A SIMPLE EVALUATION METHOD FOR INTERACTION BETWEEN COARSE AGGREGATE AND MORTAR PARTICLES IN SELF-COMPACTING CONCRETE

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Abstract
The aim of this paper is to establish a simple evaluation method for the interaction between coarse aggregate and mortar's particles in self-compacting concrete, one of the major factor in shear deformability of fresh mortar in concrete. A simple evaluation method for the interaction, which largely depends on the physical characteristics of mortar's particles, is indispensable since mix-design method for self-compacting concrete should be more applicable to materials with wider variation of properties. The authors newly developed a simple evaluation method for the interaction by adopting mortar funnel test, in which funnel speeds of mortar with and without model coarse aggregate are compared. It was found out that the ratio of funnel speed of mortar with model coarse aggregate to that without coarse aggregate was influenced mostly by the physical property of particles in mortar and independent on the flowability or viscosity of the mortar itself. The ratio was proposed as the index for the interaction.

1. Introduction

1.1 Limit of conventional mortar tests for self-compactabiliy

Self-compactability test of fresh concrete is indispensable to mix-proportioning since self-compactability largely depends on the characteristics of materials in use. *Okamura* et. al proposed mortar flow and funnel tests for mix-proportioning in order to rationalize mix-proportioning, in which proper water-powder ratio and superplasticizer dosage can be obtained by estimating from relative flow area Γm and relative funnel speed Rm (**Figs. 1 and 2**) [1].

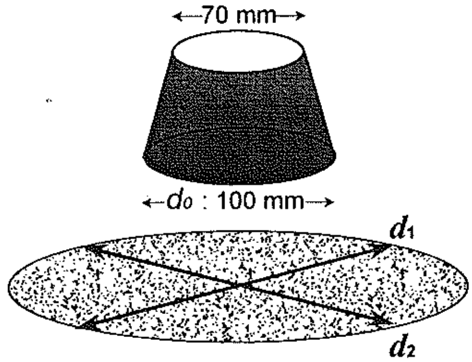

Fig. 1 Mortar flow test
$\Gamma m = (d_1 d_2 - d_0^2) / d_0^2$

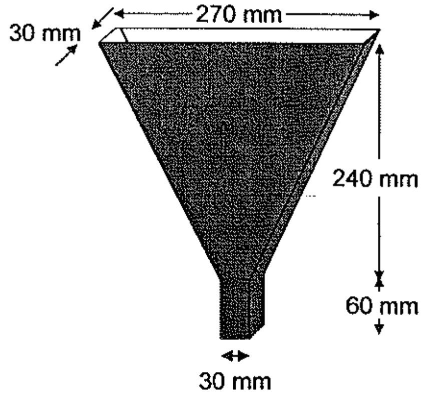

Fig. 2 Mortar funnel test
$Rm = 10 / \textit{funnel time}$ (sec)

However, it was reported that even if coarse aggregate's physical property and its content are the same, the relationship between concrete's and mortar's properties cannot be uniform due to the difference in the property of sand in use or its content in mortar **[1]**. That is because the degree of the interaction between coarse aggregate and mortar's particles, which largely depends on the physical property of sand or powder materials in use or sand content in mortar, cannot be evaluated by the conventional mortar tests for deformability or viscosity of mortar itself.

1.2 Interaction between coarse aggregate and mortar's particles

The interaction between coarse aggregate and mortar's particles is remarkable when concrete deforms in front of a narrower section. When concrete deforms, mortar deforms while coarse aggregate particles approach to each other and then the mortar's shear deformability resistance τ increases due to the normal stress σ generated in the mortar (**Fig. 3**) [1]. The degree of the increase in mortar's shear deformability resistance τ depends on the physical property of powder or sand in use or the sand content in mortar. It was reported that higher sand content in mortar or less spherical shape of particles results in larger increase in the shear deformability resistance τ due to the normal stress σ.

1.3 Necessity for simple evaluation method for the interaction

The decrease of mortar's shear deformability cannot be evaluated with conventional mortar tests since it is due to the dynamic interaction between coarse aggregate and mortar's particles. At this stage, self-compactability test for concrete is indispensable to examining the sand content in mortar when new type of sand or powder material is to be used in self-compacting concrete.

However, the sand content in mortar should be evaluated with simple and easy test since materials with wider variation of properties should be used in concrete in the future and then the mix-proportioning for self-compacting concrete should be simplified. That is because simple evaluation method for the interaction between coarse aggregate and mortar's particles was developed in this research.

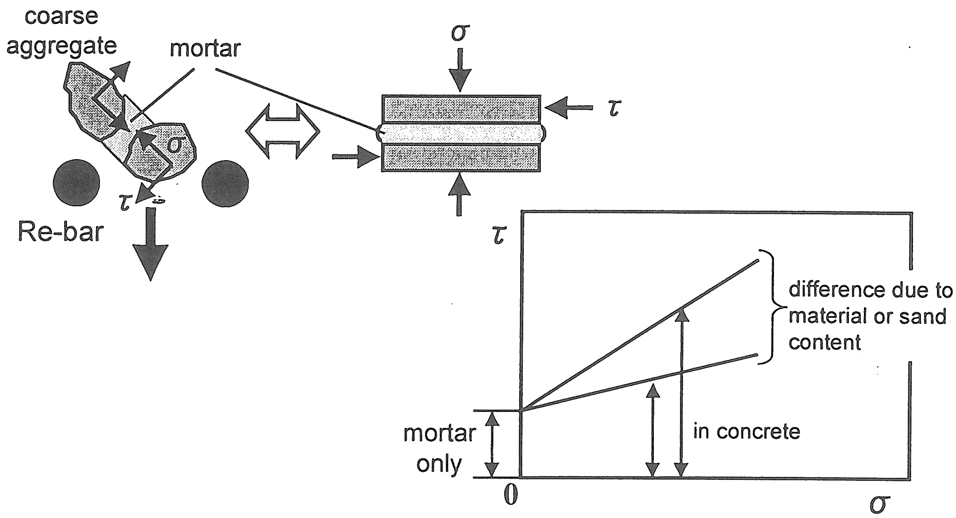

Fig. 3 Increase in mortar's shear deformability resistance τ due to normal stress σ generated when concrete deforms

2. Development of Simple Evaluation Method

2.1 Extent of this research

The evaluation method developed in this paper is to be used for evaluating the sand content in mortar from the viewpoint of achieving moderate interaction between coarse aggregate and mortar's particles on condition that the sand content in mortar has been decided from the material properties (Fig. 4). A rational method for estimating proper sand content in mortar from each material property should be established in the long run, and the evaluation method established in this research is the first step.

2.2 Outline of simple evaluation method

Ozawa and *Nagamoto* investigated on the influence of sand content in mortar on the interaction between coarse aggregate and mortar's particles by comparing concrete and mortar test results (**Fig.s 5 and 6**) [2]. It was shown that higher flow area or funnel speed of mortar is required for concrete in case that the sand content in mortar is higher. It was also found out that the degree of the interaction between coarse aggregate and mortar's particles can be evaluated quantitatively by comparing the test results between concrete and mortar, especially by using funnel test results since the interaction is more remarkable due to the existence of tapered section during flowing.

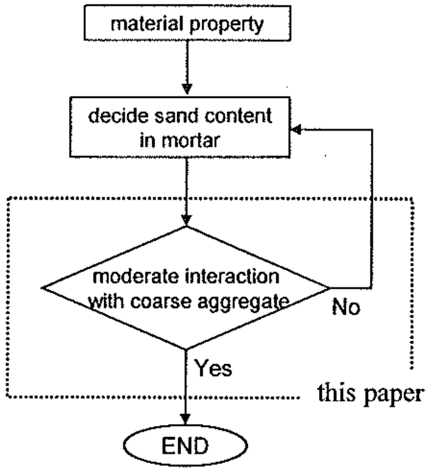

Fig. 4 Place of the evaluation for the interaction in the decision process of sand content in mortar

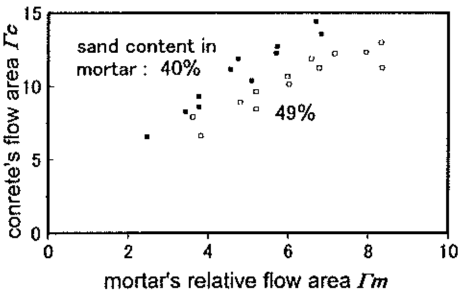

Fig. 5 Relationship between mortar's and concrete's flow areas

$\Gamma c = ((\textit{slump flow}\ (\mathrm{cm}))^2 - 400) / 400$

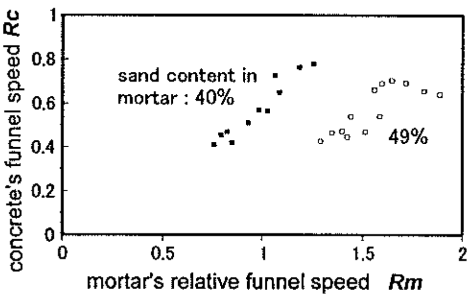

Fig. 6 Relationship between mortar's and concrete's funnel speed

$Rc = 10 / \textit{funnel time}\ (\mathrm{sec})$

The property of coarse aggregate and mortar's particles should be evaluated independent of each other since mix-proportioning method for self-compacting concrete by using each material property is indispensable, and then the property of coarse aggregate used for evaluating the property of mortar's particles should be common. The authors adopted glass beads as the model coarse aggregate in evaluating mortar's particles and then the evaluation is to be carried out by comparing the funnel speed of mortar with glass beads to that without glass beads. Larger interaction can result in larger decrease of funnel speed due to the existence of glass beads in mortar, which leads to larger decrease in shear deformability of mortar when concrete deforms (Fig. 7). Although this method is a kind of concrete test with model coarse aggregate, the labor is almost the same as mortar funnel test, which is effective in saving labor for experiments.

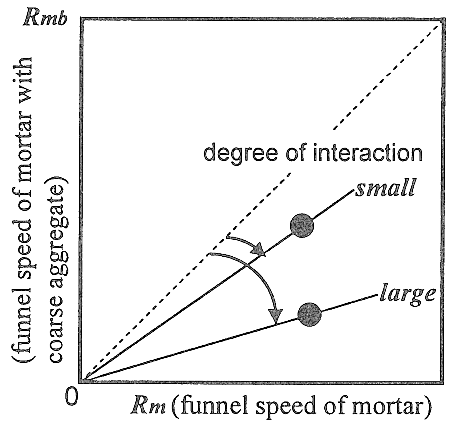

Fig. 7 Concept of the evaluation method for the interaction between coarse aggregate and mortar's particles established in this research
(The interaction is to be evaluated quantitatively by comparing the funnel speeds.)

3. Detail of Evaluation Method

3.1 Conventional mortar funnel as testing apparatus

The conventional mortar funnel for self-compacting concrete was adopted for evaluating the interaction so that water-powder ratio or superplasticizer dosage can be evaluated at the same time in mix-proportioning, which may result in saving labor for experiments (Fig. 2).

3.2 Ratio of funnel speed of mortar to concrete as index for interaction

The interaction should be evaluated independent of mortar's deformability or viscosity, since it does not need adjusting water-powder ratio or superplasticizer dosage when evaluating the interaction. It was found out that the ratio of mortar funnel speed to that of concrete can be almost constant independent of the mortar's deformability or viscosity itself on condition that the effect of coarse aggregate is the same (**Fig. 6**). The authors defined the ratio of the mortar funnel speed with glass beads (***Rmb***) to that without glass beads (***Rm***) as the index for the interaction between coarse aggregate and mortar particles, which is independent of mortar's deformability or viscosity itself. The index is described as ***Rmb/Rm***. Larger ***Rmb/Rm*** indicates less interaction between coarse aggregate and mortar's particles, which results in less decrease in the shear deformability of mortar when concrete deforms.

3.3 Glass beads of 10 mm as model coarse aggregate

The diameter of the glass beads in use was decided to be 10 mm. That is because the diameter in practical coarse aggregate in self-compacting concrete ranges 5 to 20 mm, and because the thickness of mortar funnel in use is 30 mm and then the diameter of the model coarse aggregate has to be less than 15 mm for fear of blocking in the funnel.

3.4 20% of glass beads content

The content of glass beads should be moderate so that the blocking might not be occur during flowing and that the difference of the characteristics of particles in mortar can be clearly indicated in the funnel speed. The content of glass beads with the diameter of 10 mm was decided to be 20% by volume in total volume of mortar and model coarse aggregate since in case of 30% of glass beads content blocking occurred everytime (**Fig. 8**).

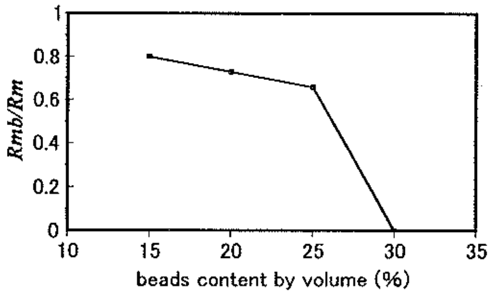

Fig. 8 Relationship between glass bead content and *Rmb/Rm*

OPC+RS, Γm = 3 to 5, Rm=1.4, sand content: 40% by volume

3.5 Range of mortar's deformability and viscosity applicable to *Rmb/Rm*

The value of ***Rmb/Rm*** was obtained with variation of ***Γm*** or ***Rm*** of mortar itself so that the extent in which ***Rmb/Rm*** can be considered to be constant independent of mortar's deformability or viscosity itself (**Fig.s 9 and 10**). Judging from the experimental results, the area in which ***Rmb/Rm*** can be considered to be constant is ***Γm*** of 3 to 7 and ***Rm*** of 1 to 2, which is almost the same as the range of ***Γm*** and ***Rm*** for achieving self-compactability of fresh concrete. The lower limit for ***Γm*** or ***Rm*** was decided so that larger decrease of

Rmb due to the addition of model coarse aggregate might be inhibited. The upper limit for ***Γm*** was decided so that sinking glass beads into the mortar might be prevented. The upper limit for ***Rm*** was decided so that the inaccuracy of measuring funnel time can be inhibited due to too high funnel speed.

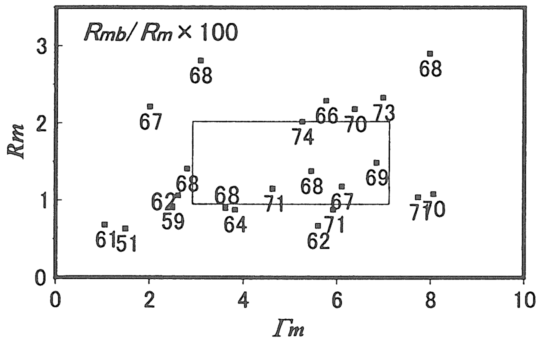

Fig. 9 Relationship between *Rmb/Rm* and *Γm* & *Rm*
OPC+RS, sand content: 40%

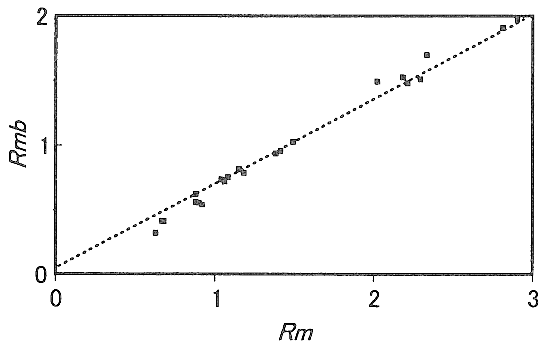

Fig. 10 Relationship between *Rm* and *Rmb*
OPC+RS, sand content: 40%

4. Verification of the Evaluation Method by Experiments

4.1 Mortar test

Mortar's ***Rmb/Rm*** was obtained from experiments for wide variation of powder materials (OPC: ordinary portland cement and FA: fly ash) or sand (RS: river sand, LS: land sand and CS: crushed sand) and sand content in mortar (**Fig. 11**). It was verified that the variation of sand content in mortar corresponds to the variation of ***Rmb/Rm***, obtained by comparing funnel speeds, and that the physical property of materials in use also corresponds to ***Rmb/Rm***, which had been able to be estimated qualitatively as yet. It is possible that the degree of the influence of mortar's particles or sand content on the interaction can be evaluated quantitatively.

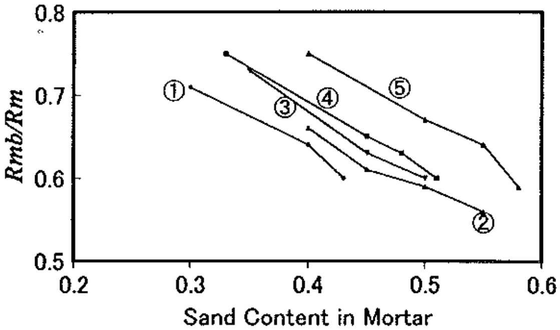

Fig. 11 Relationship between sand content in mortar and *Rmb/Rm* depending on the property of sand or powder materials in use
①OPC+CS, ②FA+CS, ③FA+RS, ④OPC+RS, ⑤OPC+LS

4.2 Verification of the evaluation method by concrete test

The relationship between ***Rmb/Rm*** and self-compactability of fresh concrete was investigated by experiments in order to verify the testing method for the interaction mentioned above (**Fig. 12**). Self-compactability of fresh concrete was tested by box-shaped test, one of the recommended standard test for self-compactability in Japan (**Fig. 13**) [3]. The filling height of the box-shaped test shown in **Fig. 12** is the maximum value obtained by adjusting water-powder ratio and superplasticizer dosage so that only the degree of the interaction can be indicated by the filling height. It was found out that the relationship between ***Rmb/Rm*** and the filling height is unique on condition that the effect of coarse aggregate on the interaction is constant. It is possible that the evaluation method "***Rmb/Rm***" can be substitution for self-compactability test of fresh concrete for examining the sand content in mortar.

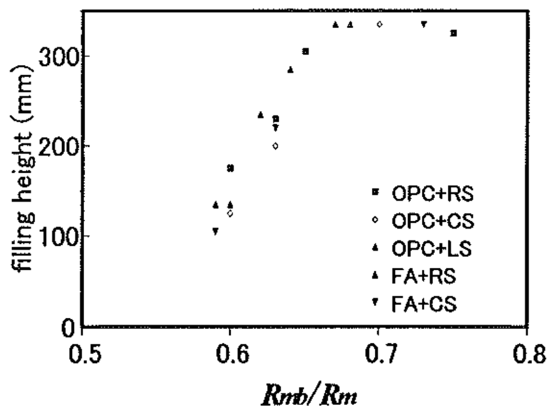

Fig. 12 Relationship between *Rmb/Rm* and degree of self-compactability of concrete indicated by filling height of box-shaped test

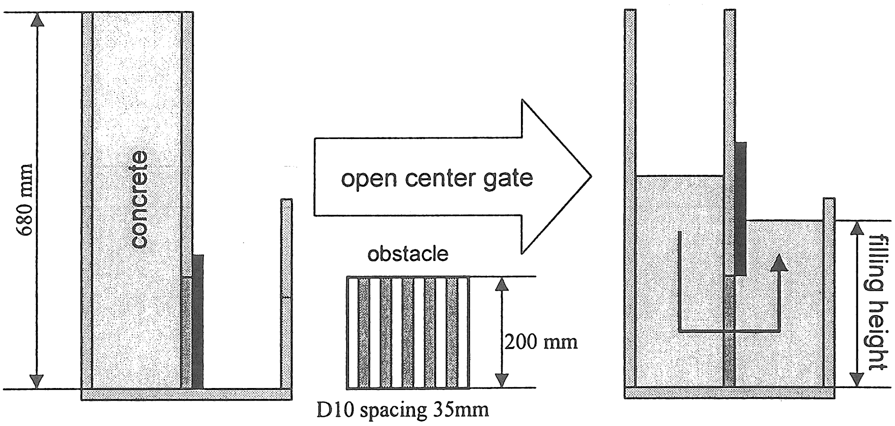

Fig. 13 Box-shaped test

5. Conclusions

1. The testing method for the interaction between coarse aggregate and mortar's particles in self-compacting concrete was proposed in which funnel speed of mortar with coarse aggregate and that without coarse aggregate are compared.
2. The conventional funnel for mortar in self-compacting concrete was adopted as the testing apparatus. Glass beads with the diameter of 10 mm was adopted as the model coarse aggregate and the content in total volume of mortar and model coarse aggregate was decided to be 20% so that blocking might not occur.
3. The index for the interaction was proposed as the ratio of the funnel speed of mortar with glass beads (***Rmb***) to that without glass beads (***Rm***). It was found out that the index ***Rmb/Rm*** can be constant on condition that the deformability or viscosity of mortar itself is in the range for achieving self-compactability of fresh concrete.
4. It is possible that the evaluation method developed in this research can be the substitution for the self-compactability test of fresh concrete for examining the sand content in mortar.

6. References

1. Nawa, T., Izumi, T., and Edamatsu, Y., "State-of-the-art report on materials and design of self-compacting concrete," Proceedings of the International Workshop on Self-

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2. Nagamoto, N. and Ozawa, K., "Mixture proportions of self-compacting high-performance concrete," High-performance Concrete: Design and Materials and Advances in Concrete Technology, ACI SP-172 (1997), 623-636.
3. Japan Society Civil Engineers (1998), "Recommendations for construction of self-compacting concrete."

7. Appendix

7.1 Materials

Powder materials	specific gravity	fineness
Ordinary portland cement (OPC)	3.13	3,630 cm^2/g
Fly ash (FA)	2.34	4,220 cm^2/g

Sand	specific gravity	solid volume	F.M.	Water absorption
River (RS)	2.56	66.9%	3.03	1.17%
Land (LS)	2.67	68.1%	2.45	1.04%
Crushed (CS)	2.64	59.1%	2.42	0.82%

Coarse aggregate: crushed stone, specific gravity 2.7, solid volume 58.6%, F.M. 6.87, maximum size 20 mm
Model coarse aggregate: glass beads, specific gravity 2.54, diameter 10 mm
Superplasticizer: poly-ether-based type

7.2 Mixing and testing of mortar

mixer: mortar mixer meeting Japanese Industrial Standard (JIS R 5201)
mixing volume: 1.5 litter per batch

mixing procedure

$\boxed{\text{POWDER + SAND}}$ → mixing 30 sec → + $\boxed{\text{WATER (1)}}$ → mixing 120 sec → + $\boxed{\text{WATER (2) + SUPERPLASTICIZER}}$ → mixing 120 sec → end

testing procedure for the interaction

$\boxed{\text{MORTAR}}$ → flow & funnel tests → + $\boxed{\text{GLASS BEADS}}$ → stir by hand power → $\boxed{\text{MORTAR WITH GLASS BEADS}}$ → funnel test → end