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EFFECT OF POWDER TYPE VISCOSITY MODIFYING AGENT ON FLOWABILITY OF SELF-COMPACTING MORTAR

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ABSTRACT:

This paper presents the results on flowability and viscosity of self-compacting mortar affected by means of powder type viscosity modifying agent (VMA). Higher amount of superplasticizer was necessary for maintaining slump flow by standard cone flow test of mortar in the desire range of 250-270 mm. due to the increase in amount of viscosity modifying agent. Moreover, the viscosity of self-compacting mortar significantly increased with the increase in amount of viscosity modifying agent which could be measured by standard v-funnel test. The measured funnel time gradually increased by increasing amount of viscosity modifying agent. A frictional index ($1-R_{mb}/R_m$) representing internal interaction between model coarse aggregate and mortar was employed in order to evaluate flowability and self-compactability of mortar and concrete. The reduction in value of the frictional index meant that internal friction reduced which resulted in the preferable self-compactability of mortar and concrete. Powder type of viscosity modifying agent could be used to increase level of self-compactability of mortar with moderate water to cement ratio (32-35%). The internal friction of mortar increased approximately 14-18% by adding optimum amount of viscosity modifying agent which depended on water to cement ratio. However, this agent was not effective for mortar with low and high water to cement ratio (30% and 40%). The value of index $1-R_{mb}/R_m$ slightly increased when the viscosity modifying agent was added. The power type viscosity modifying agent could be considered as a flowability improvement material for self-compacting concrete and mortar. However, it had a limitation that water to cement ratio should be in the range of 32-35%.

KEYWORDS: Viscosity modifying agent, Flowability, Superplasticizer, Self-compacting mortar, Internal friction

1. Introduction

Self-compacting concrete (SCC) has been noticed as high-performance concrete which can be filled in formwork by its own weight without any vibration. It was first developed in 1986 by a concrete team from The University of Tokyo, Japan in order to increase durability of concrete structures. At that time, this high-performance concrete needed high amount of cement content to react with superplasticizer for producing repulsing forces between cement particles. Cement amount of SCC was approximately 2 times higher than that of normal concrete. Mix proportion of SCC comparing to normal concrete is shown in Figure. 1[1]. Moreover, aggregate content was limited and recommended by Japan Society of Civil Engineer (JSCE) [2] approximately as 0.3 m^3/m^3 and 0.35 m^3/m^3 for coarse aggregate and fine aggregate respectively. Water to cement ratio (W/C) was also recommended by JSCE (JSCE, 1999) approximately as 30%-37% by weight, which ensured that SCC can be achieved without segregation. Recently, W/C can be increased approximately to 45% by means of new-type superplasticizer which is blended with viscosity modifying agent during production process. However, cement amount could not be reduced much because solid particles was still high. Mechanism of self-compacting concrete during flowing was proposed by Prof. Okamura and Prof. Ozawa in 1993 as shown in Figure 2. Mortar was compressed by coarse aggregate when it passed through rebars or any obstacles, which increase shear resistance of mortar. High shear resistance meant that mortar could not move conveniently, thus level of self-compactability became lower. This mechanism could be explained similarly to the test that mortar was applied normal stress, then measured shear resistance. To reduce cement content in SCC apparently, shear resistance of mortar must be reduced so that fine aggregate content can be increased.

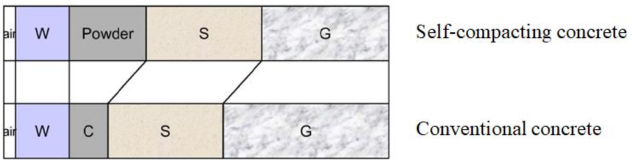


Figure 1 Mix proportion of self-compacting concrete and conventional concrete [1]

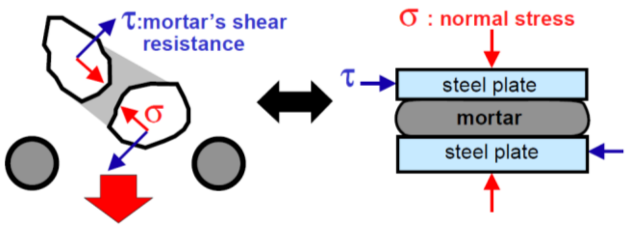


Figure 2 Shear resistance of mortar (τ) in accordance with normal stress (σ) [3]

In recent years, viscosity modifying agent (VMA) has been used in concrete industry to prevent the variation of fluidity of concrete due to the error from measuring process. Workability of concrete could be maintained by adding suitable amount of VMA although water amount was 7% error from the design mix proportion [4]. Moreover, anti-washout property was simultaneously improved which was very crucial for under water concrete. The aim of this is to study the effect of viscosity modifying agent on flowability and internal friction of mortar which is the fundamental properties of self-compacting concrete.

2. Material used and Research methodology

According to the objectives of this research, the parameters and experiment procedures are described as follow.

2.1 Materials used

This study was conducted in Japan, all materials used were produced and supplied in Japan. Ordinary Portland cement was only one cementitious material for mortar. Fine aggregate was crushed limestone with fineness modulus of 2.6. Glass beads with uniform diameter of 10 mm. and unit weight of 2.55 g/cm3 were used as coarse aggregate as shown in Figure 3. This model coarse aggregate could be added to mortar to evaluate self-compactability of concrete [5]. Superplasticizer used was Polycarboxylate ether without retarder and viscosity modifying agent. This type of superplasticizer was effective for self-compacting concrete that could reduce yield stress in cement paste of over 70% [6]. Amount of superplasticizer was recommended in range of 0.5-2% Viscosity modifying agent for this study was powder type called “Welan gum”. Figure 4 shows the chemical structure of Welan gum consists of repeating tetrasaccharide units with single branches of L-rhamnose [4]. Basic properties of materials used are shown in Table 1.

Figure 3 Model coarse aggregate
(Glass beads dia. of 10 mm)

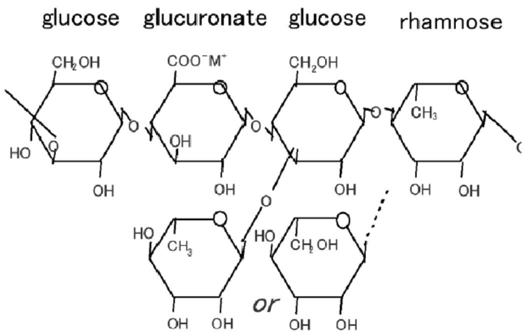


Figure 4 Chemical structure of Welan gum [4]

Table 1 Materials used

Materials used	General properties
Cement	Ordinary portland cement type 1 (3.15 g/cm3)
Fine aggregate	Crushed limestone sand (2.68 g/cm3), FM 2.6
Model coarse aggregate	Glass beads (2.55 g/cm3, diameter 10 mm.)
Superplasticizer	Polycarboxylate ether without retarder
Viscosity modifying agent (VMA)	Welan gum (powder), exopolysaccharide

2.2 Mix design

Mix proportions of mortar were started with the recommendation range from JSCE. Water to cement ratio (W/C) used between 30-40% while sand to mortar ratio (s/m) was constant at 45% by volume. Amount of superplasticizer and VMA were varied because they related to each other. VMA increases viscosity and reduces flowability while superplasticizer increases flowability, thus both admixtures amount must be balanced to achieve the target flowability. All mortar mixes are shown in Table 2.

Table 1 Materials used

s/m (%)	W/C (%)	SP/C (%)	VA/C (%)
45	30	2.1	0.0
		2.3	0.2
		2.4	0.4
45	32	1.6	0.0
		1.7	0.1
		1.8	0.2
		1.9	0.3
		2.0	0.4
		2.2	0.5
		2.3	0.6
		2.4	0.7
		2.5	0.8
		2.6	1.0
45	35	1.3	0.0
		1.3	0.2
		1.4	0.4
		1.5	0.6
		1.7	0.8
		1.7	1.0
45	40	0.8	0.0
		0.9	0.2
		1.0	0.4

2.3 Mixing procedures

All mortar mixes were mixed with the same process by first adding all dry materials (cement, sand and VMA) to mortar mixer. Cement, sand and VMA were mixed for 30 s, then water and superplasticizer were added and mixed for more 2 mins. Figure 5. shows the mixing process for all mortar mixes. At 5 mins, viscosity test and deformability test were performed by standard v-funnel for mortar and standard cone for mortar respectively. These 2 tests were performed again at 20 mins by stirring mortar only 5 s before the tests. Finally, 20% glass beads by volume of mortar was added to mortar mixes and stirred for 20 times as shown in Figure 6. The viscosity test by v-funnel was conducted again for mortar with glass beads.

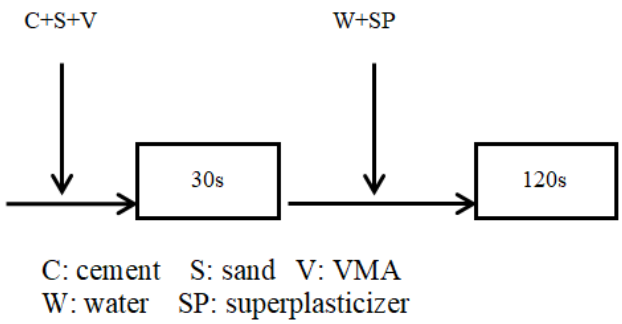


Figure 5 Mixing process

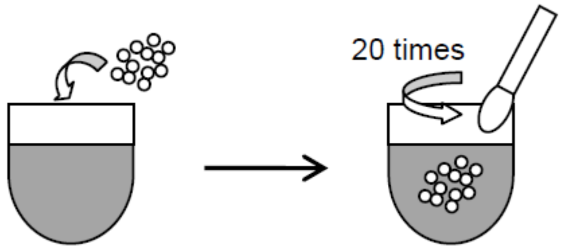


Figure 6 Mixing glass beads with mortar

2.4 Deformability and viscosity test

To measure deformability and viscosity of mortar, the standard cone flow and v-funnel for mortar test were used. Figure 7 and Figure 8 show standard size of cone flow and v-funnel of mortar. The target flow diameter was in range of 250-275 mm which was suitable for mixing with coarse aggregate to make self-compacting concrete. Figure 9 shows relationship between mortar and concrete flow diameter. This flow diameter range could be achieved by adjusting amount of superplasticizer. There was no limitation of funnel time, thus viscosity of mortar changed due to the amount of VMA while deformability of all mortar mixes was in the same range.

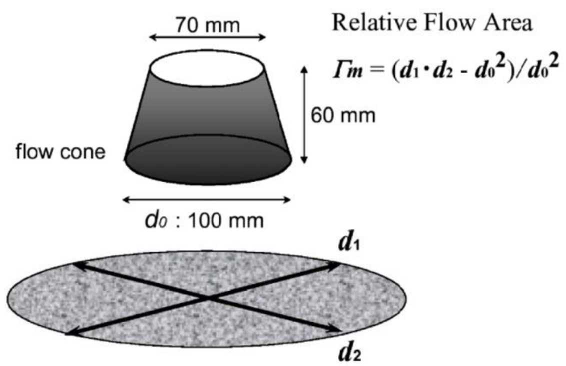


Figure 7 Mortar deformability test [1]

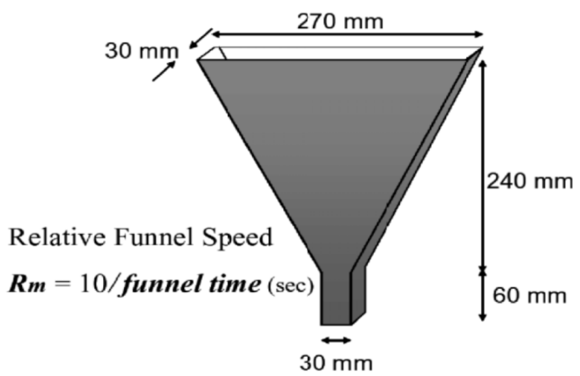


Figure 8 Mortar viscosity test [1]

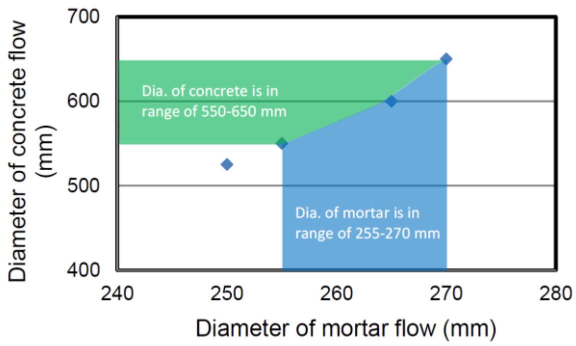


Figure 9 Relationship between mortar flow and concrete flow

Internal friction relating to shear resistance of mortar could be evaluated using v-funnel time obtained form plain mortar and mortar with model coarse aggregate [5]. Viscosity index of mortar was calculated using equation (1) and (2) plain mortar and mortar with model coarse aggregate respectively. These 2 indices were calculated using equation (3) to obtain the friction index of mortar.

$$R_m = \frac{10}{t_m} \tag{1}$$

$$R_{mb} = \frac{10}{t_{mb}} \tag{2}$$

Where t_m and t_{mb} are funnel time of mortar and mortar with model coarse aggregate in unit of sec.

$$1-(R_{mb}/R_m) \tag{3}$$

The friction index of mortar, $(1-(R_{mb}/R_m))$ could be used to evaluate self-compactability of concrete as shown Figure 10. Filling height of self-compacting concrete should be over 250 mm which was linked to the friction index of mortar of approximately 0.37. This index can be effectively evaluated level of self-compactability of concrete, thus this method will save not only time but also budget of the experiments. Therefore, this study is focusing on mortar experiments.

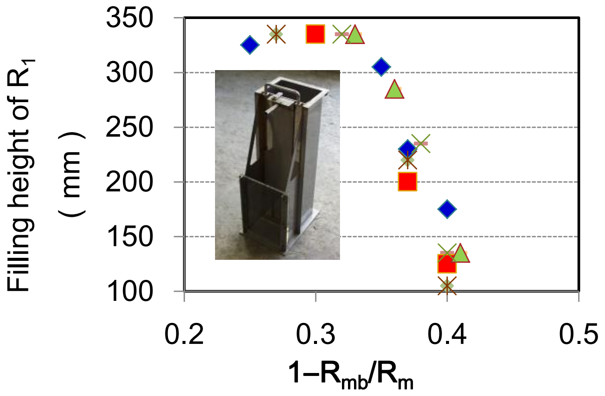


Figure 10 Relationship between friction index of mortar and self-compactability of SCC [5]

3. Experimental results and Discussions

3.1 Sufficient amount of superplasticizer for VMA mortar

It is general result that flow diameter reduces when adding VMA to mortar. The reduction of flow diameter resulted in higher amount of superplasticizer needed for achieving target flow of mortar. Figure 11 shows the increase in superplasticizer dosage needed for achieving the target flow diameter (250-275 mm) of mortar with higher amount of VMA and lower W/C. Mortar mixes without VMA needed SP/C amount of 0.8%, 1.3%, 1.6% and 2.1% in case of W/C 40%, 35%, 32% and 30% respectively. Lower amount of SP was added to mortar with higher W/C ratio because free water amount was high which enhanced flowability of mortar. It can be seen that amount of superplasticizer gradually increased according to the increase in VMA in all cases of W/C.

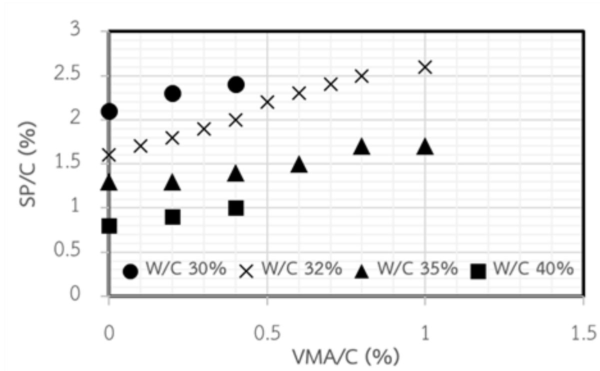


Figure 11 Amount of superplasticizer for achieving the desirable flow diameter

3.2 Initial funnel time affected by VMA

Funnel time was an index representing viscosity of mortar and concrete which was generally in range of 3-30 s. Figure 12 shows the funnel time of mortar exhibiting flow diameter in range of 250-275 mm. Mortar without VMA spent approximately 4-9 s. Viscosity of mortar slightly changed due to the increase in VMA dosage in case of mortar with W/C 40%, whereas it significantly increased especially in case of low W/C (30-32%). This means that free water amount played an important role on viscosity of mortar although VMA was added. Overall tendency was similar to that of SP/C-VMA relationship that the funnel time increased due to the increase in VMA dosage, except mortar with W/C of 40%.

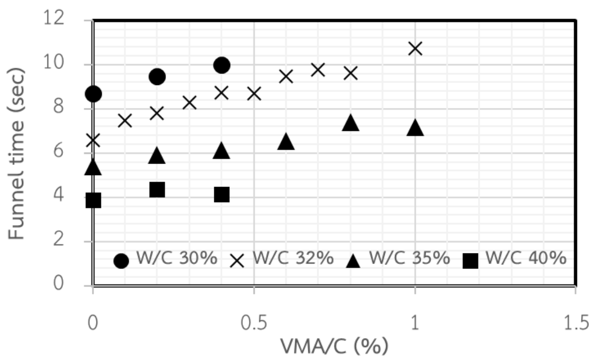
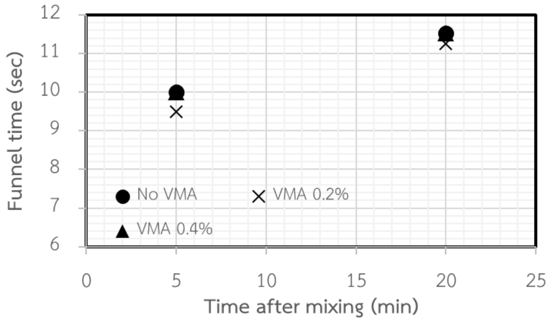


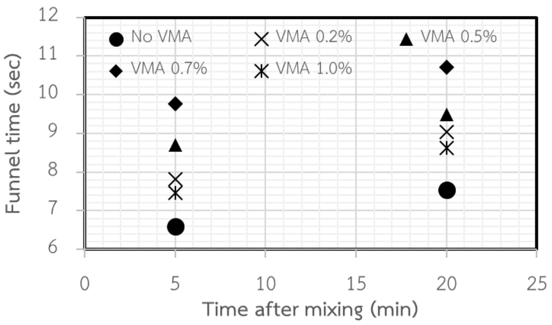
Figure 12 Initial funnel time with various amount of VMA

3.3 Increase of viscosity after mixing

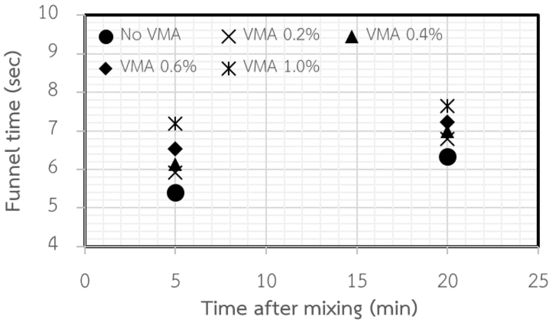
Figure 13. shows the increase of viscosity of mortar from 5 mins to 20 mins after mixing. In case of mortar with W/C of 30%, funnel times were very close inspite of different VMA/C. Funnel time increased approximately from 8.5-11.5 s from initial state to 20 mins. The different funnel time due to VMA amount was observed in mortar with moderate W/C (32-35%). It can be seen that funnel time mortar with higher VMA amount was higher than that mortar with lower VMA amount because free water inside the mortar was partially used to react with VMA, resulted in longer funnel time. However, in case of mortar with W/C of 32% and VMA of 1.0%, funnel time was not the highest among other mixes. There might be some mistakes occurred during mixing or the test. Viscosity of mortar with the highest W/C (40%) with respect to time after mixing is shown in Figure 13 d). Funnel time varied in small range of 4-5 s because of high free water volume inside mortar. This was also the reason that funnel time at 20 mins was close that at 5 mins.



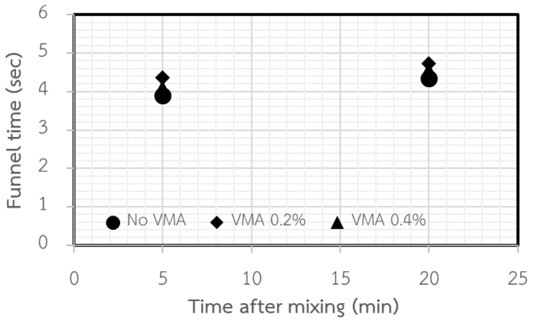
a) W/C 30%



b) W/C 32%



c) W/C 35%



d) W/C 40%

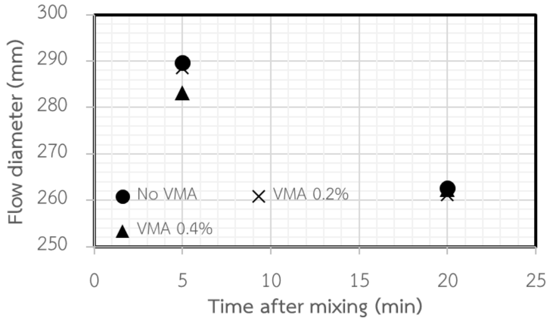
Figure 13 Funnel time increased after mixing

3.4 Reduction of deformability after mixing

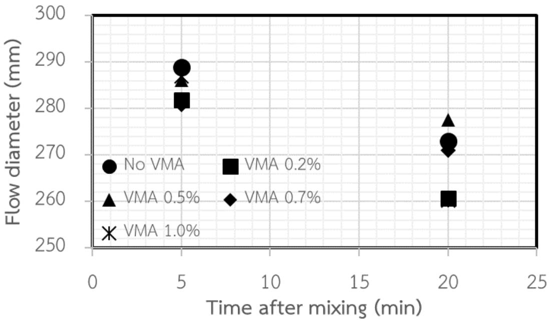
Figure 14 shows the deformability of mortars represented by flow diameter regarding time passed after mixing. Rate of reduction in flow diameter depended on amount of water to cement ratio and viscosity modifying agent. Flow diameter of all mortar mixes was targeted at 250-257 mm. at 20 mins, thus the initial flow diameters were varied according to mix proportions. The initial flow diameter was highest approximately 290 mm. in mortar without VMA because of high reduction rate, except mortar with W/C of 40%. It was observed that the reduction rate became lower when VMA increased in all case of W/C. This result confirmed that viscosity modifying agent could be used to maintain flowability of mortar and concrete at least in the first 20 mins. Flow diameter of mortar with W/C of 40% slightly changed in range of 255-265 mm. from the initial state to 20 mins because free water inside these mortar mixes was sufficient to lubricate solid particles inside.

3.5 Relationship between flow diameter and funnel time

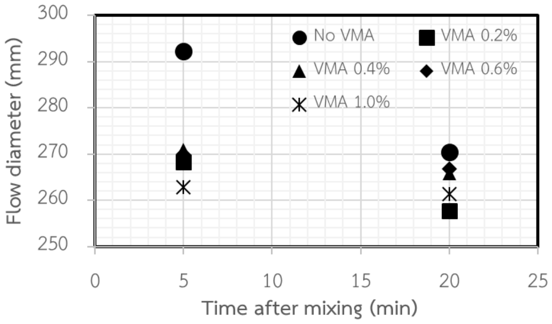
Generally, viscosity and deformability are related to each other. Mortar with high deformability will possess low viscosity. This assumption was clearly explained using relationship between funnel time and flow diameter of mortar at initial state in Figure 15 a). This Figure shows relationship between funnel time and flow diameter of mortar at initial state and 20 mins. The initial flow diameters of mortar containing W/C 32% and 35% significantly differed from that of mortar containing W/C 35% and 40% because of high reduction rate of deformability as mentioned previously as shown in Figure 15 a). At initial state, funnel time tended to reduce according to the increase in flow diameter. However, this relationship of mortar at 20 mins could not be clearly observed as shown in Figure 15 b). Viscosity of mortar containing W/C of 35% and 40% seemed stable although flow diameter varied from 255-270 mm. While the data was distributed in mortar with low W/C (30-32%).



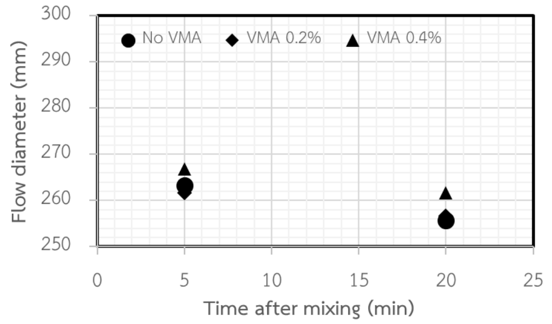
a)



b)

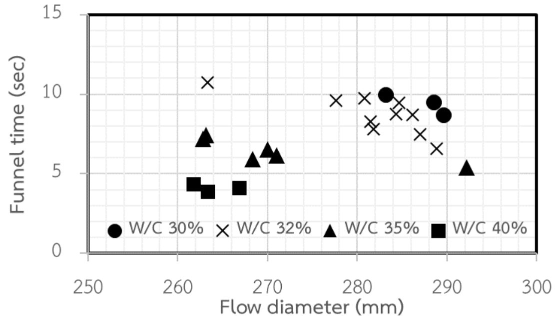


c)

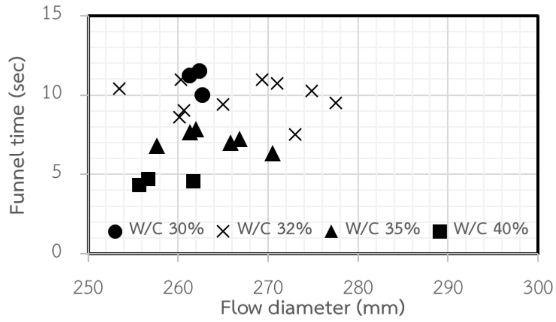


d)

Figure 14 Reduction in flow diameter after mixing



a) 5 mins after mixing



b) 20 mins after mixing

Figure 15 Reduction in flow diameter due to time passed after mixing

There were many factors involved in this relationship such as amount of superplasticizer, VMA and free water inside mortar. The relationship between flow diameter and funnel time could be maintained once the free water was sufficient after reacting with VMA which was clearly seen in Figure 15 b). This free water was used and became insufficient after being used for VMA in mortar with low W/C (30-32%), resulted in unclearly relation between flow diameter and funnel. Therefore, flowability of mortar and concrete using VMA could be not be directly predicted by this relationship. It must be considered case by case for each mix proportions.

3.6 Internal friction affected by viscosity agent

Figure 16 shows the internal friction of mortar for all W/C regarding amount of viscosity modifying agent. Mortar mixes containing W/C of 30% and 40% were terminated at VMA/C 0.4% since the 1-Rmb/Rm was not improved by increasing VMA, comparing to mix proportions without VMA. In these 2 cases the 1-Rmb/Rm slightly increased due to the addition of viscosity modifying agent. On the other hand, the 1-Rmb/Rm reduced due to the addition of viscosity modifying agent in mortar mixes containing moderate W/C (32% and 35%). However, there was no significant reduction on 1-Rmb/Rm observed in mortar with high amount of viscosity modifying agent (1.0%), comparing to mortar without viscosity modifying agent. The increase in amount of viscosity modifying agent reduced the friction index to the optimum point, which were 0.313 and 0.296 of mortar with W/C of 32% and 35% respectively. After the optimum point, it can be seen that the tendency of 1-Rmb/Rm increased according to the increase in the amount of viscosity modifying agent. The optimum amounts of VMA were 0.4% and 0.2% of cement weight for mortar with W/C of 32% and 35% respectively. According to the results, the interaction between coarse aggregate and mortar or friction index (1-Rmb/Rm) could be reduced by adding optimum amount of viscosity modifying agent. However, it is effective only for the mix proportions, which contain moderate W/C (32%-35%), it was not effective for the mix proportions, which contain high and low W/C (30% and 40%).

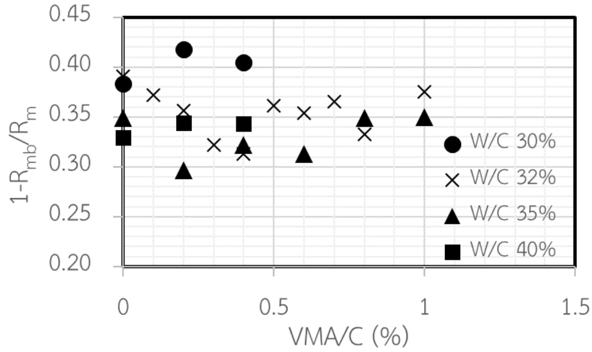


Figure 16 Variation of friction index by adding viscosty agent

4. Conclusion

According to the experimental results, conclusions can be written as follow;

1. To increase viscosity of mortar by adding viscosity modifying agent, amount of superplasticizer was also increased to achieve the target flowability which may cause higher unit cost of concrete.

2. Flowability and viscosity of mortar with W/C of 40% were not significantly changed after mixing since free water was sufficient for maintaining these properties

3. Deformability of mortar could be maintained during the first 20 mins by adding viscosity modifying agent.

4. Funnel time and deformability were related at initial state. The relation was not predicted at 20 mins after mixing due to the change of free water absorbed by viscosity modifying agent.

5. The internal friction of mortar represented by $1\text{-}R_{mb}/R_m$ could be reduced by adding the optimum dosage of viscosity modifying agent which depended on water to cement ratio.

5. Reference

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