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A BASIC STUDY ON FLUID PREDICTION OF MORTAR WITH VARIOUS POWDERS

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ABSTRACT: In the field of concrete, Fly ash and crushed stone powder which are by-product powders and limes stone powder are used as admixture materials for concrete from the viewpoint of environmental load. Then we should use by-product powders as materials of the concrete as a substitute of fine aggregate. Therefore, it is necessary to predict fluidity of the concrete with powders in large quantities. In this study, we tried a fluid evaluation of mortar with various by-products powders and a fluid prediction by grasping a fluid tendency of mortar with various powders as a part of fine aggregate, and adopted the thickness of a surplus water film theory and the relative flow area ratio as an evaluation index. We clarified when used by-product powders as a part of fine aggregate, we can use excess water film for an index. But the value of the relative flow area ratio was different because of the same thickness of a surplus water film depending on the kind of the powder. It was thought that the fluidity of mortar was able to predict by applying the correction value proposed by this study in various mixtures that used the by-product powder.

Keywords: Excess water film thickness, Fresh properties, Fly ash, Crashed stone sand

1. INTRODUCTION

In late years, measures to depletion of natural resources and realization of the low-carbon society are problems in the field of Japanese concrete. So, the technique that using by-products powders such as fly ash and crush stone powder or the limestone fine powder as a concrete material is considered as solution to these problems. Therefore, a fluid evaluation and prediction of the concrete using by-product powders are required.

T.C. Powers [1] reported that many researchers have proposed a theoretical mix proportion design method of concrete utilizing an ideal aggregate particle size curve, the theory on dispersion of aggregate and particle interference and the theory such as formulas of various required water content so far. One of these theories is the excess paste theory proposed by C. T. Kennedy [2]. In this theory, concrete is regarded as a two-phase material composed of aggregate and paste, voids between aggregates are filled with paste, and aggregate is dispersed by the existence of surplus paste, so that fluidity is given to fresh concrete. Regarding the possibility of application to concrete formulation design of this theory, Matsushita et al. [3] showed that it was possible to determine the optimum sand-total aggregate ratio with the thickness of the excess paste as an index, but reported that only approximate values could be predicted for unit water content, and it was tried to evaluate fluidity by experiment in mortar. Also, Abe et al. [4] showed that slump of concrete using various aggregate could not be evaluated only by the thickness of excess paste. Then, Matsushita et al. [5] clarified the index which could uniformly evaluate the influence of the fine particle aggregate size, shape, and unit fine aggregate volume on the flow value of mortar. In addition, Teranishi et al. [6] comprehensively evaluated the influence of the particle size distribution of aggregate, the aggregate content and sand-total aggregate ratio on the fluidity of concrete by utilizing the excess paste theory. However, studies utilizing the excess paste theory in consideration of the influence of powder as cement substitute have hardly been carried out so far.

In this study, we confirm a fluid tendency of mortar which mixed several kinds of powders as a substitute for fine aggregate and evaluated fluidity using excess water film thickness (δ) and the relative flow area ratio (Γ).

2. THORY OF MORTOR FLOW

2.1 Excess Water Film Thickness

In this study, excess water thickness was used as an index to show how the composition of mortar and byproduct-based powders influences fluidity [1][2]. The excess water theory of Miyake et al. [7] used in this study considers the liquid phase as water and the solid phase as powder and fine aggregate; the correlation with liquidity was reported, assuming that the excess water forms a uniform water film on each particle. The following formula proposed by Fukuyama [8] was used to calculate the thickness of the excess water film.

$$Wexc = 10^{-2} \cdot (G - Gs) \quad (1)$$

$$\delta = 10^{4} \cdot \frac{Wexc}{Sp + Ss} = 10^{8} \cdot \frac{G - Gs}{Sp + Ss} \quad (2)$$

Refer to "$Wexc$" is excess quantity of water (m^3/mortar m^3), "G" is solid content in aggregate of the thing which mixed fine aggregate with powders (%), "Gs" is the volume of powders and fine aggregate ratio in the mortar volume (%), "Sp" is surface area of powders in mortar $1m^3$ (cm^2/m^3), "Ss" is surface area of fine aggregates in mortar $1m^3$ (m^2/m^3), "δ" is excess water film thickness (μm).

Further, in order to eliminate the influence of particle size distribution, Miyake et al. performed analyses with a dimensionless value δ/d, where δ is found from the excess water film and d is the volume-surface average particle size of the solid. The calculation of δ/d is described below.

$$Acs = \frac{Sp + Ss}{10^{-2} \cdot Gs} = \frac{6 \cdot \pi(10^{-6} \cdot d)^2}{\pi(10^{-6} \cdot d)^3}$$

$$d = 6 \times 10^{4} \cdot \frac{Gs}{Sp + Ss} \quad (3)$$

Refer to "Acs" is mean ratio surface area of cement and fine aggregate per volume (cm^2/m^3), "d" is average particle size of cement and fine aggregate (μm).

It is expressed by equation (4) by dividing equation (2) in equation (3)

$$\frac{\delta}{d} = \frac{G - Gs}{6 \cdot Gs} \quad (4)$$

I found the ratio surface area of fine aggregate in the following equations.

$$Ssu = 6 \cdot \sum \frac{X_i}{100 \cdot a_i} \quad (5)$$

Refer to "Ssu" is the ratio surface area of fine aggregate (mm^2/mm^3), "X_i" is Capacity percentage between sieve opening l_i and l_{i+1} (%), "a_i" is average particle size by the geometric mean between sieve opening l_i and l_{i+1} (mm) $= (l_i \cdot l_{i+1})^{0.5}$.

2.2 The Relative Flow Area Ratio

The relative flow area ratio (Γ) is a thing used for a self-filling-related index, and fluidity is high so that a value is big.

$$\Gamma = \frac{(d_1 \cdot d_2 - d_0^{\,2})}{d_0^{\,2}} \quad (6)$$

Refer to "d_0" is the inside diameter of the lower flow corn, "d_1 and d_2" is I do it with the value that measured the direction that is a right angle in greatest dimension and that of mortar after the transformation.

3. EXPERIMENT PROCEDURES

Used materials showed in table 1. I used fly ash of the prescribed II class equivalency for JIS A 6201, crushed stone powder of the prescribed for JIS A 5041, crushed sand of the prescribed for JIS A 5005. In addition, I kept it more than 24 hours and used these materials for a constant temperature room of 20 degrees Celsius.

Compounding showed in table 2. The admixture-free mixes NS and N-CS were the standard formulations, and the three byproduct components—fly ash powder, limestone fine powder, and crushed stone powder—mixed to a concentration of 5, 7.5, 10 or 15% by volume were used as partial replacement of fine aggregate. In the experiment, mixing was carried out with the formulation in Table 2. The CSPs 10 and 15 are excluded from the formulation table because they could not be mixed with either sea sand or crushed sand. In contrast, FA/LP15-CS, which was also

Table1: Materials

Item	Type	Properties	Mark
Cement	Ordinary portland cement	Density3.16g/cm^3	C
Water	Tap water	-	W
Admixture	Fly ash (JIS Ⅱ class)	Density2.43g/cm^3	FA
		Ignition loss1.67%	
		Blain's specific surfacearea4270cm^2/g	
	Limestone powder	Density2.74g/cm^3	LP
		Blain's specific surfacearea2975cm^2/g	
	Crushed stone powder	Density2.70g/cm^3	CSP
		Blain's specific surfacearea4624cm^2/g	
Fine aggregate	Sea sand	Surface dry density2.59g/cm^3	S
		Water absorption0.76%	
		Blain's specific surfacearea55.9cm^2/g	
		Fineness modulus2.4	
		Solid content61.5%	
	Crushed Sand	Surface dry density2.66g/cm^3	CS
		Water absorption1.96%	
		Blain's specific surfacearea33.6cm^2/g	
		Fineness modulus3.1	
		Solid content57.1%	

Table2: Mix proportions and Experimental Result

Symbol	W/C	W/P	Unit content(kg/m^3)						G(%)	Gs(%)	δ(μm)	Flow(mm)	mini-slump Ms(cm)
	(%)	(%)	W	C	FA	LP	CSP	S (CS)					
N-S30	30	30	280	934	0	0	0	917	70.7	65.0	0.18	142	1.9
N-S40	40	40	280	701	0	0	0	1109	75.8	65.0	0.45	185	6.2
N-S50	50	50	280	560	0	0	0	1223	76.7	65.0	0.60	189	7.6
N-S(CS)60	60	60	280	467	0	0	0	1300(1360)	77.9(78.2)	65(65)	0.79(0.82)	190(189)	7.3(7.7)
N-S70	70	70	280	400	0	0	0	1355	75.9	65.0	0.77	192	6
FA5-S(CS)	60	43	269	449	182	0	0	1157(1211)	75.2(74.1)	66.4(66.4)	0.38(0.33)	204(183)	10(6.2)
FA7.5-S(CS)	60	37	264	440	267	0	0	1090(1140)	74.2(73.8)	67(67)	0.27(0.26)	176(154)	6(3.2)
FA10-S(CS)	60	33	259	432	350	0	0	1025(1072)	72(73.4)	67.6(67.6)	0.15(0.19)	180(152)	5.7(3.2)
FA15-S(CS)	60	27	250	416	505	0	0	902(944)	71.3	68.8	0.07	175	6.6
LP5-S(CS)	60	41	269	449	0	207	0	1157(1211)	73.4(73.4)	66.4(66.4)	0.32(0.32)	184(167)	4.8(3.6)
LP7.5-S(CS)	60	35	264	440	0	305	0	1090(1140)	72.6(71.0)	67(67)	0.23(0.17)	166(163)	3.4(3.1)
LP10-S(CS)	60	31	259	432	0	399	0	1025(1072)	70.7(69.1)	67.6(67.6)	0.12(0.06)	150(142)	1.7(2.0)
LP15-S(CS)	60	25	250	416	0	576	0	902(944)	70.6	68.8	0.06	121	0.4
CSP5-S(CS)	60	41	269	449	0	0	206	1157(1211)	74.4(75.3)	66.4(66.4)	0.32	153	2.7(2.0)
CSP7.5-S(CS)	60	36	264	440	0	0	303	1090(1140)	74.3(73.8)	67(67)	0.25	119	0.6(0.6)

impossible to mix, is listed in the formulation table because it could be mixed with sea sand. As for the notation method of the compounding sign, "FA" "LP" "CSP" shows a use powders name followed by the written number shows a substitution rate.

In addition, the "S" "CS" of the end expresses sand name which I used, and the number of the end of the standard compounding expresses a water cement ratio. "P" in the compounding list means powders, and "W/P" expresses water powders mass ratio. I worked it out using a mortar mixer and mixed mortar. I measured a mortar flow and mini-slump, the solid content in aggregate of the thing which mixed fine aggregate with powders. For deriving the solid content concentration in the mixture, a steel mortar form (⌀50 mm, height 100 mm) was filled with the mix in a mixer and tapped using a flow table of once per second, and then the volume was derived from the sinking depth of the material in the container; this volume is divided by the container volume to derive the solid content in aggregate. The number for tapping was set at 500 times on the basis of a preliminary test.

4. RESULT AND DISCUSSION

4.1 Excess Water Film Thickness And Fluidity

Figs.1,2 showed a water film thickness and relations of the relative flow area ratio, mini-slump. In both Figs. 1 and 2, there was a tendency in all formulations for the relative flow area and the mini-slump to increase as the excessive water film became thicker. This is taken to indicate that the change in the excess water film thickness influences the fresh state, such as the relative flow area and the mini-slump of mortar. However, when comparing the powders in Figs. 1 and 2, it can be seen that there is a large difference in relative flow area and mini-slump between them, even when the water film

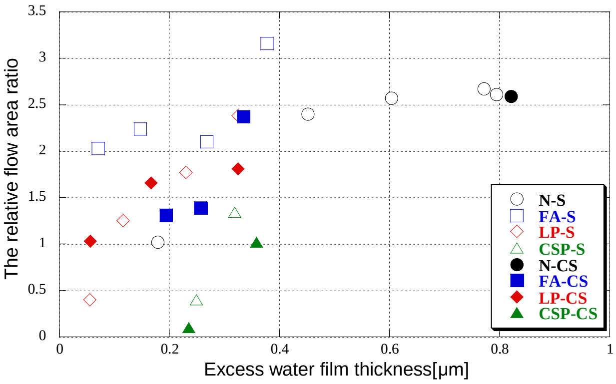

Fig.1 Water film thickness and Relative flow area ratio

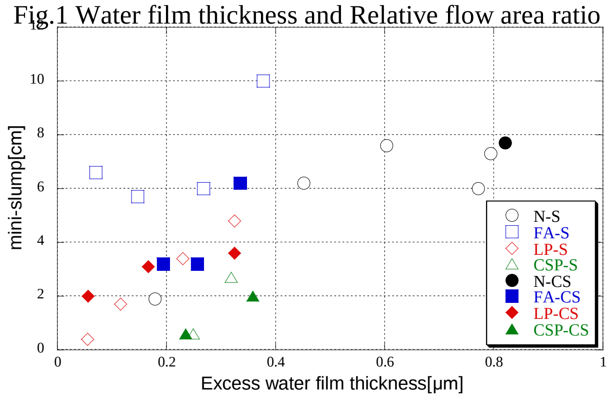

Fig.2 Water film thickness and Mini-slump

thicknesses are the same. This seems to indicate the influence of the properties of the powders. A possible influencing factor is the difference in particle shape. Whereas fly ash has a smooth spherical shape, it is reported that for crushed powder with fine surface irregularities, the BET-specific surface area is larger than for other types of powders [8]. That is, we assume that the difference in particle shape influenced fluidity. Also, in the process using fly ash, the relative flow area and mini-slump were differed sharply between sea sand

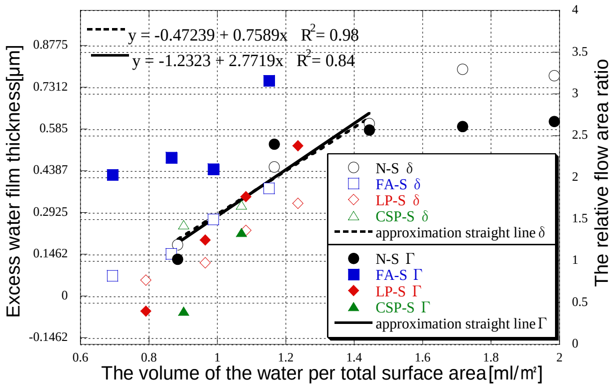

Fig.3 volume of the water per total surface area and δ ,Γ

and crushed sand, while in the standard formulation, little fine aggregate choice had little influence.

5. FLUID PREDICTION

5.1 Examination By Excess Water Film Thickness

From the results of preceding section, it can be inferred that it is difficult to predict fluidity from only water film thickness when comparing between processes that use different powders. We consider whether it is possible to predict the fluidity using water film thickness by applying a correction value for each powder, assuming that the way the unique properties of each powder influences fluidity can be evaluated from its water film thickness. To do so, we need an intermediary indicator that correlates with both water film thickness and relative flow area. It has been confirmed in a previous study [7] that the unit amount of water relative to the total surface area of the powder is correlated with fluidity. In this, Water volume per total surface area was used as an index to evaluate both water film thickness and relative flow area. Even within this experiment, in each powder, the water volume per total surface area was correlated with the ratio between water film thickness and relative flow area, as shown in Fig. 3.

In order to evaluate the characteristics peculiar to the powder, the y-axis was adjusted on the graph so that the reference formulation is approximately a straight line. Figure 3 shows the fitted curves. Here, a linear approximation was found for the cases N-S 30, 40, and 50; in these, a linear relationship was clearly observed. It is assumed from this that the differences between the curves of water film thickness and relative flow area for each powder (Fig. 3) are due to the characteristics peculiar to the powder. Therefore, approximately straight lines were drawn for the curves of water film thickness and relative flow area for the powders, and the correction value was obtained by averaging the difference between the straight lines and converting it into water film thickness; the water film thickness

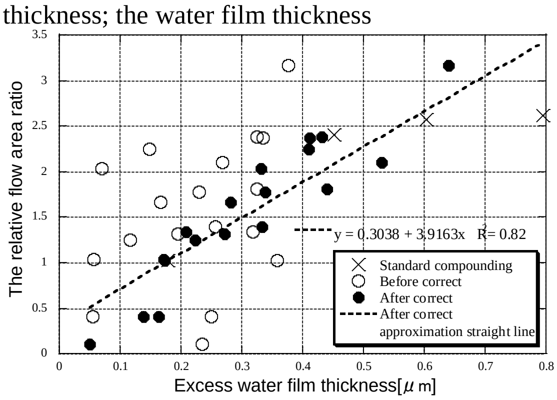

Fig.4 Before and after correct- δ , Γ

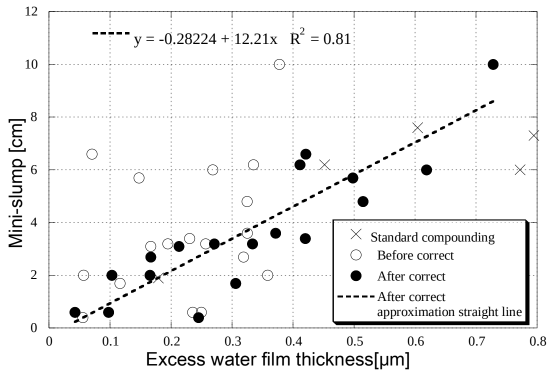

Fig.5 Before and after correct- δ , Mini-slump

calculated using the correction value was taken as the corrected water film thickness.

A similar technique was also used for the mini-slump. By correcting the water film thickness for each powder using the correction value, it was possible to express the relation between water film thickness and relative flow area and mini-slump as a straight line. In other words, it is assumed that fluidity can be approximately evaluated and predicted using both correction values and straight-line approximations, as seen in Figs. 4 and 5. Looking at the correction values in Table 3, significant differences were observed according to powder. The correction value of fly ash is larger than that of other types of powders. This seems to be due to the ball-bearing effect caused by the smooth and round shape of the fly ash, which improves the fluidity such that the fluidity becomes theoretically large against the water film thickness. In contrast, with the crushed powder, the correction value for the relative flow area and mini slump is negative. This is interpreted as being because fine irregularities on the particle surface of the crushed stone powder decrease the fluidity, and so the fluidity becomes theoretically small against the water film thickness.

5.2 Examination by δ/d

In comparison with the excess water film thickness, which is derived by dividing excess water volume by total surface area, and so depends on the surface area, the index *δ/d* proposed by Miyake et al. [7] excludes the influence of the particle size distribution and is more concise than the water film thickness, which does not include the surface area in the derivation. Therefore, a consideration similar to that made for water film thickness was also made for the index *δ/d*. Before the correction, the relative flow area ratio and mini-slump increased with *δ/d*, as in the case of the water film thickness, but when comparing different powders for the same value of *δ/d*, variations were observed from powder to powder. However, we could derive a linear relationship between *δ/d* and relative flow area and mini-slump through corrections. Also, looking at the correction values in Table 4, the correction value of fly ash was large, and the correction value of the crushed powder was negative, a result similar to the result for water film thickness; therefore, δ/d seems adequate to use as an index of fluidity.

Table3: Water film correction value

Powder	Fine aggregate	Water film correction value Γ(μm)	Water film correction value Ms(μm)
FA	S	2.62×10^{-2}	3.50×10^{-2}
	CS	7.72×10^{-3}	7.65×10^{-3}
LP	S	1.07×10^{-2}	1.90×10^{-2}
	CS	1.12×10^{-2}	4.62×10^{-3}
CSP	S	-1.12×10^{-2}	-1.52×10^{-2}
	CS	-1.85×10^{-2}	-1.93×10^{-2}

6. CONCLUSION

1) Even when a byproduct-based powder is mixed as a water film thickness as an index of fluidity, though the properties of the powders must be taken into account when doing so.

2) The correction value was given as a converted water film thickness to indicate the influence of the characteristics of the powder on the fluidity, and the corrected water film was obtained by adding the correction value to the theoretical water film thickness. By using the corrected value for the water film, the relation the between corrected water film and relative flow area and mini-slump, which serves as an index of fluidity, can be given by a straight line. From this, it seems that the liquidity can be approximately evaluated and predicted simply by using water film thickness, even for a process using byproduct-based powders.

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Table4: δ /d correction value

Powder	Fine aggregate	δ/dcorrection value Γ (μm)	δ/dcorrection value Ms(μm)
FA	S	1.62×10^{-2}	1.83×10^{-2}
	CS	3.59×10^{-3}	2.80×10^{-3}
LP	S	6.37×10^{-3}	8.50×10^{-4}
	CS	7.46×10^{-3}	2.76×10^{-3}
CSP	S	-8.71×10^{-3}	-7.59×10^{-3}
	CS	-1.30×10^{-2}	-1.37×10^{-2}

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