FACTORS FOR MITIGATION OF INTERACTION BETWEEN COARSE AGGREGATE AND MORTAR IN SELF-COMPACTING CONCRETE

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***ABSTRACT*:** Self-compacting concrete (SCC) has been developed over the past 25 years in order to improve the durability of concrete structures. The cement content in mix proportion of SCC must be approximately 2 times higher than that of conventional concrete, hence SCC cost is higher than that of conventional concrete. Air-entraining agent (AE), new-type superplasticizer, viscosity agent were added to the mix in order to reduce the interaction between coarse aggregate and mortar ($1-R_{mb}/R_m$) and to increase the sand to mortar ratio (s/m). This resulted in a reduction in cement content of the mix proportion. The interaction between coarse aggregate and mortar depend on various factors such as sand content (s/m), water to cement ratio (W/C), type of superplasticizer, amount of viscosity agent and type of air entraining agent. The interaction between coarse aggregate and mortar was reduced by adding viscosity agent in mix, however it is effective for mix proportion, which contain moderate W/C (32%-35%). Furthermore, the interaction between coarse aggregate and mortar can be reduced by using of new-type superplasticizer and new-type air entraining agent. These results demonstrated that sand content can be increased, which resulted in the decrease automatically in cement content by adding optimum amount of viscosity agent, using new-type superplasticizer and using new-type air entraining agent.

KEYWORDS: self-compacting concrete, viscosity agent, entrained air

1. INTRODUCTION

Self-compacting concrete has been widely used around the world because it can be compacted by its own weight without any vibration and high compressive strength due to low W/C. To achieve self-compacting concrete, it need higher cement content than that of conventional concrete and the aggregate must be limited, as shown in Fig. 1 (Okamura and Ozawa, 1995). Sand to mortar ratio (s/m) and water to cement ratio (W/C) are recommended by JSCE (JSCE, 1999) approximately as 0.3 m^3/m^3 by unit absolute volume of coarse aggregate and 30%-37% by weight respectively, which is ensured that SCC can be achieved without segregation. Recently, W/C can be increased approximately to 45% by using of new-type superplasticizer. However, the cement content is still high according to the limitation of the aggregate content in mix proportion. At constant coarse aggregate content, sand to mortar ratio (s/m) is an influence factor on viscosity and fluidity of fresh concrete that affect directly the interaction between coarse aggregate and mortar. Therefore the reduction in ($1-R_{mb}/R_m$) with respect to s/m was investigated. Furthermore, viscosity agent, new-type superplasticizer and air entraining agent were added to mix proportion in order to reduce ($1-R_{mb}/R_m$).

The interaction between coarse aggregate and mortar ($1-R_{mb}/R_m$) is an index which indicates the shear resistance of mortar when normal stress is approached by coarse aggregate, as shown in Fig.2. R_m and R_{mb} indicate the viscosity of mortar and mortar with model coarse aggregate respectively that obtained from the mortar funnel test, as shown in Fig.3. R_m and R_{mb} are defined as equation (1) and (2) respectively.

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

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

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

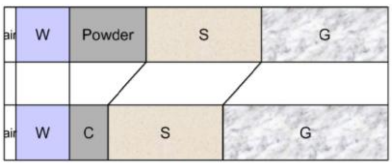

Figure1. Mix proportion between self-compacting concrete and conventional concrete (Okamura and Ozawa, 1995)

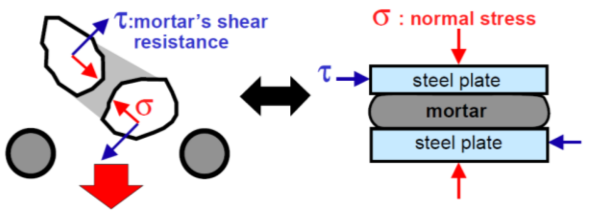

Figure 2. Shear resistance of mortar (τ) in accordance with normal stress (σ) (Okamura et al., 1993)

Superplasticizer has been known as high range water reducers, which is used as dispersants to prevent the aggregation of cement particles in mortar. New-type superplasticizer has been developed in order to reduce the shear resistance between coarse aggregate and mortar and maintain the prevention of aggregation of cement particles simultaneously. Recently, new-type superplasticizer is suitable for the mix proportions, which use W/C higher than 35% Entrained air is added to concrete mix in order to improve the freezing and thawing resistance. Furthermore, slump of fresh concrete can be increased approximately 10mm-50mm by increasing entrained air 5% in fresh concrete (Bratos, 1992).

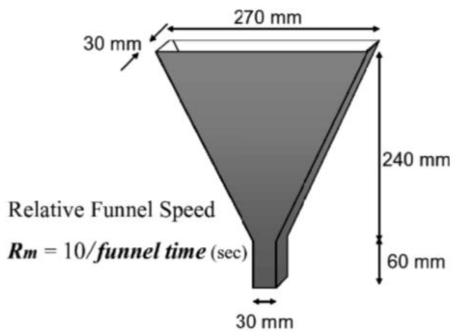

Figure 3. Mortar funnel test (Okamura and Ozawa, 1995)

Viscosity agent is added to concrete mix in order to prevent the variation of fluidity of concrete (Sakata et al., 2003). There are no research, which is considered the effect of viscosity agent and entrained air on the friction between coarse aggregate and mortar have been found.

The purpose of this study is to investigate the effects of W/C, s/m, type of superplasticizer, amount of viscosity agent and type of air entraining agent on the interaction between coarse aggregate and mortar ($1-R_{mb}/R_m$). This experiment was conducted based on mortar with model coarse aggregate, therefore results should be verified with concrete experiment to confirm the practical usage.

2. METHODOLOGY

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

2.1 Materials

Experiment is separated into 5 series, which are different in parameters that affect the interaction between coarse aggregate and mortar. Table 1 shows the materials used in each series, which are produced in Japan.

Table 1 Materials used in this study

	Series 1	Series 2	Series 3	Series 4	Series 5			
Cement	Ordinary portland cement (3.15 g/cm^3)							
Fine aggregate	Crushed limestone sand (2.68 g/cm^3, F.M. 2.6)							
Coarse aggregate	Glass beads (2.55 g/cm3, uniform diameter of 10 mm.)							
Superplasticizer	BASF 8SB		BASF 8SB / BASF 6550	BASF 8SB				
Air-entraining agent	-	-	202	-	101	202	775	785
Viscosity agent	-	-	-	Welan gum	-			

Series 1 and series 2 were conducted in order to study the effect of W/C and s/m on $(1-R_{mb}/R_m)$ respectively. Effect of the difference in type of superplasticizer was conducted in series 3. There are 2 types of superplasticizer used in this study, conventional type of superplasticizer (8SB) was developed more than 10 years and new-type superplasticizer (6550) was developed in order to increase W/C in mix by adding viscosity agent during production process. Effect of viscosity agent "Welan gum" by means of conventional type of superplasticizer (8SB) was studied in series 4, chemical structure of Welan gum is shown in Fig.4. Various type of air entraining agents were added to mix proportions in series 5 in order to study the effect of air entraining agent's chemical materials on $(1-R_{mb}/R_m)$, chemical compound of each air entraining agent are shown in Table 2.

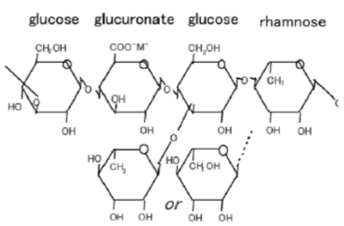

Fig.4. Chemical structure of Welan gum (Sakata et al., 2003)

Table 2 Chemical compound of air entraining agent

Air entraining agent	Chemical compound
101	Alkyl ether-based anionic surfactants
202	Modified rosin acid compound-based anionic surfactants
775	High-alkyl carboxilic acid-based anionic surfactants
785	High-alkyl carboxilic acid-based anionic surfactants and non-ionic surfactant

2.3 Mixing process

The experiments were conducted in the controlled room that temperature and relative humidity were constant as 20°c and 95% respectively. Every mix proportions were mixed by the same process, which is very strict about the time in each step. First, cement, sand and viscosity agent (in case, which study the effect of viscosity agent) were mixed together for 30s, and then liquid materials (water, superplasticizer and air-entraining agent) were added and mixed for 120s. Mortar flow was checked at 5mins, subsequently funnel test and measuring air content by air meter (pressure method) were performed. Mortar flow test was performed again at 20mins. Mortar must satisfy the proper mortar, which flow cone is in range 255-275mm, otherwise mix proportion will be adjusted and mix from the first step until it satisfies cone flow range. Once the proper mortar was achieved, the funnel test of mortar and mortar with model coarse aggregate were performed respectively. Finally, mortar mix was repeated 2 more times for confirming the stability of data. Mixing process is shown in Fig. 4.

2.4 Deformability test

The deformability of self-compacting mortar is defined as the relative flow area (Γ_m), which is obtained from mortar flow test, as shown in

Fig. 5. The proper deformability is represented by Γ_m, which is approximately 5.5-6.5, it means that the average flow diameter must be in range 255-275 mm. Every mix proportions satisfied proper deformability. The proper deformability is a significant factor which can make sure that mix proportions were self-compacting mortar and can be mixed with coarse aggregate to achieve self-compacting concrete without segregation.

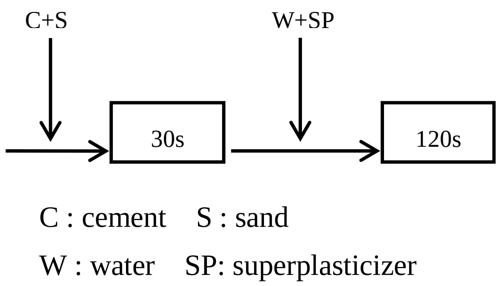

Figure 4. Mixing process

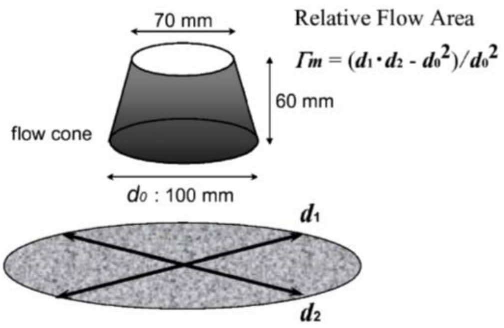

Fig. 5 Mortar flow test [2]

3. RESULTS AND DISCUSSION

3.1 Effect of s/m on 1-R_{mb}/R_m

To study the effect of s/m on 1-R_{mb}/R_m, s/m was varied as 45%, 50% and 55% and W/C was fixed as 37%, which is recommended by JSCE (JSCE, 1999). It can be seen apparently that the 1-R_{mb}/R_m increased according to the increase in s/m, approximately 0.1 per 5% s/m increased. An increase in solid particles in mortar caused clearly the increase in 1-R_{mb}/R_m. In case of s/m of 45% with W/C 37%, this mix proportion was recommended by JSCE (JSCE, 1999) that SCC can be achieved by mixing this mortar mix with coarse aggregate following JSCE recommendation for self-compacting concrete. Thus the 1-R_{mb}/R_m of this mortar mix was considered as a control value in this study. To achieve SCC, 1-R_{mb}/R_m should be lower than 0.4. This is a reason that s/m cannot be increased more than 45% for conventional SCC. Result of series 1 is shown in Fig. 6.

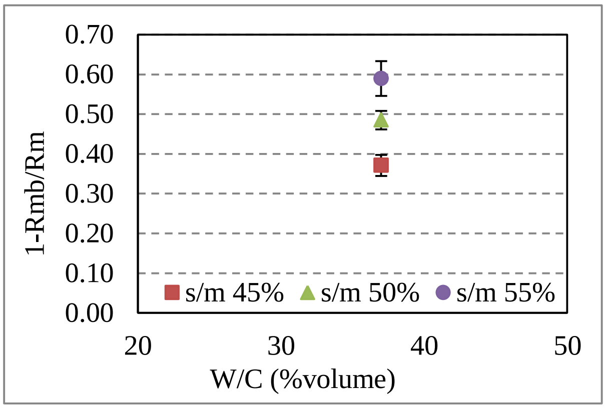

Figure 6. Effect of s/m on 1-R_{mb}/R_m

3.2 Effect of W/C on 1-R_{mb}/R_m

Fig. 7 shows effect of W/C on 1-R_{mb}/R_m, it can be seen that 1-R_{mb}/R_m decreased gradually due to the increase in W/C because water behave like the lubricant of sand particles in mortar. However, segregation was observed when W/C was limited as 45%. In mix, which is s/m of 50% with W/C of 45%, the 1-R_{mb}/R_m is approximately 0.426. It means that W/C 45% is not enough to achieve SCC, which contains s/m 50%. However, flowability of SCC can be improved by increasing W/C, but W/C must not be over 45%, which can be ensured that SCC can be achieved without segregation.

3.3 Effect of new-type superplasticizer on 1-R_{mb}/R_m

In series 3, 1-R_{mb}/R_m, which was affected by conventional type and new-type superplasticizer was compared. This series was separated into 2 set, which s/m was fixed as 55% and W/C were 40% and

45% in order to study the influence of superplasticizer on the difference in free water inside mortar matrix. Results of set of W/C 40% and 45% are shown in Fig. 8 and Fig. 9 respectively. 1-R_{mb}/R_m decreased according to the increase in air content because when air content increased, total volume of mortar also increased, therefore sand to mortar ratio (s/m) was reduced due to the increase in air content. This reason is the same as series 1. Results cannot be directly compared because air content was not equal, therefore tendency of results has been drawn. There is no significant difference in 1-R_{mb}/R_m between mix proportions, which used of 2 types of superplasticizer in set of W/C 40%. Mix proportions, which used new-type superplasticizer caused lower 1-R_{mb}/R_m than that used conventional type in case of W/C 45%, which high air content. According to the compound of new-type superplasticizer, viscosity agent in superplasticizer enhanced the reduction in 1-R_{mb}/R_m, especially in set of high W/C and high air content (low s/m). It can be explained that the ball bearing effect by entrained air is effective when mortar contain appropriate viscosity condition. Free water increase due to the increase in W/C. Viscosity agent in superplasticizer retained free water, which resulted in the appropriate viscosity condition of mortar. Therefore in 1-R_{mb}/R_m decreased effectively by increasing air content and using new-type superplasticizer simultaneously, according to the high effectiveness of ball bearing effect by entrained air.

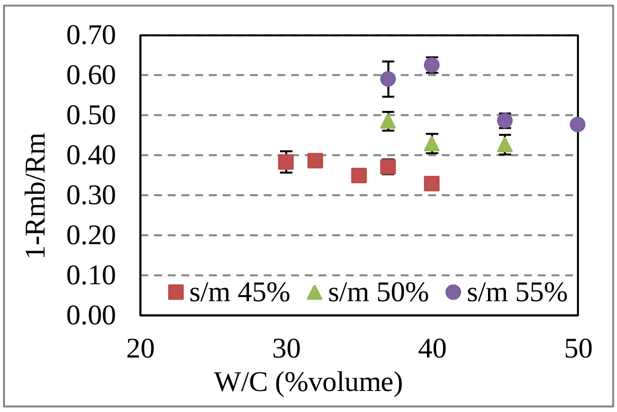

Figure 7. Effect of W/C on 1-R_{mb}/R_m

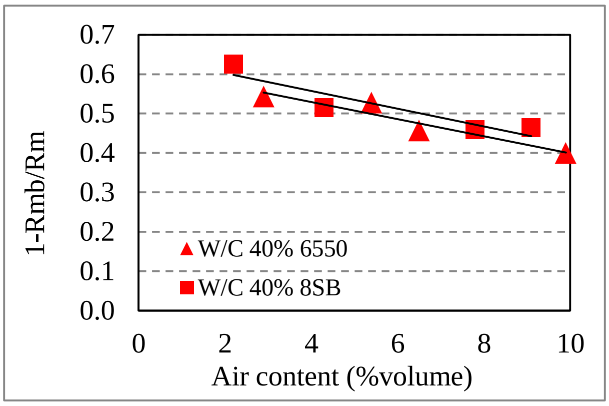

Figure 8. Effect of different type of superplasticizer on 1-R_{mb}/R_m, which W/C 40%

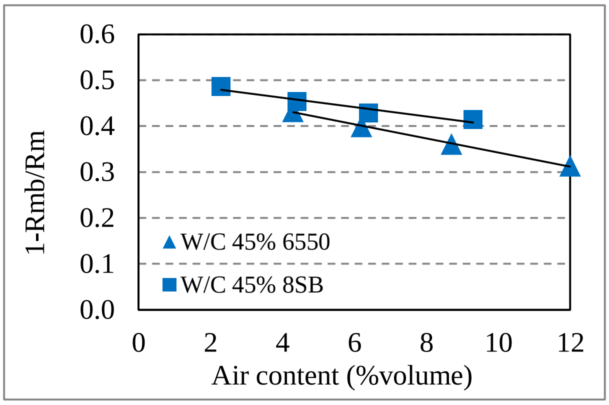

Figure 9. Effect of different type of superplasticizer on 1-R_{mb}/R_m, which W/C 45%

3.4 Effect of viscosity agent on 1-R_{mb}/R_m

In series 4, s/m was kept constant as 45%. Result of series 4 is shown in Fig, 10. Mix proportions, which contain W/C 30% and 40% were finished at VA/C = 0.004% because the 1-R_{mb}/R_m was not improved by increasing viscosity agent, compared to mix proportions without viscosity agent. In mix proportions, which contain W/C 30% and 40%, the $1\text{-}R_{mb}/R_m$ slightly increased due to the addition of viscosity agent. On the other hand, the $1\text{-}R_{mb}/R_m$ decreased due to the addition of viscosity agent in mix proportions, which contain W/C 32% and 35%. However, there is no significant reduction on $1\text{-}R_{mb}/R_m$ in mix proportions, which was added high amount of viscosity agent (0.01% of cement), comparing to mix proportion without viscosity agent. The increase in amount of viscosity agent reduced the $1\text{-}R_{mb}/R_m$ to the optimum point, which were 0.313 and 0.296 of mix proportions, which contained W/C 32% and 35% respectively. After the optimum point, it can be seen that the tendency of $1\text{-}R_{mb}/R_m$ increased according to the increase in the amount of viscosity agent. The optimum amounts of viscosity agent were 0.004% and 0.002% of cement content for mix proportions, which contained W/C 32% and 35% respectively. According to the results, the interaction between coarse aggregate and mortar ($1\text{-}R_{mb}/R_m$) can be reduced by adding optimum amount of viscosity agent in mix proportion. However, it is effective only for mix proportions, which contain moderate W/C (32%-35%), it is not effective for mix proportions, which contain high and low W/C (30% and 40%).

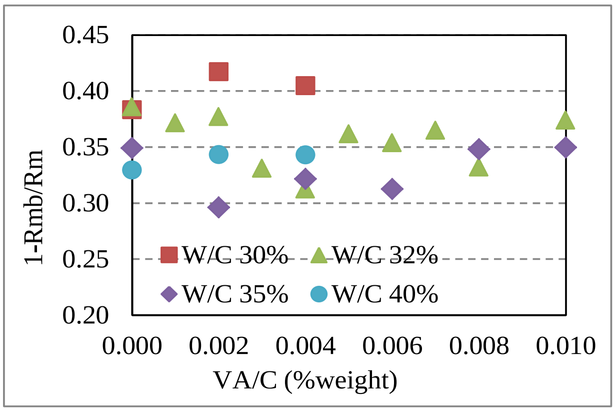

Figure 10. Effect of viscosity agent on $1\text{-}R_{mb}/R_m$

3.5 Effect of type of air entraining agent on $1\text{-}R_{mb}/R_m$

4 types of air entraining agent were used in series 5, the results are illustrated in Figure 11. Sand to mortar ratio (s/m) shown in Figure 11. is s/m, which is calculated by including the extension volume by air content. Mix proportions, which added air entraining agent type 101 and 202, air content is approximately 12% and mix proportions, which added air entraining agent type 775 and 785, air content is approximately 9%. In case of s/m is approximately 45%, it can be seen that there was no significant diference in $1\text{-}R_{mb}/R_m$. On the other hand, the difference in $1\text{-}R_{mb}/R_m$ can be observed in case of s/m is approximately 49%. It can be expained that the ball bearing effect by entrained air is effective in case of high s/m (short distance between mode coarse aggregate). On the other hand, flowability of mortar with model coarse aggregate depend mainly on properties of mortar in case of low s/m (long distance between model coarse aggregate), as shown in Figure 12.

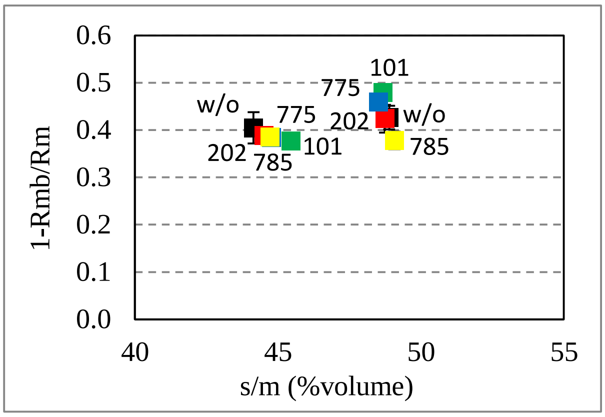

Figure 11. Effect of different type of air entraining agent on $1\text{-}R_{mb}/R_m$

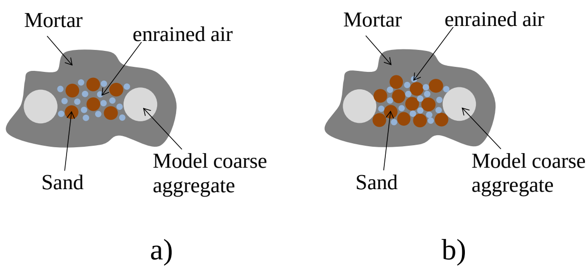

Figure 12. Effect of entrained on distance between sand particles a) long distance (low s/m), b) short distance (high s/m)

Therefore, no significant results were observed because properties of mortar is almost the same as each other. In case of s/m is approximately 49%, air entraining agent showed both positive and negative results on $1\text{-}R_{mb}/R_m$, compared to mix proportion without air entraining agent. Air entraining agent type 101 and 775 showed negative effect on $1\text{-}R_{mb}/R_m$, on the other hand the positive effect on $1\text{-}R_{mb}/R_m$ was found, which is deceased effectively by means of 785. However, effect of 202 on $1\text{-}R_{mb}/R_m$ was not clear. Furthermore, it can be observed that $1\text{-}R_{mb}/R_m$ was maintained approximately 0.39, although s/m increased from 45% to 49%. Air entraining agent type 785 will be applied to concrete experiment in order to confirm practical use.

4. CONCLUSIONS

Factors affected $1\text{-}R_{mb}/R_m$ based on mortar experiment were performed. Conclusions can be written as follow.

1) $1\text{-}R_{mb}/R_m$ depend on s/m and W/C, which is decreased according to the increase in W/C and decrease in s/m. However, segregation occurred when W/C is 50%. W/C can be increased up to 45%.

2) New-type superplasticizer is more effective than conventional type, especially in case of high air content. Flowability of SCC, which need high amount of air content can be improved effectively by using new-type superplasticizer.

3) Viscosity agent can be used to improve the flowability of SCC, however it is effective only in mix proportions, which contain moderate W/C (32%-35%).

4) To study effect of ball bearing effect by entrained air in mortar matrix, s/m should be set approximately to be 50%.

5) By using air entraining agent type 785, s/m in mix can be increased up to approximately 49%. This results in the reduction in cement content and unit cost of SCC.

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