with higher starch concentrations exhibit slower loss. For setting times, mixes with higher starch concentrations demonstrate longer setting times. Compressive strength of starch concretes, which always have higher water to cement ratio (w/c), are lower than that of the concrete without starch as their initial slumps were controlled to be the same in this experiment, however, their strengths are higher or comparable to or higher than the strength range mostly used for conventional concrete.

KEYWORDS: Viscosity Modifying Agent, Self-compacting concrete, Fresh concrete, Filling ability, Compressive strength

 ©2017 J. of TCA All rights reserved

1. Introduction

Self-compacting concrete (SCC) was first developed in Japan in 1980's, in order to solve the construction problems due to the lack of skill workers. SCC is a concrete that can fill into every corner of formworks by means of its own self weight without the need of vibration. The main key of this unique workability is to have high deformability, segregation resistance, and passing ability. SCC can be classified into 4 types based on the ingredients in use as follows;

1) Powder based: It could be achieved by use of high binder content (500-600 kg/m^3), low water to binder ratio (0.25-0.35) and high super plasticizer dosage (0.5-1.0% for polycarboxylate based superplasticizer). It has high durability due to its high strength and low porosity.

2) Viscosity modifying agent (VMA) based: VMA is a viscosity modifying agent. Its main function is to modify the rheological properties of cement paste so that its plastic viscosity is increased. Due to modification on viscosity, the binder content could be reduced to be around 400-500 kg/m^3, which is lower when compared with the powder based SCC. The water to binder ratio of this SCC is around 0.35-0.45.

3) Entrained air based of Aired SCC: High stability entrained air is incorporated into the SCC to increase paste but reduce binder. The high stability air can behave as lubricating particles in the mixture. The binder content of this type of SCC can be reduced to 350-400 kg/m3 which is extremely low for SCC.

4) Combine based: This is the hybrid between the above 2 or 3 types of SCC.

Powder based SCC is the most widely used type in Asian countries such as Japan, Taiwan, China and Thailand. VMA based is widely used in European countries. General requirements of SCC are shown in Table 1. However, the price of SCC is relatively expensive than that of normal concrete. Due to this, ready-mixed concrete companies try to reduce amount of binder in order to minimize the cost of the concrete. Using VMA is possible to reduce binder content in the mixture as well as segregation since VMA can enhance viscosity and thicken the mixture. [1]-[5] describe about type of Self-compacting concrete and General requirements of SCC.

Table 1 General requirements of self-compacting concrete

Concrete Properties	Values
Deformability	Slump flow: 600-800 mm
Deformation velocity	T50: 2-5 sec
Passing ability	L-Box: 0.8-1.0
Segregation resistance	V-funnel: 6-12 sec

Normally, concrete suppliers use admixtures for improving properties of concrete such as workability (slump flow, V-funnel test and setting time), compressive strength and durability. In some applications such as bored pile concrete, underwater concrete, self-leveling concrete (SLC) or self compacting concrete (SCC), relatively high viscosity is needed. Therefore, conventionally these kinds of concrete require high amount of cementitious materials, resulting in high cost of the mixtures.

Tapioca starch is the main product from an economic plant of Thailand, cheap and might be usedas a viscosity modifying agent (VMA) for concrete, especially SCC. Tapioca starch can dissolve in and change viscosity of the water. Performances of concrete using starch have been investigated by many researchers. Therefore, tapioca starch might have potential to be used as a viscosity modifying agent (VMA) in order to achieve the preferable properties of self-compacting concrete (SCC). An essential problem of SCC used in Thailand is that SCC in Thailand is mainly the powder-type SCC which requires high binder content. The use of VMA can reduce binder content and make SCC cheaper with varieties of strength.

It is commonly known that viscosity of concrete is mainly dominated by the viscosity of its mortar. Therefore, this project concentrates first on fresh properties of mortars with tapioca starch. A viscosity checking technique was adapted from the design method for SCC proposed by JSCE, (Okamura, et al.). Concrete mix proportion is determined by firstly obtaining the mortar mix proportion that passes the criteria for mortar in SCC. Then additional properties of concrete will be tested, such as setting time, bleeding and compressive strength.

The objective of this research is to study the application of modified starch in improving the performances of powder based self-compacting concrete and to reduce the binder content to develop a low-cost SCC with the use of starch.

 ©2017 J. of TCA All rights reserved

2. Experiments

2.1. Materials

In this study, binders used for conducting concrete trial mixes include OPC type 1 and fly ash. Modified tapioca starch was used as the viscosity modified agent. Type F naphthalene (Mighty MX-T) and polycarboxylate based (CP-RS) superplasticizers were used.River sand complying with ASTM C33-92a and crushed limestone having a maximum size of 20 mm were used as fine and coarse aggregates, respectively.

2.2. Experimental investigations

2.2.1. Mortar tests

Effect of starch on workability of mortar was checked by 1) Mini cone slump and 2) V-funnel speed test.

Mortar was formulated by fixing S/M = 0.5. In this project, starch with the required concentration was added into the mixing water, referred to as "starch water". The weight of the starch was not included into the batching of unit water content to maintain the correct amount of unit water content. Cement-only mortars with water to cement ratios (w/c) of 0.25 to 0.48, superplasticizer dosages of 1% to 2.5%, starch concentrations of 0%, 0.25% and 0.5%, were tested for workability.

2.2.2. Concrete tests

Mortar mixes that have equivalent workability (flow diameter of 250 mm, and funnel flow time of 5 seconds) for each starch concentration were identified and used to prepare SCC by adding coarse aggregate with a fixed S/M (sand to mortar) ratio of 0.5 (see Table 3 for mix proportions of the tested concrete). The following tests were carried out for concrete.

1) Compressive strength

Compressive strength of concrete according to ASTM C39 was conducted. The strength development of concrete for the considered binder systems were investigated according to requirement of each mix. (at the ages of 7, 14, 28 days)

2) Initial workability and workability loss (slump flow, T50, V-funnel)

Selected testing methods from EAFNAC, Specification and Guidelines for Self-Compacting Concrete [2], were used to measure initial concrete workability. The workability loss with elapsed time of all concrete mixes was also measured.

3) Setting time

Setting time of concrete according to ASTM C403 was investigated.

4) Bleeding

Bleeding of concrete according to ASTM C232 was investigated.

3. Experiment results

3.1 Flow and V-funnel speed test results

The mini cone slump flow and V-funnel speed tests of mortar samples were used to test deformability and viscosity of mortar mixtures in order to draw relationship between their indices Γ_m and R_m, respectively. Γ_m and R_m[1] are defined as;

Deformability index: $$\Gamma_m = \frac{(d_1 d_2 - d_o^2)}{d_o^2} \quad (3.1)$$

Viscosity index: $$R_m = \frac{10}{t} \quad (3.2)$$

Where d_1 and d_2 are measured flow diameters in two perpendicular directions, mm (see Figure 1), d_0 is flow cone's bottom diameter, mm (see Figure1), t is measured time to flow through V-funnel, sec (see Figure 2).

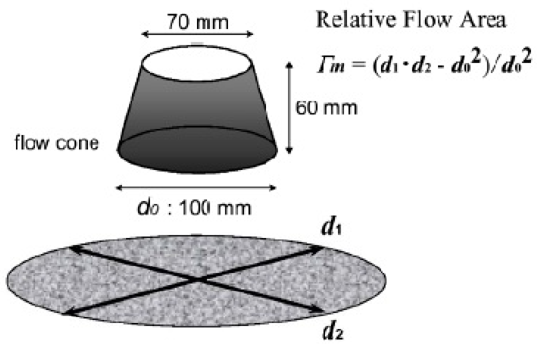

Figure 1 Flow test

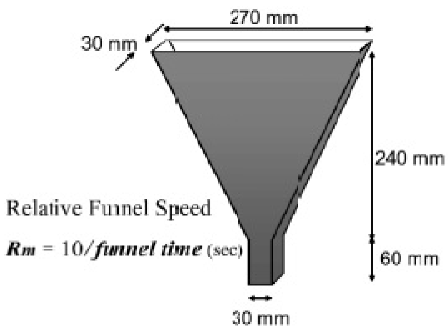

Figure 2 V-funnel speed test

 ©2017 J. of TCA All rights reserved

Figure 3 shows the relationship between flow and V-funnel speed of non-VMA cement-only mortars with varied water to binder ratios and MX-T dosages. It can be seen that changing small dosage of superplasticizer results in drastic change in deformability and viscosity of the mortar mixtures. For each curve of constant superplasticizer dosage, the ratio of Γ_m and R_m are constant regardless of water to binder ratio. It was found in a previous study [1] that a point of (Γ_m =5, R_m = 1) on a curve of constant dosage of superplasticizer gives the proper self-compacting mortar mix proportion. By considering Figure 3 the point of (Γ_m =5, R_m = 1) lies between the curve of sp/b of 1.5% and the curve of sp/b of 2%; therefore, the estimated self-compacting mortar mix proportion is w/c = 0.28 and sp/b = 1.95%, according to the recommendation in EFNARC [2].

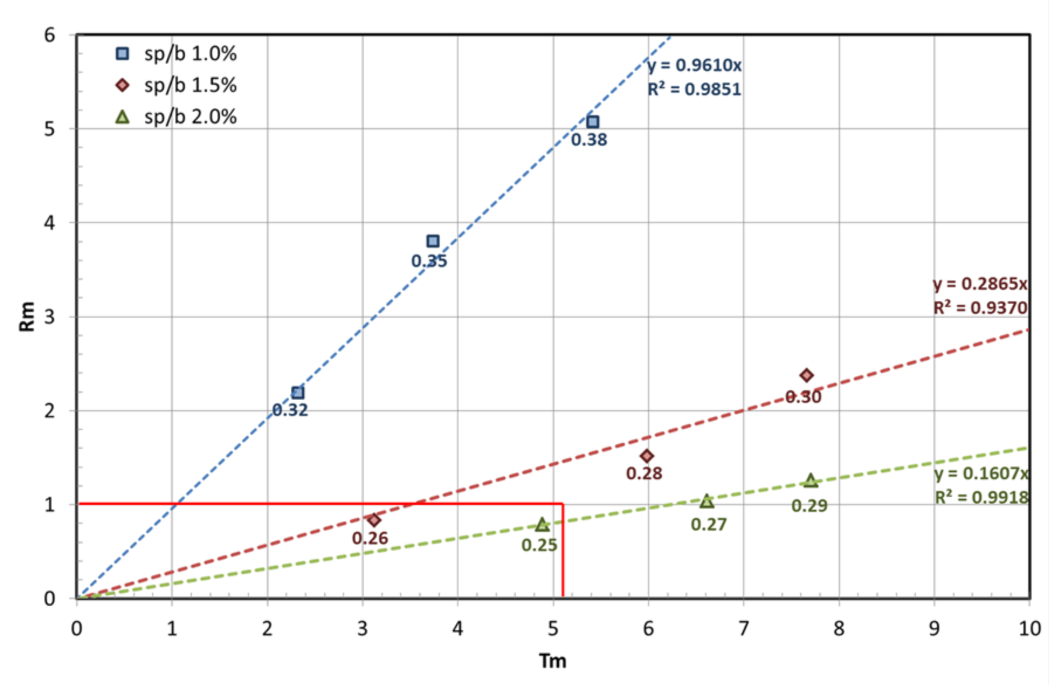

Figure 3 Relationship between flow and V-funnel speed of non-VMA cement-only mortar with varied water to binder ratios and MX-T dosages

Figure 4 and Figure 5 shows the relationship between flow and V-funnel speed of cement-only mortars containing 0.25% and 0.50% starch with varied water to binder ratios and MX-T dosages, respectively. Similar to the previous case, for each curve of constant superplasticizer dosage, the ratio of Γ_m and R_m are also constant regardless of water to binder ratio. However, the self-compacting mortar mix proportion was found to be at the point of (Γ_m =5, R_m = 2) instead of (Γ_m =5, R_m = 1)confirmed by the l-box filling ability test of concrete. It means that the ratio of (Γ_m =5, R_m = 1) is good only for powder-type SCC but for VMA-type SCC, the optimum V-funnel speed should be increased from 1 to 2 in order to achieve the self compactability of the concrete or higher V-funnel speed is required for the concrete with higher viscosity by the use of VMA. By considering Figure 4 and Figure 5, the estimated self-compacting mortar mix proportions are w/c = 0.38, sp/b = 2.0% and w/c = 0.40, sp/b = 2.0%, respectively.

The summary of self-compacting mortar mix proportions for each case is listed in Table 2. It is noted that the mix proportions shown in the table were already tested to confirm whether it fulfilled the (Γ_m =5, R_m = 1 without starch) and (Γ_m =5, R_m = 2 with starch).

 ©2017 J. of TCA All rights reserved

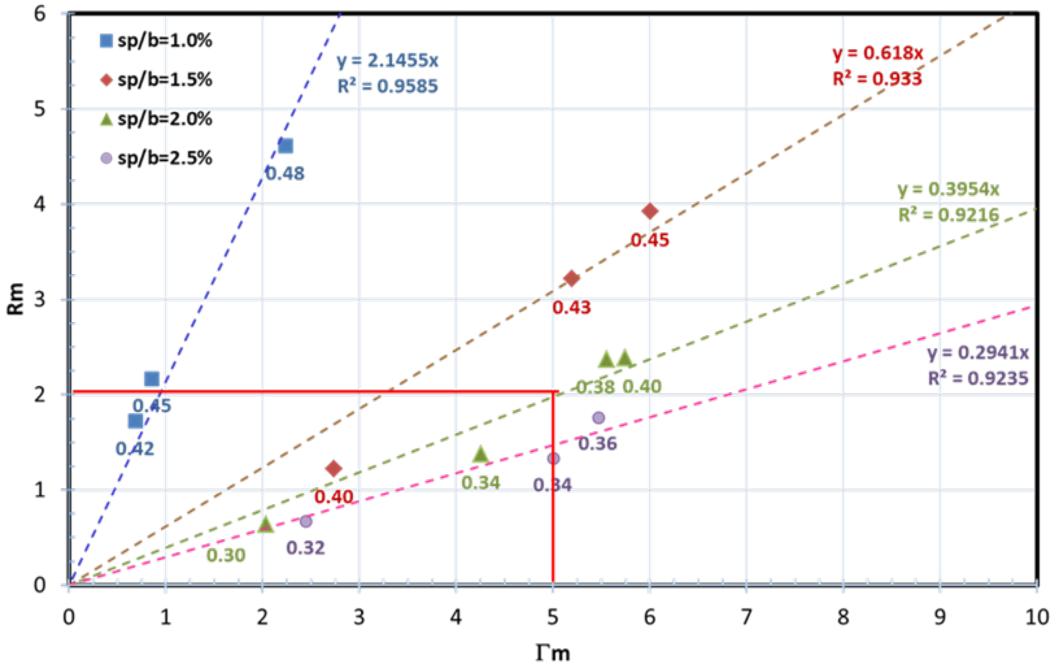

Figure 4 Relationship between flow and V-funnel speed of cement-only mortar containing 0.25% starch with varying water to binder ratios and MX-T dosages

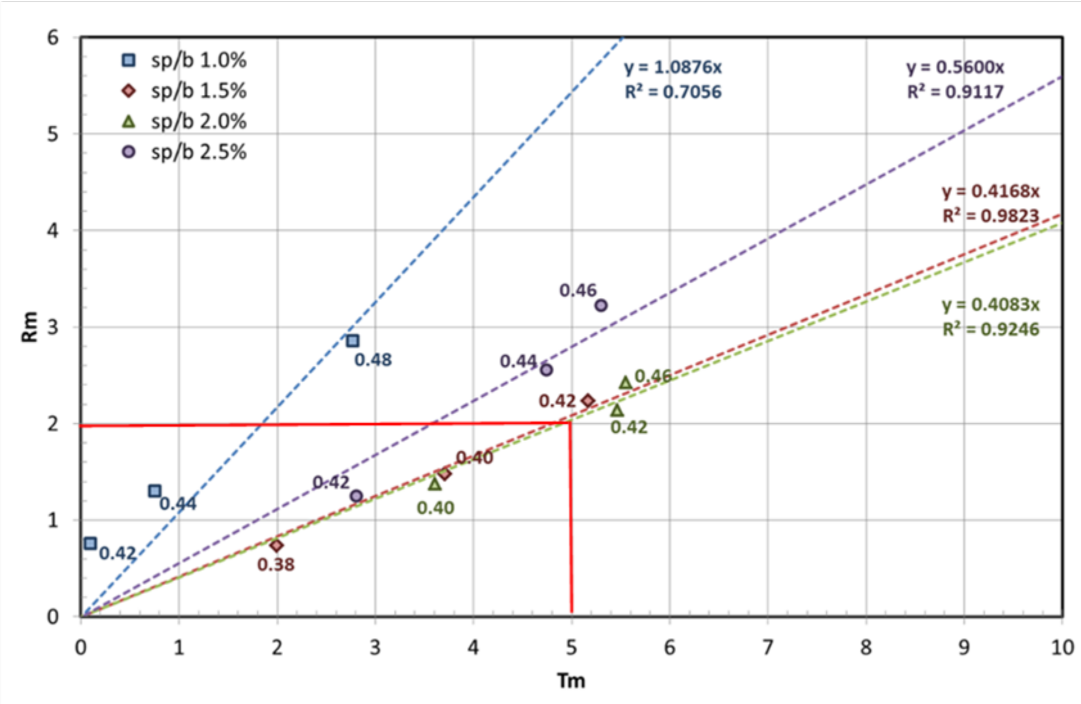

Figure 5 Relationship between flow and V-funnel speed of cement-only mortar containing 0.5% starch with varied water to binder ratios and MX-T dosages

©2017 J. of TCA All rights reserved

Table 2 Summary of self-compacting mortar mix proportions

Starch dosage (%)	Water to binder ratio	Superplasticizer Dosage (%)
0%	0.28	1.95% (M)
0.25%	0.37	2% (M)
0.50%	0.46	2% (M)
0.50%	0.46	1.5% (PC)

M: Mighty –XT
PC: Polycarboxilic

3.2 Concrete test results

3.2.1 Self-compacting concrete mix proportions

The corresponding self-compacting concrete mix proportions can be designed based on maintaining the same w/b, sand to mortar ratio, S/M (by volume), superplasticizer dosage, starch dosage as those of the self-compacting mortar mix proportions, and considering addition of coarse aggregate. The tested concrete mix proportions are shown in Table 3.

Table 3 Tested self-compacting concrete mix proportions

Mix	Cement (kg/m3)	Starch (kg/m3)	Water (kg/m3)	Superplasticizer (liter/m3)	Sand (kg/m3)	Gravel (kg/m3)
OPC+ Starch0% + MX-T	568.93	0	159.30	11.09	920.50	813.00
OPC+Starch0.25%+MX-T	496.00	9.18	174.34	9.92	920.50	813.00
OPC+Starch0.50%+MX-T	439.90	20.24	182.12	8.80	920.50	813.00
OPC+Starch0.50%+PC	442.42	20.35	183.16	6.64	920.50	813.00

3.2.2 Slump flow

Figure 6 shows the slump flow test results of SCC without starch and with 0.25% and 0.5% starch, with different dosages of MX-T. According to European Guideline for Self-Compacting Concrete (EFNARC) [2], their initial slump flows are classified as SF2 Class (660-750mm) which is suitable for many normal applications such as walls, columns etc. By applying starch, the slump of the samples can be maintained longer than that of without starch due mainly to larger water and superplasticizer contents in the mixtures with starch. It is also possible that starch, when dissolved in water, has an ability to adhere to the surfaces of cement particles, causing delay of hydration of cement and then longer slump retention. To verify the latter, more studies are needed in the future.

3.2.3 V-funnel speed

Figure 7 shows the V-funnel speed of SCC samples with different starch and superplasticizer dosages. According to [1], initial V-funnel speed values of SCCsamples containing starch are classified as VF1, whereas initial V-funnel value of SCC samples containing no starch is classified as VF2. It can be seen that SCC concrete samples containing starch have lower V-funnel speed as compared with that of SCCsample without starch, due to their higher viscosity.

3.2.4 Bleeding test results

Only two bleeding results which are the results of SCC samples containing starch 0.50% with MX-T and PC superplasticizers as shown in Figure 8. It can be seen that SCC sample with PC superplasticizer has lower bleeding than that of the SCC sample with MX-T. It is known that the steric hindrance mechanism of the PC superplasticizer, which utilizes long polymer chains to disperse cement particles by hindering the approaching of cement particles, is more beneficial than the electrostatic repulsion mechanism of other superplasticizers to resist the settlement of the cement particles in the mixtures.

 ©2017 J. of TCA All rights reserved

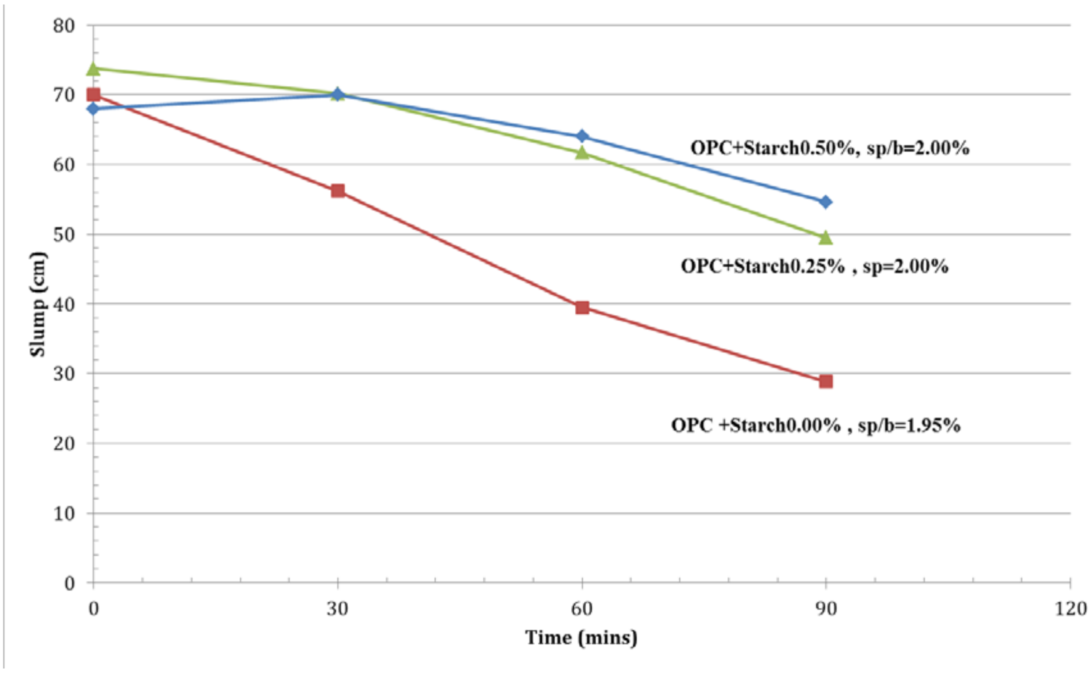

Figure 6 Slump flow of SCC samples with different MX-T dosages and with different starch dosages

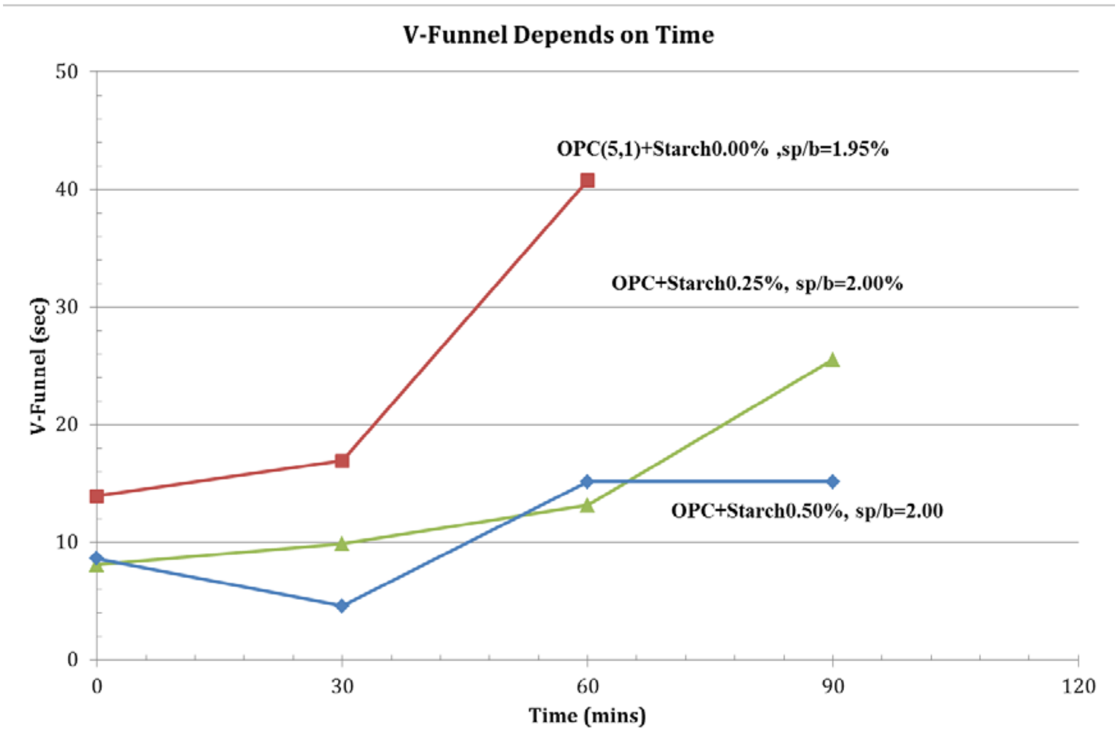

Figure 7 V-funnel speed test results of SCC samples

©2017 J. of TCA All rights reserved

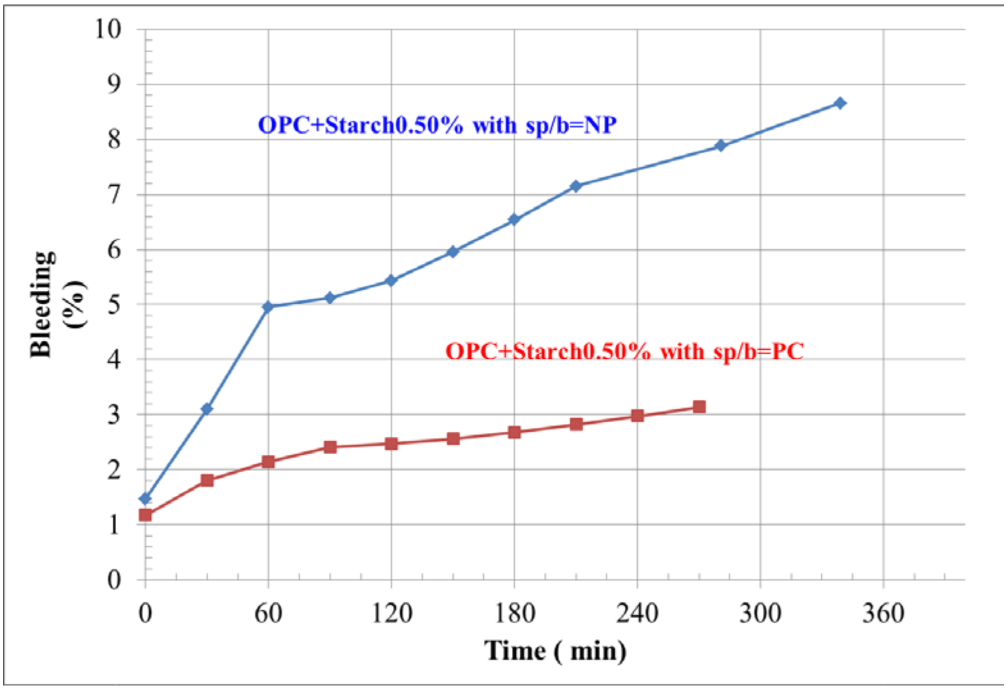

Figure 8 Bleeding of SCC samples containing starch with different superplasticizers

3.2.5 Setting time results

Table 4 show the results of initial and final setting times of samples which were wet sieved from SCC samples containing different starch and superplasticizer dosages. It is shown that applying starch can cause delay of both initial and final setting times of SCC samples. Higher starch dosage leads to longer initial and final setting times. The reasons are similar to those described for the slump loss.

Table 4 Initial and final setting times of tested SCC samples

Mix	Initial setting time (hours)	Final setting time (hours)
OPC+ Starch 0% +MX-T	4	5
OPC +Starch 0.25%+ MX-T	6	7
OPC +Starch 0.50% +MX-T	7.45	9
OPC +Starch 0.50%+ PC	7.45	9

3.2.6 Compressive strength test results

It can be seen from Table 5 that 28-day compressive strength of SCC samples containing starch are lower than that of traditional powder-type SCC samples. It is obvious that higher starch dosage causes decrease in compressive strength. By comparing between 28-day compressive strength of SCC tested in this study and 28-day compressive strength of ready-mixed concrete (see Figure 9), it illustrates the possibility of producing low-cost SCC which has 28-day compressive strength of about 24 to 32 MPa, of which this range of compressive strength covers approximately 80% of the concrete strength of ready-mixed concrete consumed in Thailand, with the use of 0.5% starch and w/c of about 0.45. It can also be seen that the cement content can be reduced from 550 kg to only 450 kg for 1m^3 of concrete to produce the SCC while the required dosage of superplasticizer is almost unchanged. The cement reduction by the use of starchin SCC is shown in Figure 10. So, a low-cost SCC with an applicable strength range becomes possible by using starch as a viscosity modifying agent.

©2017 J. of TCA All rights reserved

Table 5 28-day compressive strength of tested SCC samples

Mix	28-day Compressive strength (MPa)
OPC + Starch 0% + MX-T	60
OPC + Starch 0.25% + MX-T	44
OPC + Starch 0.50% + MX-T	33
OPC + Starch 0.50% + PC	33

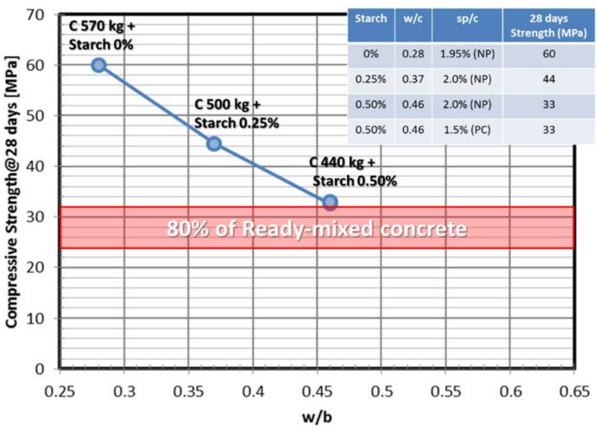

Figure 9 Comparison between 28-day compressive strength of SCC and 28-day compressive strength of ready-mixed concrete samples

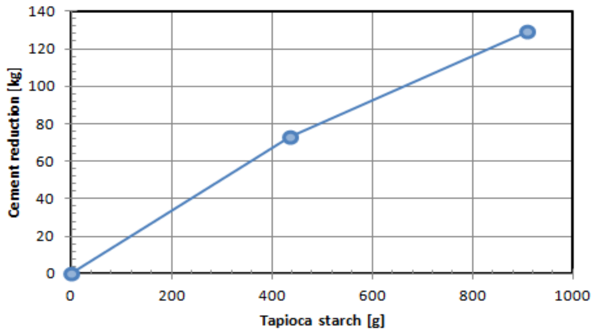

Figure 10 Cement reduction in SCC by the use of starch

3.2.7 Cost comparison

Table 6 shows the estimation of cost of concrete based only on material cost by referencing with the cost of conventional concrete having compressive strength in the range of 24 to 32 MPa as 100%. From the table it can be seen that the costs of SCC concrete mixtures are higher than the conventional concrete, especially in case of traditional powder-type SCC which costs 35% higher than the conventional concrete. The costs of SCC concrete mixtures containing 0.25% and0.5% with MX-T and PC are just 25% and 15% higher, respectively, and if PC is used for the 0.5% starch, the cost is just 12% higher than the conventional concrete.

Table 6 Cost estimation of SCC with and without starch

Mix	Cement (Baht/ m^3)	Starch (Baht/ m^3)	Water (Baht/ m^3)	Super plasticizer (Baht/m^3)	Sand (Baht/m^3)	Gravel (Baht/m^3)	Total (Baht/m^3)	Comparison bypercentage
Conventional concrete	624.05	-	2.72	42	200	480	1348.78	100%
OPC + Starch0% + MX-T	1014.41	-	2.07	266.26	230.13	325.2	1838.06	136%
OPC + Starch 0.25% + MX-T	884.37	-	2.27	238.08	230.13	325.2	1680.04	125%

©2017 J. of TCA All rights reserved

Mix	Cement (Baht/ m^3)	Starch (Baht/ m^3)	Water (Baht/ m^3)	Super plasticizer (Baht/m^3)	Sand (Baht/m^3)	Gravel (Baht/m^3)	Total (Baht/m^3)	Comparison bypercentage
OPC + Starch 0.50% + MX-T	784.34	-	2.37	211.15	230.13	325.2	1553.18	115%
OPC + Starch 0.50% + PC	788.84	-	2.38	159.27	230.13	325.2	1505.82	112%

4. Conclusions

It can be concluded that low binder type SCC concrete can be achieved by applying viscosity modifying agent such as tapioca starch. The self-compactability can be achieved by reducing binder content, applying suitable dosages of starch and superplasticizer along with the possibility to increase water to cement ratio. On the other hand, the setting times of SCC containing starch are prolonged and the 28-day compressive strength is reduced for the SCC mixtures with starch. The 28-day compressive strength of SCC containing starch is lower than that of the traditional powder-type SCC, however, its compressive strength is sufficient to meet the most applied strength range of compressive strength class of ready-mixed concrete. It is possible to reduce the cost of SCC by applying starch as a viscosity modifying agent in SCC.

5. Acknowledgement

The authors would like to acknowledge the support from the Thammasat University Research Fund under the TU Research Scholar Contract No. 2/25/2559, Center of Excellence in Material Science, Construction and Maintenance Technology, Thammasat University and Siam Modified Starch Co.,Ltd.

6. Reference

[1] H. Okamura and M. Ouchi, "Invited paper: Self-Compacting Concrete", *Journal of Advanced Concrete Technology*, Vol.1, No.1, pp. 5-15, 2003.
[2] EFNARC, 2005. The European Guidelines for Self-Compacting Concrete. The European Federation of Specialist Construction Chemicals and Concrete Systems.
[3] M. Ouchi, M. Hibino, K. Ozawa and H. Okamura, "Arational Mix design for mortar in self-compacting concrete", *the Sixth East Asia-Pacific Conference on Structural Engineering & Construction*, Taipei, Taiwan pp.1307-1312, 1998
[4] M. Ouchi, "Evaluation System for Self-Compactability of Fresh Concrete", *Dissertation Submitted to the University of Tokyo for the degree of Doctor of Engineering*, Japan, 1997
[5] M. Ouchi, M. Hibino and H. Okamura,"Effect of Superplasticizer on Self-Compactability of Fresh Concrete", Transportation Research Record: Journal of The Transportation Research Board, Vol. 1574, No.1, Washington, D.C

©2017 J. of TCA All rights reserved