REDUCTION IN INTERACTION BETWEEN COARSE AGGREGATE AND MORTAR IN SELF-COMPACTING CONCRETE AT FRESH STAGE BY SUPERPLASTICIZER WITH VISCOSITY AGENT

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***ABSTRACT*:** The purpose of this study is to clarify an effect of a new type of superplasticizer with viscosity agent on reduction in interaction between coarse aggregate and mortar in self-compacting concrete at fresh stage. The interaction was defined as an increase in shear deform resistance of the fresh mortar due to normal stress generated by the approaching coarse aggregate particles when self-compacting concrete at fresh stage deforms。The interaction was quantified by degree of reduction in the funnel speed of the fresh mortar due to model coarse aggregate mixed in the mortar in this study. The degree of the reduction in the funnel speed of mortar employing the new type of superplasticizer was smaller and the effect on the reduction of the new type of superplastcizer was verified. Also, a correlation between the increment of water to cement ratio and the decrement of the interaction between fresh mortar and coarse aggregate particles by employing the new type of superplasticizer was found.

KEYWORDS: self-compacting concrete, viscosity agent, friction between solid particles

1. INTRODUCTION

Self-Compacting Concrete (SCC) has not become so common as expected when it was developed. One of the reasons for it should be higher material cost due to high unit cement content of the concrete (**Fig. 1**).

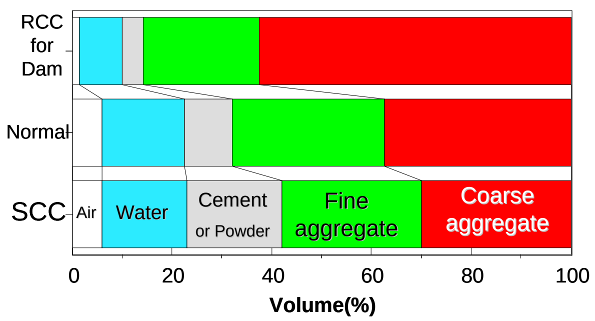


Fig. 1 Comparison of mix-proportioning of SCC with conventional concrete by volume

Recently, a new type of superplasticizer with viscosity agent was developed, by which the unit cement (powder) content can be reduced resulting in lower cost [**1**]. The authors have assumed the mechanism for achieving lower cement content, which is equal to high aggregate content in self-compacting concrete, as a reduction in interaction between the coarse aggregate particles and the mortar.

The authors defined the interaction between the coarse aggregate particles and the mortar in self-compacting concrete as an increase in shear deform resistance of the fresh mortar due to normal stress generated by the approaching coarse aggregate particles when self-compacting concrete at fresh stage deforms (**Fig. 2**) [**2**]. That is a common phenomenon as the relationship between σ and τ in soil mechanics. If the interaction is large, the increase in shear deform resistance of the fresh mortar is also large resulting in poor self-compactability of fresh concrete. That can be apparent in the mortar with higher fine aggregate content. That is why the fine aggregate content is recommended to be limited in the rational mix-design method for self-compacting concrete established by Okamura and Ozawa [**3**].

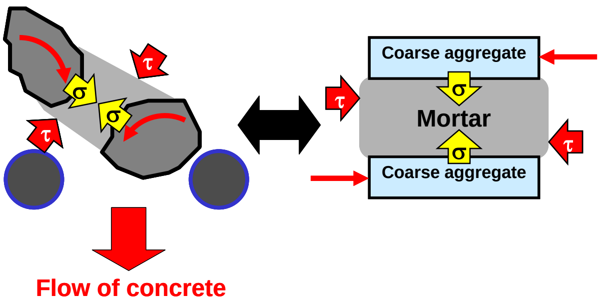


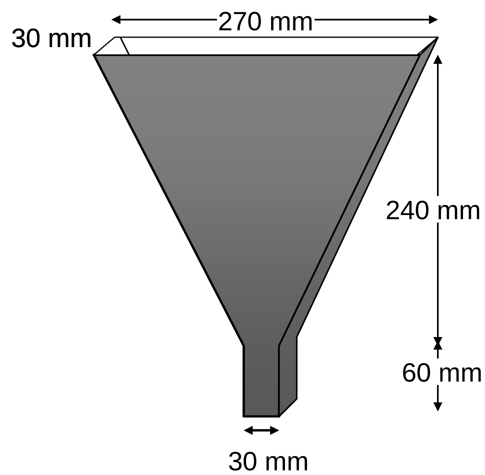
Fig. 2 Shear deform resistance τ of fresh mortar in accordance with normal stress σ

On the other hand, if the degree of the increase in the shear deform resistance of the mortar due to the approaching coarse aggregate particles is smaller when self-compacting concrete deforms, the fine aggregate content in the mortar could be increased, which can lead to higher fine aggregate content in the mortar for achieving self-compactability of fresh concrete. That is why the authors assumed the new type of superplasticizer with viscosity agent mentioned above as a desirable admixture for cheaper self-compacting concrete. It is necessary to verify the effect.

2. METHOD FOR QUANTIFYING INTERACTION BETWEEN COARSE AGGREGATE PARTICLES AND MORTAR IN SCC

It is necessary to quantify degree of the interaction between the coarse aggregate particles and mortar in self-compacting concrete at fresh stage so that the effect of the new type of superplasticizer with viscosity agent can be verified. It can be achieved only if the flowability between fresh concrete and mortar is compared because that is due to the interaction between coarse aggregate particles and mortar.

Ouchi and Edamatsu have invented a simple method for quantifying the interaction suggested by experimental results of Ozawa and Nagamoto by using funnel test of mortar (**Fig. 3**) [**4**]. Ozawa and Nagamoto showed that ratio of the funnel speed of mortar R_m to that of the concrete R_c was lower in case of higher fine aggregate content in the mortar (**Fig. 4**) [**5**]. That means larger interaction between solid particles resulted in larger reduction in flowability of mortar due to the existence of coarse aggregate in the mortar. That is how Ouchi and Edamatsu have invented the simple method for quantifying the interaction.

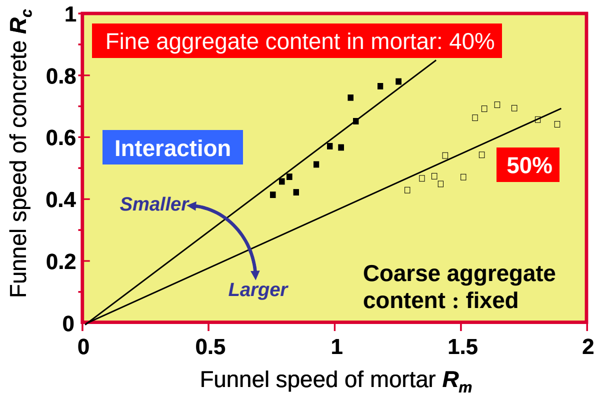


Relative funnel speed

$$Rm = 10/t$$

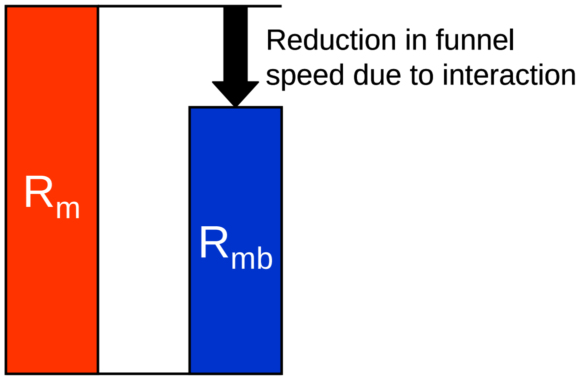
Fig. 3 Funnel for testing interaction

Fig. 4 Larger reduction in flowability due to



larger interaction by higher fine aggregate content in mortar [Ozawa & Nagamoto]

Fig. 5 Reduction in funnel speed due to



interaction between mortar and glass beads as model coarse aggregate

Concrete for the funnel test was obtained by mixing glass beads as model coarse aggregate and mortar. The volumetric ratio of the coarse aggregate was 20% of the concrete according to Ouchi et. al's experimental result suitable for quantifying the degree of interaction in self-compacting concrete. The specific gravity of the glass beads was 2.55 g/cm^3, which was almost the same as common coarse aggregate. The diameter of the glass beads was uniformly 10 mm.

The funnel speed of fresh mortar $\boldsymbol{R_m}$ was defned as 10/$\boldsymbol{t}$, in which $\boldsymbol{t}$ was the duration of mortar's discharging through the funnel (**Fig. 3**). The funnel speed of fresh concrete (mortar and glass beads as model coarse aggregate) was defined as $\boldsymbol{R_{mb}}$. The funnel for $\boldsymbol{R_m}$ and $\boldsymbol{R_{mb}}$ was common.

If the interaction was zero, the value of $\boldsymbol{R_{mb}}$ was equal to that of $\boldsymbol{R_m}$. The degree of the interaction between fresh mortar and coarse aggregate particles was defined as (1-$\boldsymbol{R_{mb}}$/$\boldsymbol{R_m}$). Larger interaction resulted in larger (1-$\boldsymbol{R_{mb}}$/$\boldsymbol{R_m}$) (**Fig. 5**).

3. EFFECT OF NEW TYPE OF SUPERPLASTICIZER WITH VISCOSITY AGENT ON REDUCING ITERACTION BETWEEN MORTAR AND COARSE AGGREGATE PARTICLES

The degree of the interaction in fresh SCC mortar and coarse aggregate (1-$\boldsymbol{R_{mb}}$/$\boldsymbol{R_m}$) was obtained for four types of mix-proportioning (**Table 1**). The fine aggregate content in the mortar by volume (s/m) was 45%, recommended value for SCC or 50%, a little bit higher than recommended. The materials in use are shown in **Table 2**. The mixing and testing procedures are shown in **Fig. 6**. and **Fig. 7.** The temperature was kept constant at 20 degree centigrade.

Table 1 Mix-proportioning of mortar

SP	s/m	W/C	Sp/C (%)
SP1	0.45	0.35	1.20
SP2		0.33	1.20
SP1	0.45	0.40	0.70
SP2		0.40	0.65
SP1	0.50	0.35	1.20
SP2		0.34	1.00

SP1	0.50	0.45	0.70
SP2		0.40	1.00

Table 2 Materials in use

Cement (C)	Ordinary portland cement (3.15 g/cm^3)
Fine aggregate (S)	Crushed limestone sand (2.68 g/cm^3, F.M.: 2.72)
Model coarse aggregate	Glass beads (2.55 g/cm^3, uniform diameter of 10 mm)
New type of superplasticizer (SP1)	BASF Pozzolyth Grenium 6550 (1.058 g/cm^3)
Conventional type of superplasticizer (SP2)	BASF Pozzolyth Rhoebuild SP-8RV(1.095 g/cm^3)

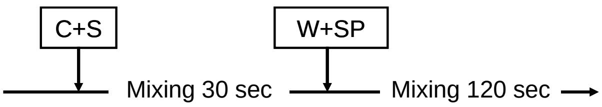


Fig. 6 Mixing procedure of mortar

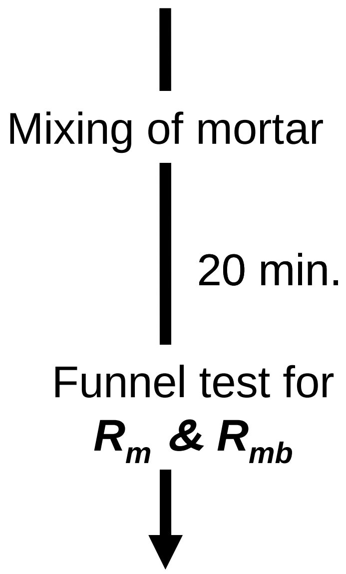


Fig. 7 Mixing procedure of mortar

For each mix-proportioning, both R_m and R_{mb} were obtained. Each mix-proportioning was mixed and tested three times and the average value and standard deviation ($m \pm \sigma$) were obtained. Both the dosage of superpasticizer and water to cement ratio were adjusted so that R_m may be almost the same between the conventional and the new types of superplasticizers. That is because the difference in the degree of interaction can be compared between conventional and new types of superplasticizer by using R_{mb} clearly.

The experimental results of R_m and R_{mb} are shown in **Fig. 8**. Also, the degree of the interaction ($1 - R_{mb}/R_m$) was compared in **Fig. 9 (left)**. In all the cases except of one, it is evident that the new type of superplasticizer (SP1) reduced the degree of the interaction compared with the conventional type of superplasticizer (SP2).

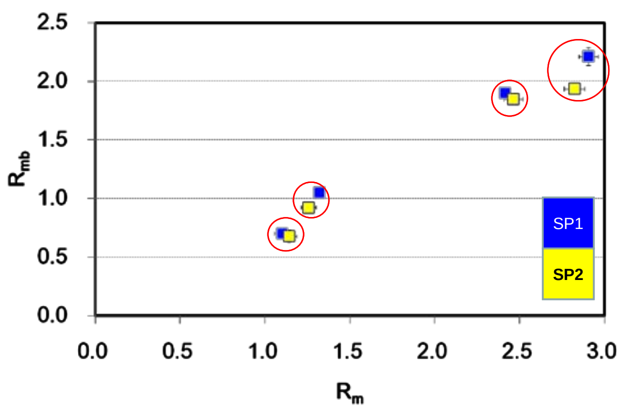


Fig. 8 R_m and R_{mb} with each type of superplasticizer and mix-proportioning-Larger R_{mb} with SP1 compared with almost same R_{mb} (SP1: new type; SP2: conventional type)

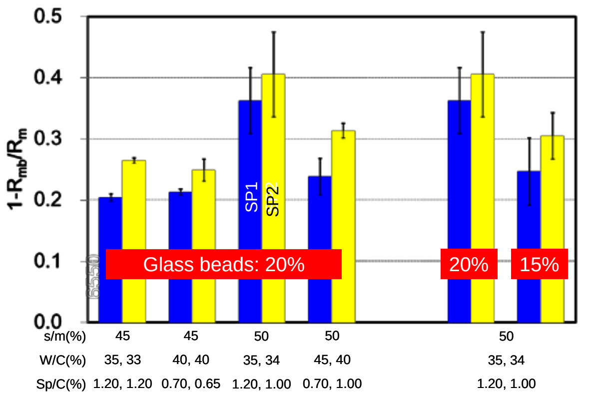


Fig. 9 Smaller degree of interaction (1-R_{mb}/R_m) with SP1

In the only case in which the reduction of the interaction was not so evident, the fine aggregate content in the mortar was larger (50%) and water to cement ratio was lower (34 or 35%) than standard type of SCC. It is possible that it may result in higher friction between fresh mortar and coarse aggregate particles than other cases and that the reduction in the friction was not clear.

In order to clarify the reduction by the new type of superplasticizer (SP1), R_{mb} was also obtained by reducing the mixed glass beads content by 5% (to 15%). The experimental result is shown in **Fig. 9 (right)**. The difference was also not so clear as expected. That may be not due to less effect by the new type of suiperplasticizer (SP1), but due to too high friction between fresh mortar and coarse aggregate particles in the mix-proportioning.

4. MECHANISM FOR REDUCING INTERACTION

Mechanism for reducing the interaction between fresh mortar and coarse aggregate particles was examined. It has been said that viscosity agent absorbs water and it compensates for poor unit cement content for self-compactability. On the other hand, a combination of viscosity agent and water can be similar to liquid phase because most of the volume of the combination comes from water.

By using the new type of superplasticizer (SP1), the water to cement ratio became higher to obtain the same funnel speed R_m, an index for the viscosity compared with the conventional type of superplasticizer (SP2) (**Table 2** or **Fig. 9**). Therefore, the unit water content was larger in the fresh mortar using the new type of superplastizier than in that using the conventional type of superplzticizer and the characteristics was closer to that of liquid. That was assumed to be why the new type of superplastizier reduced the interaction.

In order to verify the hypothesis mentioned above, the relationship between the increment of water to cement ratio (***W/C***) and the decrement of the degree of interaction (1-R_{mb}/R_m) is shown in **Fig. 10**. It is possible that the mechanism for reducing the interaction can be affected by the increment of the unit water content by employing the new type of superplasticizer (SP1).

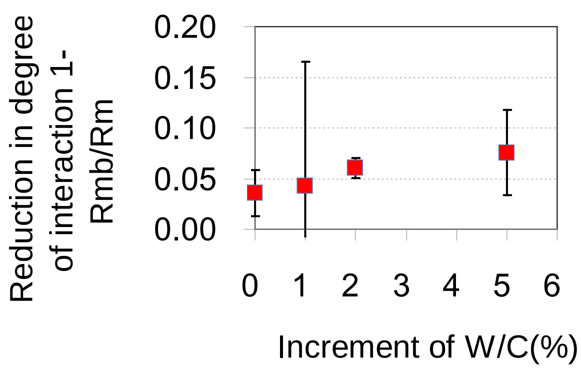


Fig. 10 Relationship between increment of W/C and reduction in degree of interaction (1-R_{mb}/R_m) of mortar with SP1

However, there was a case in which the decrement of the interaction was not zero in spite of the increment of water to cement ratio of zero. That may be due to another effect of the new type of superplasticizer in which the polymer itself can reduce the interaction. Further research on it is necessary.

5. CONCLUSIONS

The purpose of this study is to clarify an effect of a new type of superplasticizer with viscosity agent on reduction in interaction between mortar and coarse aggregate particles in self-compacting concrete at fresh stage. The interaction was defined as an increase in shear deform resistance of the fresh mortar due to normal stress generated by the approaching coarse aggregate particles when self-compacting concrete at fresh stage deforms. The interaction was quantified by degree of reduction in the funnel speed of the fresh mortar due to model coarse aggregate mixed in the mortar in this study.

The following items were clarified in this study:

(1) The degree of the reduction in the interaction between fresh mortar and coarse aggregate particles employing the new type of superplasticizer was smaller. It is possible that the effect on the reduction in friction between solid particles by the new type of superplastcizer was verified.

(2) A correlation between the increment of water to cement ratio and the decrement of the interaction between fresh mortar and coarse aggregate particles by employing the new type of superplasticizer was found. It can be a factor for mechanism of the effect of the new type of superplasticizer.

Further investigation is necessary for clarifying the mechanism for reducing the interaction.

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