Streamlining Information Transfer between Construction and Structural Engineering
Edited by Shiau, J., Vimonsatit, V., Yazdani, S., and Singh, A.

ISBN: 978-0-9960437-7-9

A STUDY ON THE FLUIDITY OF MORTAR WITH FINE AGGREGATE ADJUSTED GRAIN-SIZE AND POWDERS

SHOHEI KOIZUMI[1], KOJI TAKASU[2], HIDEHIRO KOYAMADA[2], and HIROKI SUYAMA[2]

[1] *Graduate School of Engineering, The University of Kitakyusyu, Kitakyusyu, Japan*
[2] *Faculty of Engineering, The University of Kitakyusyu, Kitakyusyu, Japan*

It has been clarified that the particle shape and particle size distribution of fine aggregate have influenced the fresh properties of concrete and mortar in the past research. But it has not been sufficiently studied how each particle size and particle size distribution of fine aggregate affects the fresh properties of mortar and concrete. In this study, we adjusted the particle size of fine aggregate, and evaluated fresh properties of mortar by indicators. We investigated the fluidity of mortar, which changed depending on the composition of particle size distribution. In addition, the behavior of fresh properties of mortar contained powder substituted as part of cement and fine aggregate adjusted particle size distribution was compared with that when no powder was mixed. Its behavior was discussed. It became clear that, the factor influencing the fluidity varied depending on the composition of particle size distribution. The influence of fine particles on fluidity of mortar varied depending on the content of fine particle and the particles size distribution. When combined with the large particles, the fluidity was improved as compared with the combination with the intermediate particles. In addition, the same tendency as in powder-free mixing was confirmed at powder mixing and increase rate of the relative flow area ratio when fly ash was contained became larger than when the limestone fine powder was contained.

Keywords: Relative flow area ratio, Mini-slump, Particle size distribution, Solid content rate, Water absorption rate, Fine particle, Fly ash, Limestone fine powder.

1 INTRODUCTION

Research on fluidity of mortar and concrete has been done so far, and it has been clarified that the aggregate particle size affects the fresh state of mortar and concrete. Fine particle content of fine aggregate as one of the factors that affects it, can be mentioned. Also, it has been clarified that the particle shape and particle size structure of fine aggregate have influenced the fresh properties of concrete and mortar in the past research. But it has not been sufficiently studied how each particle size and Particle size distribution of fine aggregate affects the fresh properties of mortar and concrete. In addition, in recent years, as one of the movements contributing to low carbon society, it is attracting attention to replace a part of cement with a by-product type powder having a small amount of CO_2 emission.

In this research, we adjust the particle size of fine aggregate, and evaluate fresh properties of mortar using indicators such as water absorption, solid content and fineness modulus, and we investigated the fluidity of mortar, which changes depending on the particle size composition. In addition, the behavior of mortar fresh when combining powder substituted as part of cement and fine aggregate with controlled particle size was compared with that when no powder was mixed, and its behavior was discussed.

2 SUMMARY OF THE EXPERIMENT

Table 1 shows the materials used in the experiment. We investigated the properties of mortar made with aggregates that had five particle size distributions. We used three kinds of oven-dried fine aggregates (two types of crushed sand [CSa, CSb], and one type of sea sand [SS]) in this experiment. The crushed sand met the criteria specified in Japanese Industrial Standards (JIS) A 5005 "Crushed stone and manufactured sand for concrete. We also used two kinds of fly ash and fine limestone powder, and the fly ash was equivalent to JIS II class. We kept the materials for more than 24 h at a constant room temperature of 20 ± 1 °C. Next, table 2 shows mix proportions. As explained below, "N-CSa", "N-CSb", and "N-SS" without admixture were the basic mix proportions, and the amount of admixture was 30% replacement of the cement volume. The volume ratio of water to powder was constant in all mix proportions. The mix proportions were indicated by "FA" for fly ash and "LP" for fine limestone powder followed by a number showing the substitution rate. The type of sand was indicated by "CSa", "CSb", or"SS". "P" in the mix proportions list indicated the powder, and "Wv/Pv" expressed the water- to-powder volume ratio. Next, table 3 shows physical properties and measured value. There were five particle size distribution patterns for the fine aggregates: no particle size adjustment, 2.5–1.2 mm, 1.2-0.6mm, less than 1.2mm, 2.5-1.2mm and less than 0.6 mm. The content ratio of 1.2–0.6 mm to less than 0.6 mm particles in pattern III was defined as the mass ratio calculated from the particle size distribution. In addition, the content ratio of 2.5–1.2 mm to less than 0.6 mm particles in pattern V was defined as a mass ratio of 1:1 because the amount of fine particles of sea sand was increased in pattern V if the particle size distribution ratio was used. The content of 2.5–1.2 mm particles in sea sand was low, and it was excluded from the mix proportions because it was difficult to obtain the amount necessary for casting. Mortar mixing was carried out with a mortar mixer in a mixing room at room temperature of 20 ± 1 °C. The measurements were mortar flow, mini-slump test, air content, solid content rate of fine aggregate, and water absorption rate.

Table 1. Materials used in the experiment.

Item	Type	Physical properties	Symbol
Cement	Ordinary portland cement	Density3.16g/cm^3	C
Water	Tap water	-	W
Fine aggregate	Crushed sand A	Water absorption rate0.75% Density2.71g/cm^3 FM3.1 Solid content rate65.5%	CSa
	Crushed sand B	Water absorption rate1.96% Density2.74g/cm^3 FM2.7 Solid content rate64.7%	CSb
	Sea sand	Water absorption rate0.76% Density2.59g/cm^3 FM2.4 Solid content rate62.3%	SS
Admixture	Fly ash(JIS class Ⅱ)	Density2.43g/cm^3 Loss on ignition2.00% Specific surface area4014cm^2/g	FA
	Limestone fine powder	Density2.77g/cm^3 Specific surface area5221cm^2/g	LP

Table 2. Mix proportions.

Symbol	W/C	Wv/Pv	Unit mass[kg/m^3]				
			W	C	FA	LP	S
N-CSa	50	1.58	280	560	0	0	1256
N-CSb	50	1.58	280	560	0	0	1282
N-SS	50	1.58	280	560	0	0	1223
FA30-CSa	71	1.58	280	392	121	0	1256
FA30-CSb	71	1.58	280	392	121	0	1282
FA30-SS	71	1.58	280	392	121	0	1223
LP30-CSa	71	1.58	280	392	0	147	1256
LP30-CSb	71	1.58	280	392	0	147	1282
LP30-SS	71	1.58	280	392	0	147	1223

A 5201 "Physical testing methods for cement", and the mini-slump test was measured in accordance with JIS A 1171 "Test methods for polymer-modified mortar". Air content was measured with a mortar air meter, and the solid content rate of fine aggregate was measured in accordance with JIS A 1104 "Methods of test for bulk density of aggregates and solid content in aggregates". In the water absorption rate measurements for each particle size composition, the smaller the particle size, the more difficult it was to identify the saturated surface-dry state of the aggregate, and we could not measure it by the JIS water absorption test. Therefore, oven-dried specimens (90 g) for each particle size composition were placed in a Le Chatelier flask containing water and allowed to stand at 20 ± 1 °C for 2 h. The water absorption rate was calculated by the value obtained by dividing the volume decrease by 90 g. The relative flow area ratio (Γ) is used as a self-filling index, and the fluidity was high so the value was big. The formula for calculating the relative flow area ratio is shown below.

$$\Gamma = \frac{(d_1 \cdot d_2 - d_0^{\,2})}{d_0^{\,2}} \tag{1}$$

Table 3. Physical properties and measured value.

Symbol			Unit mass[kg/m^3]			Frow value [mm]	Relative flow area ratio(Γ)	Mini-slump[cm]	Air content [%]	FM [%]	Solid content rate[%]	The ratio of paste volume to fine aggregate void volume	Water absorption rate[%]
			2.5-1.2 [mm]	1.2-0.6 [mm]	0.6-0.0 [mm]								
N	CSa	Ⅰ	527	410	319	178.0	2.17	5.4	4.5	3.1	65.5	315.3	1.48
		Ⅱ	1256	0	0	149.0	1.22	5.1	4.0	3.4	59.7	255.5	1.04
		Ⅲ	0	707	550	151.5	1.30	2.4	4.0	1.9	62.0	279.9	1.04
		Ⅳ	0	1256	0	150.0	1.25	3.0	5.0	2.8	57.6	245.0	1.37
		Ⅴ	628	0	628	168.0	1.82	4.2	1.3	2.3	66.4	344.4	1.26
	CSb	Ⅰ	382	372	528	167.0	1.80	4.5	4.0	2.4	64.7	288.8	0.38
		Ⅱ	1282	0	0	142.0	1.00	3.5	4.0	3.1	53.2	225.6	0.26
		Ⅲ	0	530	752	135.0	0.80	1.8	3.8	1.7	62.5	268.0	0.15
		Ⅳ	0	1282	0	133.0	0.80	1.5	6.5	2.5	52.6	222.8	0.26
		Ⅴ	641	0	641	161.5	1.60	4.8	1.9	1.8	64.7	342.8	0.49
	SS	Ⅰ	54	450	719	167.0	1.79	1.4	7.0	2.7	62.3	302.1	0.67
		Ⅱ	1223	0	0					3.3	52.4	222.4	0.05
		Ⅲ	0	471	752	154.0	1.37	1.9	5.2	1.7	61.2	288.6	0.61
		Ⅳ	0	1223	0	149.0	1.22	1.1	9.0	2.6	56.3	239.6	0.56
		Ⅴ	612	0	612	203.5	3.14	8.3	3.7	2.0	63.0	310.3	0.11

3 RESULT AND CONSIDERATION

3.1 Solid Content Rate of Fine Aggregate and Fluidity

Table 4 shows the ratio of the fine particle of 75 μm or less in the fine aggregate input amount of Pattern I, III, V, Figs.1 shows relationship between solid content rate of fine aggregate and the relative flow area ratio, mini-slump. Figure 1 shows that the relative flow area increased as the solid content rate of the fine aggregate increased. It has been reported that the flow increases as the ratio of the paste volume to the void volume of aggregate increases (Hirata *et al.* 1995). In the present work, because the paste volume was constant in all mix proportions, we assumed that the solid content rate of the fine aggregate was equal to the ratio of the paste volume to the void volume of the aggregate. However, for each particle size configuration, although the solid volume rate of fine aggregate was large, there were some points at which the relative flow area ratio did not increase. Therefore, we assumed that the factors affecting relative flow area ratio changed. We compared the relative flow area ratios for each particle size composition and examined the factors.

Compared with pattern I, for patterns II and IV, the solid content rate of the fine aggregate and the relative flow area ratio decreased for all fine aggregates. This is because the fine aggregates in patterns II and IV are 2.5–1.2 mm particles only or 1.2–0.6 mm particles only, respectively, and the intermeshing between the particles is poor. Therefore, the dispersion distance of fine aggregates in the mortar is small and the fluidity is poor. Consequently, for 2.5–1.2 mm particles or 1.2–0.6 mm particles, the most important factor affecting fluidity is the solid content rate of the fine aggregate.

Compared with the equivalent solid content rate of pattern I, the relative flow area ratio of pattern III decreased greatly for all fine aggregate. In addition, there was insufficient water in the mortar in pattern III immediately after mixing. These results suggested that as the amount of particles less than 1.2 mm in size increased, the water absorption rate increased and the fluidity became poor. However, the water absorption rate of pattern III was smaller than that of pattern I (Table 3). Therefore, although a factor other than the water absorption rate of fine aggregate affected the fluidity strongly, we could not identify this factor and intend to investigate it in future work.

The relative flow area ratio of pattern V was the largest of those with particle size adjustment, and the viscosity of the mortar immediately after mixing was the lowest. We assumed that this was because fine particles 90 μm or less in size (Yamaguchi *et al.* 1994), which function as a powder, were added to the paste, and the amount of paste increased; thus, the dispersion distance of fine aggregate decreased and the fluidity became poor. However, although the fine particle content in pattern III was comparable to those in patterns I and V, the relative flow area ratio of pattern III was smaller than those in patterns I and V, and there was a large difference in relative flow area ratio (Table 4). Therefore, the fluidities of pattern III composed of medium-sized particles (1.2–0.6 mm) and fine particles and pattern IV composed of only medium-sized particles were equivalent. On the other hand, the fluidity of pattern V, composed of fine particles, added to pattern II, with only large particles (2.5–1.2 mm), improved. Therefore, we assumed that influence on the fluidity of fine particles is different by the particle size of the particle constituted with the fine particle. In addition, the relative flow area ratio of the sea sand in pattern V was very large because the solid content rate of fine aggregate was large and contained a lot of 2.5–1.2 mm particles with very low water absorption. Thus, the water absorption rate of the fine aggregate decreased and the paste fluidity increased.

In this experiment, the particle size distribution that gave the highest fluidity was "no particle size adjustment", and the particle size of the crushed sand was adjusted with constant water–cement ratio (W/C), but no increase in fluidity was observed. Therefore, it is necessary to evaluate the fluidity of mortar when using crushed sand with particle size adjusted by changing W/C. In addition, Figure 3 shows that mini-slump increased as the solid content rate of fine aggregate increased, although the relationship was not linear. Therefore, mini-slump was not affected strongly by the solid content rate of fine aggregate. The same behavior was also observed for the solid content rate of the fine aggregate and the air content.

Table 4. The ratio of the fine particle of 75 μm or less in the fine aggregate input amount of Pattern I, III and V.

	Fine particle content[%]		
	Ⅰ	Ⅲ	Ⅴ
CSa	0.07	0.12	0.14
CSb	0.54	0.76	0.65
SS	0.69	0.73	0.59

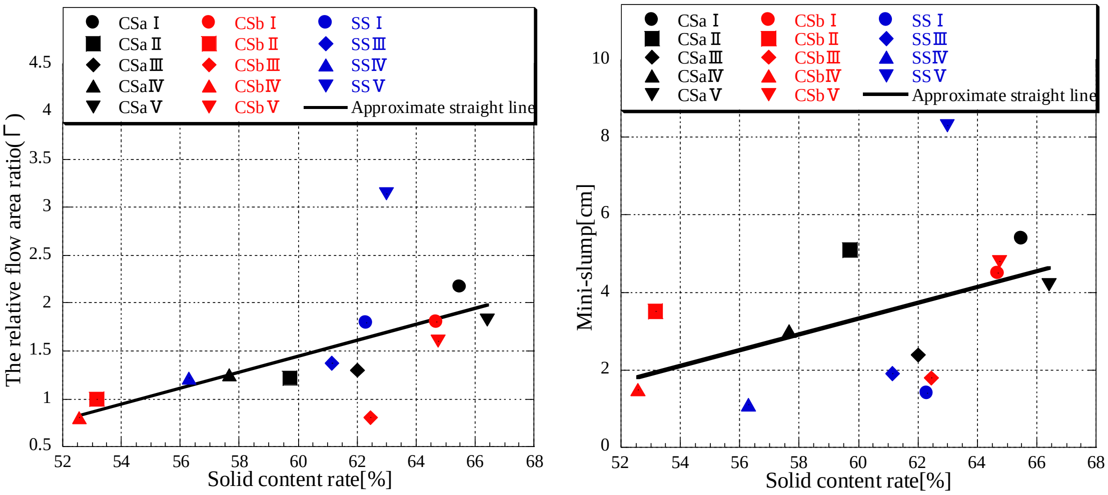

Figure 1. Relationship between solid content rate and the relative flow area ratio, mini-slump.
(Left: the relative flow area ratio/Right: mini-slump)

3.2 Solid Content Rate of Fine Aggregate and Fluidity with Powder

Table 5 shows measured value with FA and LP, Figs.2 shows relationship between solid content rate of fine aggregate and the relative flow area ratio when FA and LP are mixed. For powder-free mixing, the relative flow area ratio increased as the solid content rate of the fine aggregate increased. When fly ash was added, the relative flow area ratio increased compared with powder-free mixing, and the rate of increase of the relative flow area ratio became large. This result was explained by the ball bearing effect of the smooth, round fly ash particles increasing the paste fluidity. In addition, when limestone fine powder was added, the rate of increase of the relative flow area ratio did not change much, even compared with powder-free mixing (Figure 1). Therefore, the change in fluidity was caused by the powder characteristics of the fine aggregates with adjusted particle size. In pattern III of CSb with limestone fine powder, there was insufficient water to mix the mortar. We could not explain this result, and we intend to investigate it in future work.

Table 5. Measured value with FA and LP.

Symbol			Frow value[mm]	Relative flow area ratio(Γ)	Mini-slump [cm]	Air content [%]
FA (LP)	CSa	Ⅰ	201.1(187.3)	3.04(2.51)	8.3(4.3)	1.1(3.6)
		Ⅱ	153.2(161.5)	1.35(1.61)	5.1(4.5)	1.8(4.5)
		Ⅲ	162.7(154.5)	1.65(1.39)	3.2(0.6)	2.5(2.8)
		Ⅳ	151.5(141.5)	1.30(1.00)	3.5(1.6)	3.5(4.0)
		Ⅴ	193.9(178.0)	2.76(2.17)	7.6(3.0)	1.0(1.9)
	CSb	Ⅰ	182.0(169.5)	2.80(1.87)	4.4(4.4)	1.2(3.5)
		Ⅱ	130.5(131.0)	0.70(0.72)	1.5(1.8)	3.2(5.4)
		Ⅲ	153.5(-)	1.40(-)	2.3(-)	0.8(-)
		Ⅳ	135.0(133.5)	0.80(0.78)	0.9(0.3)	5.5(8.2)
		Ⅴ	192.0(170.0)	2.70(1.89)	7.1(3.6)	1.2(2.9)
	SS	Ⅰ	187.5(166.5)	2.52(1.77)	4.6(2.6)	3.5(5.8)
		Ⅱ				
		Ⅲ	192.0(164.5)	2.68(1.71)	4.3(2.5)	2.8(5.8)
		Ⅳ	163.5(164.5)	1.67(1.71)	2.8(2.5)	5.1(6.5)
		Ⅴ	227.5(200.5)	4.18(3.02)	11.2(7.5)	1.2(2.7)

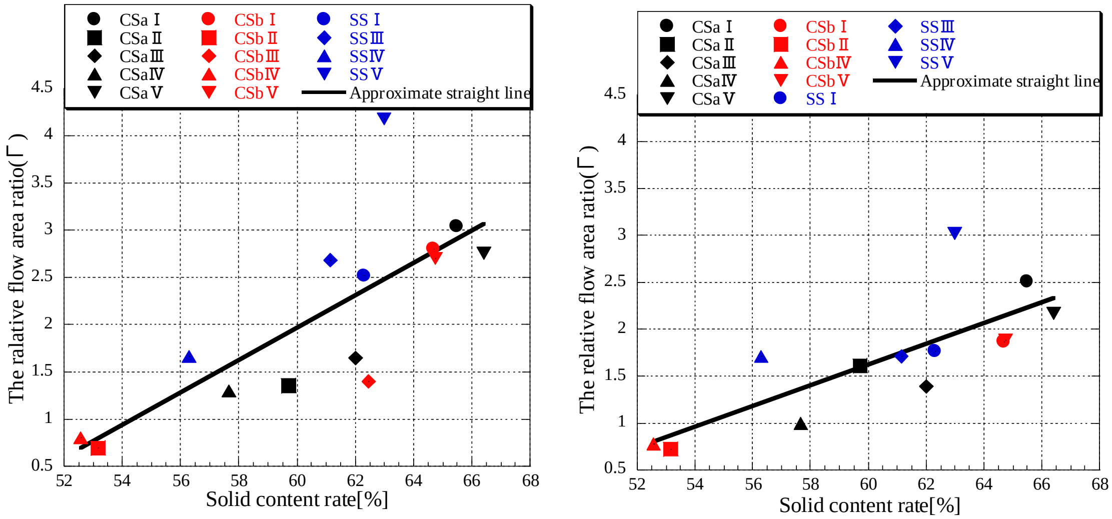

Figure 2. Relationship between solid content rate and the relative flow area ratio when FA, LP are mixed. (Left: FA/Right: LP)

4 CONCLUSION

The findings obtained in this research are shown below.

(1) Even when the particle size was adjusted, there was a tendency for the relative flow area to increase as solid volume rate of fine aggregate became increase. But, although the solid volume rate of fine aggregate was large, there were some points that the relative flow area ratio was not increased. Therefore, we assumed that the factors affecting relative flow area ratio changed by particle size composition.

(2) For 2.5–1.2 mm particles or 1.2–0.6 mm particles, the most important factor affecting fluidity was the solid content rate of the fine aggregate. In addition, for less than 1.2 mm, although a factor other than the water absorption rate of fine aggregate affected the fluidity strongly, we could not identify this factor and intend to investigate it in future work. In addition, we assumed that influence on the fluidity of fine particles is different by the particle size of the particle constituted with the fine particles.

(3) Even when powder was mixed, there was a tendency for the relative flow area to increase as solid volume rate of fine aggregate became increase. When compared with powder-free mixing, fly ash had a smooth particle shape for limestone fine powder, so the increase rate in the relative flow area ratio when fly ash was mixed was larger than when limestone fine powder was mixed.

Acknowledgements

The authors acknowledge the assistance in this work provided by Mr. Eiji Mikura, Mr. Yuki Takaki. This research was financially supported by Environmental Restoration and Conservation Agency (ERCA) No.3-1703 “Development of advanced recycling technology for fly ash to enable cement-free concrete”.

References

Hirata, T., Takada, N., Miura, N. and Sogou, S., *The Influence of the Aggregate Grading on Fresh Highly-Workable-Concrete*, Proceedings of the Japan Concrete Institute, 17(1), 81-86, June, 1995.

Yamaguchi, S., Edamatsu, Y., and Okamura, H., *Characterization of Sand in View of Mortar Flow*, Proceedings of the Japan Concrete Institute, 16(1), 83-88, 1994.