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A STUDY ON INFLUENCE OF PHYSICAL PROPERTIES OF CRUSHED SAND WITH ADJUSTED PARTICLE SIZE DISTRIBUTION FOR FLUIDITY OF MORTAR

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ABSTRACT

In this study, it was discussed the fluidity of mortar when adjusting the particle size distribution of crushed sand within the range defined by Japanese Industrial Standards (JIS A 5005) for the purpose of improving the fresh properties when using the whole crushed sand. Using the physical property values of the fine aggregate and the particle shape coefficient as the evaluation index, the particle size distribution and the fluidity of the mortar under different paste properties were verified. As a result, when the fine aggregate volume and the paste volume were constant, the particle size composition had the most influence on the flowability of the mortar, so even when crushed sand was used, it was possible to evaluate and predict the fluidity by finesses modulus.

Keywords: Crushed sand, relative flow area ratio, shape factor, fine particle content

1. INTRODUCTION

Although the demand for crushed sand has been increasing in recent years, improving its quality for use as aggregate in concrete remains problematic. Solutions include the removal of fine particles [1)] and adhering fine particles [2)] and improving the particle shape [3)]. However, these improvement methods generate the byproduct referred to as crushed stone powder. Considering the increasing opportunities to use crushed sand in the future, it is expected that large quantities of this byproduct will be generated, requiring high energy consumption to treat it as industrial waste.

In this study, to improve the fresh properties of mortar using the all crushed sand as aggregate, it is necessary to understand the fluidity of mortar when the grain size distribution of crushed sand is adjusted to within the range defined by JIS standard. In addition, we evaluated the influence of the particle size composition and paste properties on the mortar fluidity based on physical parameters and the particle shape of the fine aggregate.

2. EXPERIMENTAL METHODS

Table 1 summarizes the materials used in this study. The cement used was ordinary Portland cement. Three kinds of crushed sand and one kind of sea sand were used as the fine aggregate in a surface dry condition. The crushed sand satisfied the quality stipulated in JIS A 5005. The fly ash was equivalent to JIS type II. These materials were stored in the rmostated room at 20±1 °C for at least 24 h prior to mixing.

Table 1. Materials

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 rate0.53%	CSa
		Density2.74g/cm^3 FM4.11	
		Solid volume rate63.1%	
	Crushed sand B	Water absorption rate0.58%	CSb
		Density2.73g/cm^3 FM2.66	
		Solid volume rate60.9%	
	Crushed sand C	Water absorption rate0.93%	CSc
		Density2.70g/cm^3 FM3.18	
		Solid volume rate64.8%	
	Sea sand	Water absorption rate0.83%	SS
		Density2.62g/cm^3 FM3.18	
		Solid volume rate62.3%	
Admixture	Fly ash (JIS classII)	Density2.43g/cm^3 Specific surface area4014cm^2/g	FA
Chemical admixture	Superplasticizer	Polycarboxylic acid type	SP
	Defoaming agent	Polyalkylene glycol derivatives	AD

Figure 1 shows the particle size distribution, and Table 2 presents the mixing ratio for each particle diameter. The particle size composition was adjusted within the range defined by JIS, in a total of five patterns.

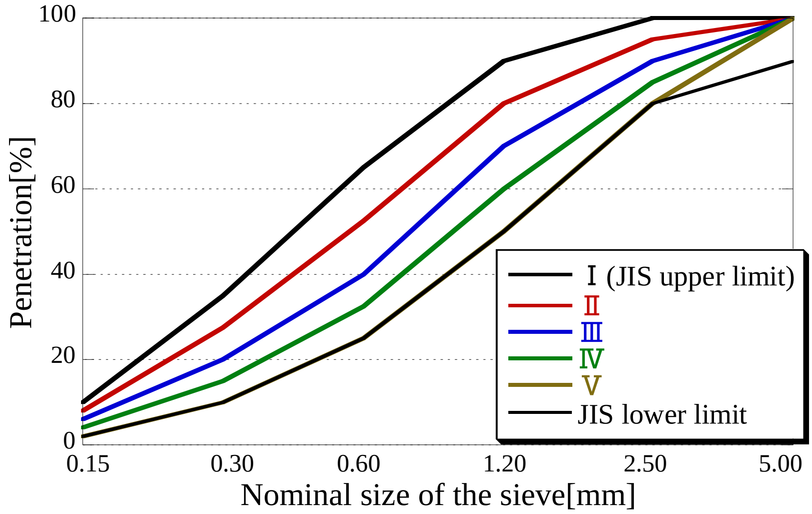

Fig.1 Particle size distribution

Table 3 shows the mix proportions used in this study. In experiment 1, a water cement ratio of W/C=50% and a total of 20 mix proportions without admixture were used, with all of the five particle size compositions of fine aggregate shown in Table 2. In experiment 2, W/C=40% or 45% and a total of 24 mix proportions with admixture were used, with three of the particle size compositions of fine aggregate shown in Table 2 (patterns I, III, and V). The addition amount of super plasticizer (SP) was set such that the original fine aggregate had a 15-stroke slump flow of 200 ± 10 mm, and the same amount was added for each fine aggregate. In experiment 3, fly ash was substituted for cement at ratios of 5%, 10%, and 15%, as in experiment 2, a total of 36 mix proportions were made. The addition amount of SP was the same as in experiment 2. In experiment 4, with W/C=50% and particle size composition pattern III, the fineness modulus for the 75–150 μm and less than 75 μm was adjusted to a constant value. The number at the end of the mix proportion symbol indicates the content ratio of particles less than 75 μm.

Table 2 The mixing ratio of each particle size

Particle size[mm]	5.0-2.5	2.5-1.2	1.2-0.6	0.6-0.3	0.3-0.15	0.15 less than
I [%]	0.0	10.0	25.0	30.0	25.0	10.0
II [%]	5.0	15.0	27.5	25.0	19.5	8.0
III [%]	10.0	20.0	30.0	20.0	14.0	6.0
IV [%]	15.0	25.0	27.5	17.5	11.0	4.0
V [%]	20.0	30.0	25.0	15.0	8.0	2.0

Table 3 Mix proportion

Esptl	Symbol	W/Pv	Unit mass[kg/m^3]			
			W	C	S CSa/CSb/CSc/SS	FA
1	N50	1.580	280	560	1290/1285/ 1275/1238	
2	N45	1.422	268	597	1290/1285/ 1275/1238	
	N40	1.264	255	639	1290/1285/ 1275/1238	
3	FA5(10/15)	1.422	269	567(537/507)	1290/1285/ 1275/1238	14(28/41)
4	N50-30(50/70)	1.580	280	560	1290/1285/ 1275/ -	

Table 4 summarizes the nominal physical properties of the fine aggregate and the measured values. The measured physical parameters were the solid volume, water absorption, fine particle content, ratio of long and short, unevenness coefficient, and shape factor (FUa). The ratio of long and short, unevenness coefficient, and shape factor were calculated for each grain size based on difference [4)]. FUa was calculated from the shape factor and the containing ratio of each grain size the proportion and FUa of each grain size distribution range, using the following formula:

$$\mathrm{FUa} = \sum_{i=1}^{5} (\mathrm{i\ Shape\ factor}\ \times \mathrm{i\ mixing\ ratio\ of\ the\ granular\ form})$$

Where,FUa: Shape factor according to the mixing ratio of each particle size distribution

The unevenness coefficient and ratio of long and short were determined based on the analysis of images obtained using a CCD camera. Twenty samples were measured for each grain size and their average values were calculated. The fine particle content for each grain size composition was measured using a sample of 500 g and a sieve with a mesh size of 75 μm.

Table 4 Physical properties and measured value

Exptl.	Symbol		FM	15 stroke flow[mm]	Relative flow area ratio Γ	Mini slump [cm]	Solid volume [%]	Water absor-ption [%]	Shape factor	Fine Particle content [%]
1	CSa50	I	2.00	177.5	2.15	3.70	63.0	1.45	1.49	4.46
	CSb50			170.0	1.89	5.90	59.1	1.06	1.51	3.02
	CSc50			179.5	2.22	5.30	62.2	1.86	1.50	7.18
	SS50			194.5	2.78	6.60	61.7	1.01	1.44	1.84
	CSa50	II	2.37	191.0	2.65	6.30	63.7	1.63	1.46	3.98
	CSb50			197.5	2.90	7.20	60.2	1.06	1.52	2.54
	CSc50			191.0	2.65	7.30	63.9	2.09	1.51	6.04
	SS50			211.5	3.47	10.20	62.6	0.86	1.43	1.38
	CSa50	III	2.74	195.5	2.82	6.10	61.9	2.07	1.43	3.24
	CSb50			202.5	3.10	7.30	59.3	1.14	1.52	1.84
	CSc50			194.0	2.76	7.30	62.9	2.35	1.51	5.02
	SS50			220.0	3.93	10.60	61.9	1.14	1.42	1.06
	CSa50	IV	3.04	216.0	3.67	10.80	63.3	1.57	1.49	2.36
	CSb50			207.0	3.28	9.50	58.4	0.76	1.51	1.54
	CSc50			202.5	3.10	9.80	63.8	1.50	1.50	3.80
	SS50			218.0	3.75	12.10	61.3	0.91	1.44	0.80
	CSa50	V	3.33	221.0	3.88	11.80	61.8	1.47	1.46	1.56
	CSb50			215.0	3.62	9.30	57.9	1.11	1.52	0.82
	CSc50			208.5	3.35	9.90	62.7	1.45	1.51	2.64
	SS50			223.5	4.00	12.40	60.9	0.86	1.43	0.48
2	CSa45(40)	I	2.00	143.0(134.0)	1.04(0.80)	0.4(0.4)	63.0	1.45	1.49	4.46
	CSb45(40)			172.5(167.5)	1.98(1.81)	3.0(2.0)	59.1	1.06	1.51	3.02
	CSc45(40)			166.0(169.0)	1.76(1.86)	2.6(2.4)	62.2	1.86	1.50	7.18
	SS45(40)			193.5(180.0)	2.74(2.24)	6.3(4.0)	61.7	1.01	1.44	1.84
	Csa45(40)	III	2.74	180.0(171.5)	2.24(1.94)	4.5(3.6)	61.9	2.07	1.46	3.24
	CSb45(40)			212.5(211.5)	3.52(3.47)	9.8(11.0)	59.3	1.14	1.52	1.84
	CSc45(40)			192.0(200.5)	2.69(3.02)	7.7(9.2)	62.9	2.35	1.51	5.02
	SS45(40)			218.0(207.5)	3.75(3.31)	11.7(9.6)	61.9	1.14	1.43	1.06
	CSa45(40)	V	3.33	199.5(207.0)	2.98(3.28)	10.5(10.8)	61.8	1.47	1.43	1.56
	CSb45(40)			215.5(233.5)	3.64(4.45)	11.3(11.9)	57.9	1.11	1.52	0.82
	CSc45(40)			216.5(221.5)	3.69(3.91)	10.8(12.0)	62.7	1.45	1.51	2.64
	SS45(40)			215.0(211.0)	3.69(3.45)	12.0(10.7)	60.9	0.86	1.42	0.48
3	CSa45-5(10/15)	I	2.00	144.5(152.5/154.5)	1.09(1.33/1.39)	1.9(1.1/1.7)	63.0	1.45	1.49	4.46
	CSb45-5(10/15)			184.5(177.5/185.0)	2.40(2.15/2.42)	4.70(4.0/4.8)	59.1	1.06	1.51	3.02
	CSc45-5(10/15)			174.5(179.5/179.5)	2.05(2.22/2.22)	3.7(3.4/3.8)	62.2	1.86	1.50	7.18
	SS45-5(10/15)			202.0(203.0/206.0)	3.08(3.12/3.24)	6.6(7.6/7.9)	61.7	1.01	1.44	1.84
	CSa45-5(10/15)	III	2.74	184.5(177.5/182.0)	2.40(2.15/3.31)	4.7(5.7/6.5)	61.9	2.07	1.46	3.24
	CSb45-5(10/15)			214.0(218.0/221.0)	3.58(3.75/3.88)	10.2(11.0/11.5)	59.3	1.14	1.52	1.84
	CSc45-5(10/15)			201.5(205.5/200.5)	3.06(3.22/3.02)	8.6(8.4/9.0)	62.9	2.35	1.51	5.02
	SS45-5(10/15)			233.0(229.0/225.5)	4.43(4.24/4.08)	11.8(12.0/11.8)	61.9	1.14	1.43	1.06
	CSa45-5(10/15)	V	3.33	200.0(207.5/212.0)	3.00(3.31/3.49)	9.6(10.6/10.1)	61.8	1.47	1.43	1.56
	CSb45-5(10/15)			222.5(231.5/222.0)	3.95(4.36/3.93)	12.3(11.9/12.1)	57.9	1.11	1.52	0.82
	CSc45-5(10/15)			222.5(221.0/226.0)	3.95(3.88/4.11)	12.5(11.3/12.8)	62.7	1.45	1.51	2.64
	SS45-5(10/15)			219.0(231.0/227.5)	3.80(4.34/4.18)	12.1(12.8/13.0)	60.9	0.86	1.42	0.48
4	CSa50-30	Ⅲ	2.74	168.0	1.82	3.8	61.8	1.47	1.43	1.80
	CSb50-30			185.5	2.44	6.2	57.9	1.11	1.52	1.80
	CSc50-30			165.0	1.72	3.2	62.7	1.45	1.51	1.80
	CSa50-50			163.5	1.76	3.5	61.8	1.47	1.43	3.00
	CSb50-50			177.0	2.13	4.5	57.9	1.11	1.52	3.00
	CSc50-50			166.0	1.76	3.1	62.7	1.45	1.51	3.00
	CSa50-70			159.0	1.53	2.7	61.8	1.47	1.43	4.20
	CSb50-70			179.0	2.20	4.6	57.9	1.11	1.52	4.20
	CSc50-70			163.5	1.67	3.2	62.7	1.45	1.51	4.20

The mixing time of the mortar was fixed at 4 min. The mortar flow and mini slump were measured. To allow the influence of the air content on the fluidity to be neglected, antifoaming agent was added for all of the mix proportions.

3. RESULTS AND DISCUSSION

3.1. Relationship between Particle Size Uniformity of Crushed Sand and Fluidity

(1) Influence of Grain Size Distribution

Figure 2 shows the relationship between the fineness modulus and relative flow area ratio for each grain size distribution of experiment 1, and Fig. 3 shows the relationship between the fineness modulus and mini slump. The relative flow area ratio Γ in Fig. 2 is used as an index of self-compacting ability. The formula for calculating the relative flow area ratio is as follows:

$$\Gamma = \frac{(d_1 \times d_2 - d_0^2)}{d_0^2}$$

Where, Γ: relative flow area ratio

$d_1 . d_2$: 15 shots flow [mm]

As shown in Figs. 2 and 3, both the relative flow area ratio and mini slump tended to increase linearly with increasing fineness modulus for all of the fine aggregates. For each fine aggregate, similar tendencies were observed for CSa and CSc. These tendencies have also been reported in previous research [5]. In experiment 1, since the paste volume and fine aggregate volume were kept constant, the grain size composition appeared to influence the fluidity of the mortar. Furthermore, for each grain size distribution, differences were observed in the relative flow area ratio and mini slump when varying with the fineness modulus. This was attributed to the effect of the physical properties and grain shape of the fine aggregates for each grain size distribution. Therefore, as described below, the influence of the physical parameters and particle shape of the fine aggregates, which changed upon grain size adjustment, on the fluidity of the mortar was investigated.

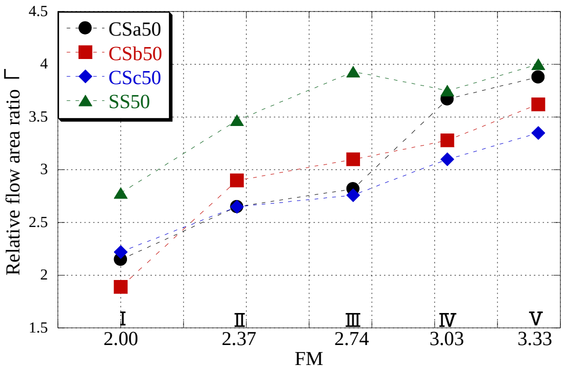

Fig. 2 FM of each particle size distribution and relative flow area ratio

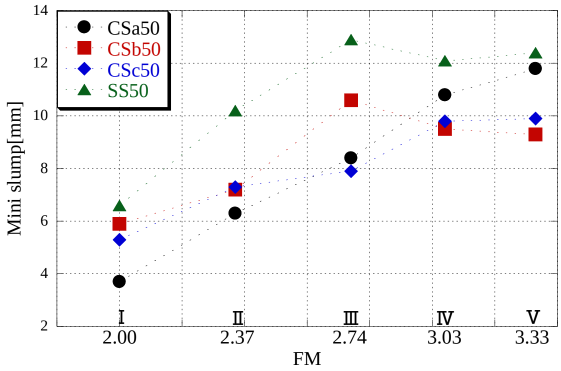

Fig. 3 FM of each particle size distribution and mini slump

(2) Influence of Physical Properties and Grain Shape

Figure 4 shows the relationship between the water absorption and relative flow area ratio for each grain size distribution in experiment 1. The water absorption of each grain size distribution had little influence on the relative flow area ratio. For each grain size distribution, although the water absorption increased, the relative flow area ratio did not change. Furthermore, for each fine aggregate, opposite relation to the above was observed. Therefore, the variation in the fluidity of the mortar with the grain size distribution could not be explained by water absorption.

Figure 5 shows the relationship between the percentage of solid volume and relative flow area ratio for each grain size distribution in experiment 1. There was a tendency for the relative flow area ratio to decrease with increasing percentage of solid volume. A previous study [6] reported that the fluidity improved upon increasing the percentage of solid volume. However, in this study, the percentage of solid volume was found to increase as the fineness modulus decreased, and it seemed that the grain size distribution influenced the fluidity of the mortar more strongly than in the previous study. Furthermore, for each fine aggregate and grain size distribution, the same tendency was observed as for the water absorption.

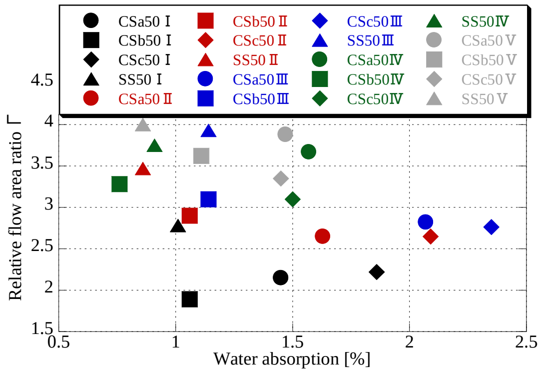

Fig. 4 Water absorption of each particle size distribution and relative flow area ratio

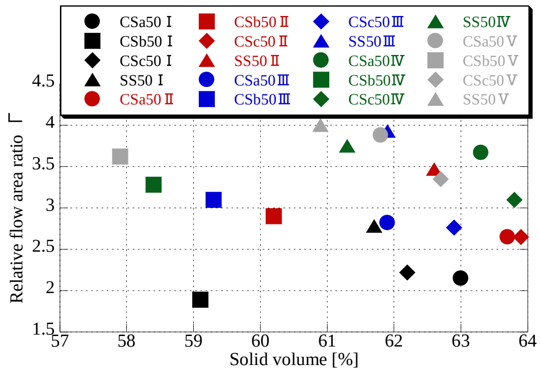

Fig. 5 Solid volume of each particle size distribution and relative flow area ratio

Figure 6 shows the relationship between the shape factor and relative flow area ratio for each grain size distribution in experiment 1. For each fine aggregate, there was a tendency for CSa and SS that the relative flow area ratio increased as the shape factor approached 1.0. As the shape factor became larger for CSb and CSc, the opposite tendency was observed. Overall, SS possessed a favorable grain shape, whereas CSa possessed an unfavorable grain shape (1.2–0.3 mm). Because the shape factor of 5.0–1.2 mm was favorable, it was considered that the shape factor affected the fluidity.

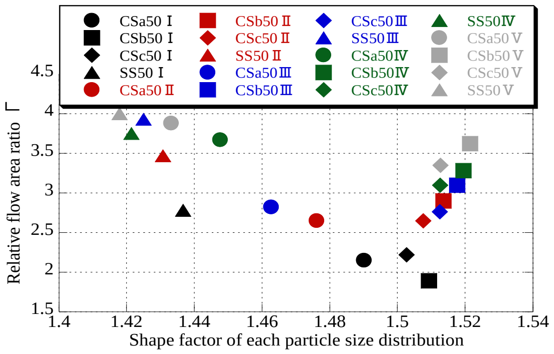

Fig. 6 Shape factor of each particle size distribution and relative flow area ratio

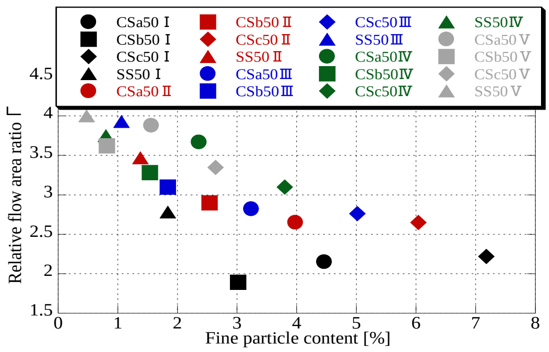

Fig. 7 Fine particle content of each particle size distribution and relative flow area ratio

(3) Influence of fine particle content

In a previous study [7], it was reported that as the specific surface area increased with increasing fine particle content, the fluidity decreased. Figure 7 shows the relationship between the fine particle content and relative flow area ratio for each grain size distribution in experiment 1. Overall, the relative flow area ratio tended to decrease with increasing fine particle content. Furthermore, a similar tendency was confirmed for each fine aggregate, namely, the content ratio of small particles increased as the coarse grain ratio decreased, which was considered to originate from the corresponding increase in the fine particle fraction. Therefore, in this study, it appeared that the fine particle content affected the fluidity of the mortar.

3.2. Relationship between Crushed Sand with Grading Adjustment and Paste Properties

Experiment 1 did not consider the fluidity of the mortar for different paste properties. Figure 8 shows the relationship between the fineness modulus and relative flow area ratio for each grain size composition in experiments 2 and 3, and Fig. 9 shows the relationship between the fineness modulus and the 0-stroke 15-stroke ratio. The formula for calculating the 0-stroke 15-stroke ratio is as follows:

$$\Gamma = \frac{(d_1 \times d_2 - d_3 \times d_4)}{d_3 \times d_4}$$

Where, Γ: 0-stroke 15-stroke ratio

$d_1 . d_2$: 15 shots flow ［mm］

$d_3 . d_4$: 0 shots flow ［mm］

For each grain size composition, the difference in the 0-stroke 15-stroke ratio decreased with increasing fineness modulus for each fine aggregate. Therefore, as the fineness modulus increased, the grain size composition, rather than the grain shape and physical parameters, of the fine aggregate strongly influenced the fluidity. As shown in Fig. 9, when the fineness modulus exceeded 4, the fluidity increased. However, it was confirmed that the deformability of the mortar due to shock became small. The paste properties were also examined. Samples with higher paste viscosity and lower water–cement ratio were more sensitive to the grain size composition. Conversely, samples with lower paste viscosity and higher water–cement ratio were more sensitive to the paste properties. Furthermore, even when fly ash was added, the fluidity improved with increasing fineness modulus. This was the result of the “ball bearing” effect of fly ash. As a representative example, Fig. 10 shows a comparison between with no admixture and mini slump. Therefore, the same trend as with the relative flow area ratio was

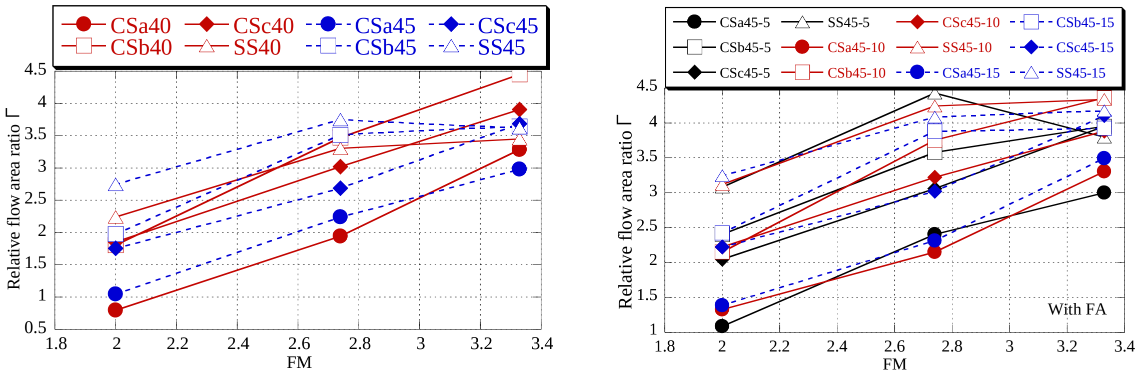

Fig. 8 FM and relative flow area ratio（Left：Exptl.2、Right：Exptl.3）

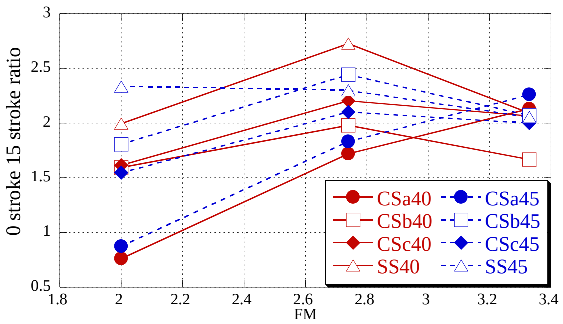

Fig. 9 FM and 0 stroke 15 stroke flow area ratio（Exptl.2）

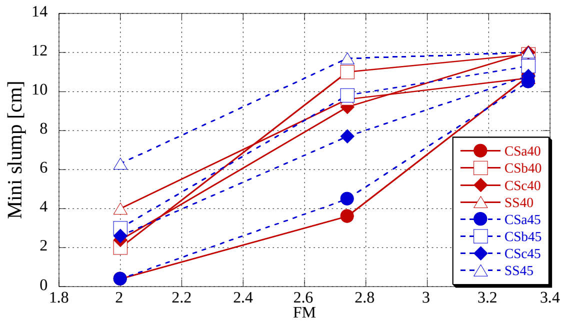

Fig. 10 FM and mini slump（Exptl.2）

observed.

Figures 11 and 12 show the relationship between the fine particle content and relative flow area ratio for each grain size distribution at W/C = 40% and 45% and a fly ash content of 5%. As shown in experiment 1, there was a tendency for the fluidity to decrease with increasing fine particle content for all of the fine aggregates, regardless of the paste properties. Furthermore, as shown in Fig. 13, the mini slump exhibited the same tendency. Therefore, when using the whole amount of crushed sand as the fine aggregate, it was possible to evaluate the fluidity using the fine particle content in the crushed sand, irrespective of the rock type and quality. However, since the fine particle content increased with the adjustment of the grain size composition under the current experimental conditions, it could not be determined whether the fineness modulus or the fine particle content exerted a strong influence on the fluidity. Therefore, it was necessary to investigate the fluidity for the same grain size composition with the same fineness modulus and different fine particle contents.

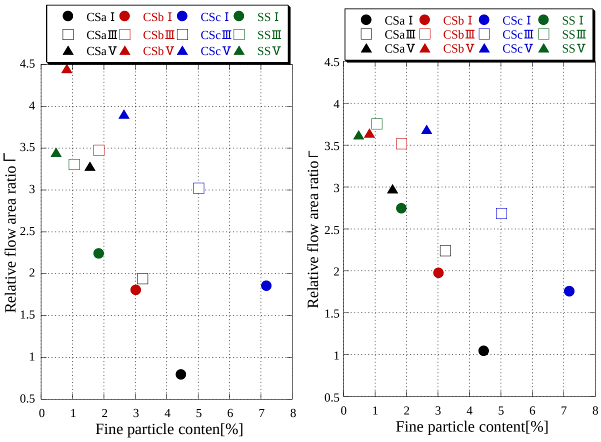

Fig. 11 Fine particle content and relative flow area ratio
(Left：W/C=40%、Right：W/C=45%)
(Exptl.2)

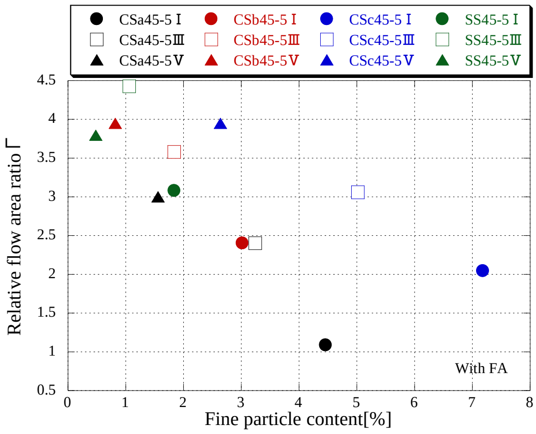

Fig. 12 Fine particle content and relative flow area ratio（FA5%）（Exptl.3）

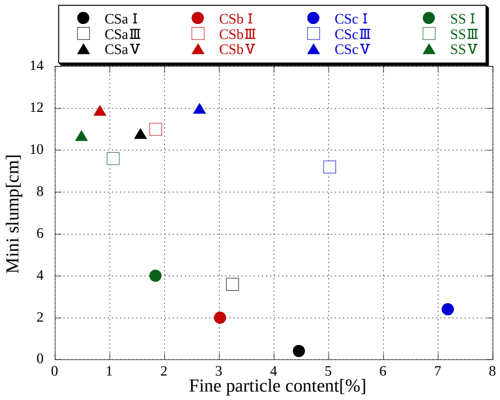

Fig. 13 Fine particle content and mini slump（W/C=45%）（Exptl.2）

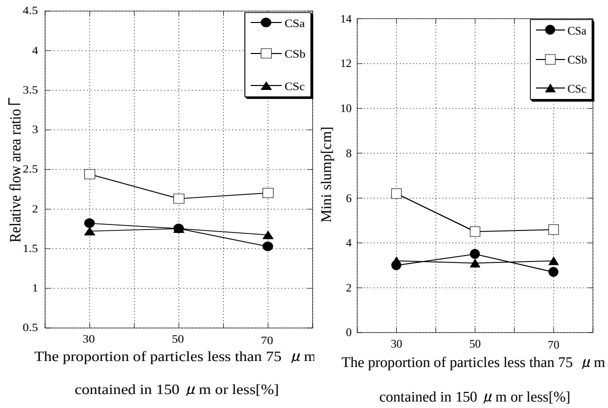

Fig. 14 Mixing ratio（Exptl.4）
（Left：Relative flow area ratio,
Right：Mini slump）

3.3. Influence of Content Ratio of Particles Below 150 μm

Figure 14 shows the relationships of the relative flow area ratio and mini slump with the content ratio of particles less than 75 μm contained out of particles of 150 μm or less. In experiments 1, 2, and 3, the fluidity was found to decrease with increasing content of fine particles below 75 μm. However, for the same fineness modulus, there was no significant change in the relative flow area ratio and mini slump. These results indicate that, under the same conditions of fine aggregate and paste properties, the change in the grain size composition exerted a strong influence on fluidity.

4. CONCLUSIONS

In this study, the parameters of water absorption, percentage of solid volume, and particle shape factor of fine aggregate were found to be unsuitable for evaluating mortar fluidity, which changed depending on the particle size distribution of the crushed sand, and the most suitable parameter was found to be the fineness modulus. In addition, when the fine aggregate volume and paste volume were kept constant, the particle size composition exerted the greatest influence on the flowability of the mortar, so even when crushed sand was used, it was possible to evaluate and predict the fluidity using the fineness modulus. These results are considered important in order to achieve the stable utilization of crushed sand, to investigate mortars with intermediate and high flow areas, and to elucidate the compressive strength properties. Since the current study was performed using mortar, it is necessary to verify the obtained results using concrete in a future study.

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