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- Technical Paper -

NONUNIFORMITY OF FRESH CONCRETE RESULTING FROM BLEEDING

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ABSTRACT
Because of the bleeding and the settlement of aggregate particles, hardened concrete becomes not uniform. The evaluation of the non-uniformity is important for understanding the properties of hardened concrete. In order to estimate the concrete's non-uniformity through the measurement of bleeding capacity, in this study a non-destructive measuring method of water-cement ratio distribution of concrete was firstly developed, following by a series of experiments to examine the relationships between the bleeding capacity (B_c) and the segregation degree (S_i), standard deviation (σ_{wc}) of actual water-cement ratio (W/C) of freshly mixed mortar and concrete. The experimental results indicate that actual W/C in the upper zone of concrete is larger than in the middle zone, but in the lower zone the actual W/C is smaller. The S_i and the σ_{wc} are greatly related to the Bc. With the increase of the B_c, the S_i and the σ_{wc} increase.
Keywords: bleeding capacity, fresh concrete, segregation degree, water-cement ratio distribution

1. INTRODUCTION

The bleeding is a rising phenomenon of mixing water of cementitious materials in fresh state. Bleed water may contribute to preventing concrete from drying out and plastic cracks. However, excessive bleeding gives bad effects on mechanical properties and durability of concrete[1], [2]. Water-cement ratio (W/C), which affects definitely the internal structure and properties of hardened concrete, greatly changes in vertical direction due to water movement after cast. Fig. 1 shows the distribution of actual water-cement ratio of two columns, 150 minites later after construction, which were cast up to 200cm height with two types of concetes with the slump of 8cm, and 21cm, repectively [3]. As shown in this figure, the lower the section of column, the smaller the actual water-cement ratio of concrete on it. The variation of compressive strength in vertical direction shown in Fig.2 would be explained by the unevenness of W/C caused by the bleeding [4].

The bleeding is resulted from excessive pore water pressure[5]. In fresh concrete, the weight of solid particle is supported by adjacent paticles that contact with it. If particle interlocking is not enough tight to support the weight of solid paiticles, the unsupported weigth is applied to the pore water to result in an excessive pore water pressure. The particles that are not completely supported by other particles move gradually to their stable positions. With the settlement of solid patticles, excessive pore water pressure decreases gradually, and the bleeding comes to end eventually. Hence, the bleeding is one of segregation behaviors accompanying with settlement of solid particles. As shown in Fig.3, the lower the position, the larger the concrete's mass of unit volume and the coarse aggregate content [6].

The principle of the Japanese Building Standards Act has been changed from the specification-based design to the performance-based design. This change makes it easy to utilize new material and construction technologies in building, but it requests to establish

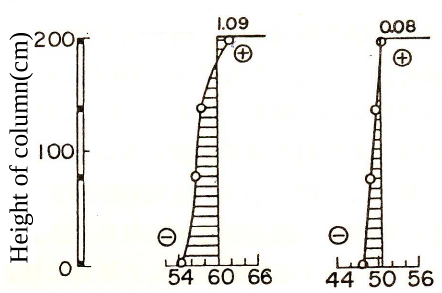

Fig.1 W/C distribution of concrete column 150 min. later after cast [3]

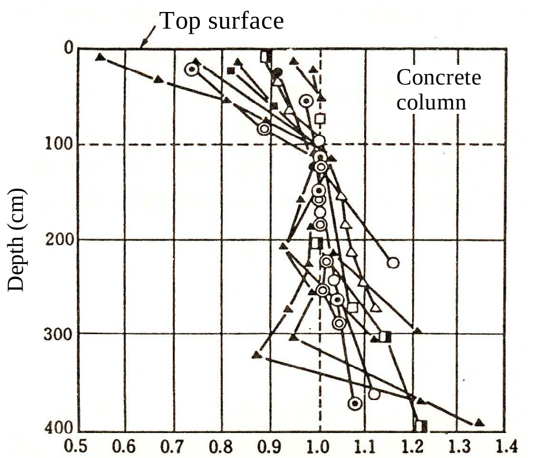

Fig.2 Variation of compressive strength of ordinary concrete column in vertical direction [4]

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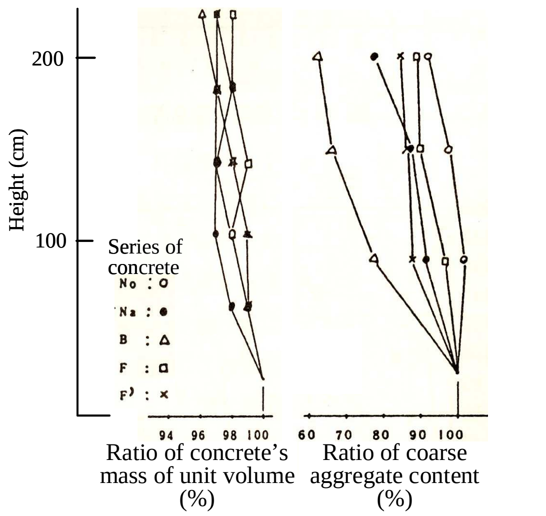

Fig.3 Variation of the mass of unit volume and the coarse aggregate content of placed concretes with height [6]

performance inspection technology for structural concrete. The authors already proposed a method to estimate the final bleeding capacity of concrete placed by vibration in construction site [7]. In this study, we aim to investigate the relationships between the bleeding capacity and the segregation index, the unevenness of W/C of concrete in order to develop a method to evaluate the non-uniformity of hardened concrete from the bleeding capacity. The segregation index is defined as a standard deviation of the concrete's density in the vertical direction. The density of concrete in each zone is estimated by using a γ-ray density meter. The W/C distribution after the bleeding is calculated on the basis of the density estimation.

2. EXPERIMENTAL PROGRAM

2.1 Mortars and Concretes Used

The concretes and mortars used in this study were prepared with ordinary portland cement, sea sand, and crushed stone. The physical properties of sea sand and crushed stone are shown in Table 1. One kind of retardation-type AE super-plasticizer (SP) was also used in the concretes and mortars. The mix proportions of the mortars and concretes are shown in Table 2. For making the mortar and concrete to have different fluidities and viscosities, the water-cement ratio, water content, sand-aggregate volume ratio, and SP content, etc. were set to be different from series.

Table 1 Physical property of the used aggregates

Property	Sea sand	Crushed stone
Density in water-saturated state (g/cm^3)	2.60	2.73
Water absorption ratio (%)	1.04	0.47
Fineness modulus	2.61	6.56
Maximum size (mm)	5	20

The mixing procedure of the mortar and concrete was as follows. Firstly, the fine aggregate and the cement were mixed for 60 seconds by a forced-mixing type mixer. Then mixed for 60 seconds to get the mortar after adding the water and the AE super-plasticizer, In the case of concrete, further added the coarse aggregate and mixed for 60 seconds. The slumps of C1 and C2 were 16.0 cm and 21.5cm, and the air contents were 4.6 % and 4.5%, respectively.

2.2 Experimental Method and Equipments

Freshly mixed concrete or mortar was filled into a vinyl chloride-made cylindrical container with 200mm of diameter up to 200mm high. For investigating the effect of vibrating time on the relationship between bleeding capacity and non-uniformity of concrete or mortar, the sample was vibrated by a rod- type vibrator for different times (0s, 5s, 10s, 30s).

After the samples were prepared, at intervals of 30 minutes we measured the density of the sample of each zone in the cylindrical container using a γ-ray density meter, following by sucking up bleed water with a pipette and further calculating the bleeding capacity (B_c, cm^3/cm^2).

The equipment is shown in Fig 4. The γ-ray density meter consists of a γ-ray source (three 60Co 3.7MBq sealed into a stainless steel capsule) and a detector (NaI (TI) scintillation, the size of window is 20mm height and 50mm width) that were placed on a elevator driven by a pulse motor to move up and down, γ-ray count, as well as control system of pulse motor,

Table 2 Mix proportions of the used mortars and concretes

Series		W/C (%)	Unit mass (kg/m^3)					ρ (g/cm^3)
			W	*C*	*S*	*G*	*SP* (C×%, by mass)	
Mortar	M1	0.45	310	689	1097	-	0.55	2.10
	M2	0.57	360	632	1015	-	0.55	2.01
	M3	0.53	348	657	1026	-	0.50	2.03
	M4	0.42	295	702	1125	-	0.55	2.13
	M5	0.49	325	663	1080	-	0.25	2.07
	M6	0.57	350	614	1055	-	0.00	2.20
Concrete	C1	0.42	160	381	719	1070	0.80	2.33
	C2	0.56	185	330	696		0.50	2.28

[Notes] *W/C*: Water-cement ratio; *s/a*: Sand-aggregate volume ratio; *W, C, S,* and *G*: Mass of water, cement, sand, and crushed stone in 1m^3 concrete, respectively (kg); *Sp*: Retardation-type AE super-plasticizer.

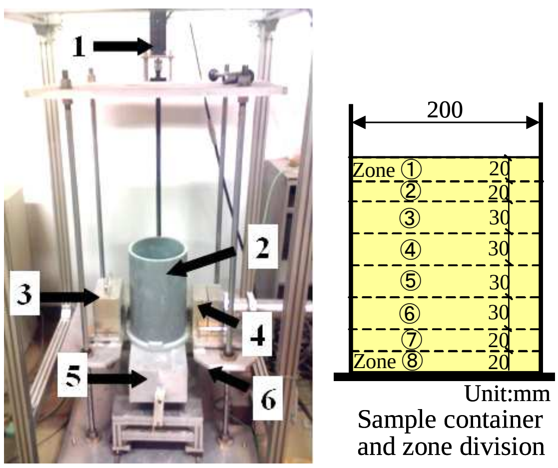

Fig.4 The experimental equipment:
(1) Pulse motor, (2) Specimen, (3) γ-ray source, (4) γ-ray detector, (5) Pedestal, (6) Elevator.

etc. The cylindrical container was located on a pedestal between the γ-ray source and the detector.

When γ-rays emitted from the γ-ray source pass through a substance, only some of them reach to the detector, others escape to other directions, or are desorbed by the substance. The greater the density of substance, the fewer the γ-rays detected. The count of detected γ-rays decreases exponentially with the density of substance. By this method, the local measurement of sample's density becomes possible and quickly. Moving the γ-ray density meter up and down can measure continuously the density of any position, but for guaranteeing the measurement decision, we selected 8 positions in vertical direction to measure. At each measuring point, the density meter stopped for 60s. The measuring result of each point represents the density of each zone. The division of zones is shown in Fig.4.

As stated above, escaping γ-rays can't be directly detected, but part of them may return to the detector due to the reflection of wall, or articles around the density meter. Therefore, even if the γ-ray counts at different points are the same, the densities of the substances at the points must not be equal. Density estimation equations should be given for each measuring point.

Due to the material segregation including bleeding, settlement of solid particles, the density of mortar or concrete varies with position in vertical direction. Li, et al. proposed to use the standard deviation of density of fresh concrete to express its segregation degree [8], as shown in Eq.(1), called Density Deviation Method.

$$S_i = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(\rho_i - \rho_m)^2} \tag{1}$$

where S_i is segregation index, n is number of sample zones, ρ_i is density in each sample zone, ρ_m is mean density of sample in all zones.

We used four kinds of homogeneous materials with known densities or mass of unit volume: water (1.029g/cm^3), Toyoura dry sand (1570kg/m^3), mixture of sodium silicate and plaster (2.084g/cm^3), and mixture of plaster and sand (2.089g/cm^3) as calibration materials. The γ-rays passed through the four kinds of calibration materials at 8 zones were detected, respectively, and then regression analyses were performed for the 8 zones about the exponential relationship between density and γ-ray count ratio R_p. Obtained estimation equations of density for 8 zones are shown in Table 3. By these equations, we can estimate the density distribution of any substance in vertical direction.

We used the estimation equations of density to calculate the densities of four kinds of calibration materials. The errors between calculating and real densities are shown in Fig.5. The real densities of the uniform calibration materials were known and didn't vary with the zones.

3. Estimating method of water-cement variation

As stated above, the bleeding occurs in company with the settlement of solid particles. Due to the material segregation, the water content and the aggregate content

Table 3 Estimation Equation of Density

Range of sample zone (mm)	Estimation equation of density	Coefficient of determination
① 180~200	ρ_1=(ln$R_{\rho1}$-1.865)/-0.563	0.9972
② 160~180	ρ_2=(ln$R_{\rho2}$-1.928)/-0.577	1.0000
③ 130~160	ρ_3=(ln$R_{\rho3}$-1.935)/-0.562	1.0000
④ 100~130	ρ_4=(ln$R_{\rho4}$-1.951)/-0.566	0.9996
⑤ 70~100	ρ_5=(ln$R_{\rho5}$-1.947)/-0.563	0.9997
⑥ 40~70	ρ_6=(ln$R_{\rho6}$-1.959)/-0.569	0.9996
⑦ 20~40	ρ_7=(ln$R_{\rho7}$-1.961)/-0.569	0.9990
⑧ 0~20	ρ_8=(ln$R_{\rho8}$-1.953)/-0.547	0.9971

[Notes] ρ_i: estimated density of substance in zone i, $R_{\rho i}$: count ratio of γ-rays, being equal to (γ_d-γ_b)/γ_s, γ_d: count of the detected γ-rays by the γ-ray detector, γ_b: count of the γ-rays coming from surrounding articles, and γ_s: count of the γ-rays emitting from the γ-ray resource.

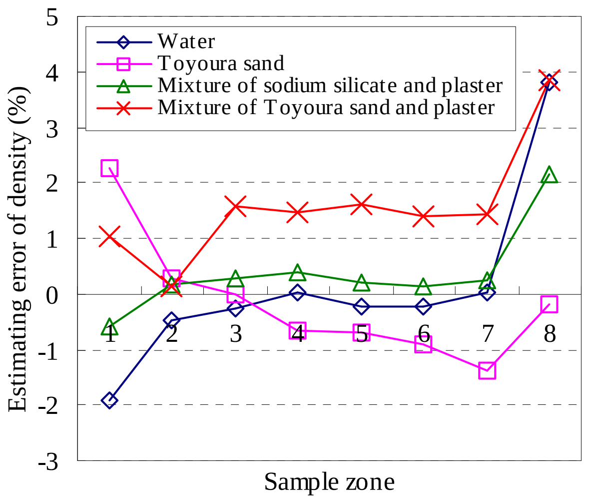

Fig.5 Estimating error of density using γ-ray density meter

become to not be consistent in vertical direction. It is considered that the change in volume of water in zone i is equal to that of fine or coarse aggregate, as shown in the second equation of Eq.(2) and Eq.(3), because cement particles' sedimentation is less and can be ignored. Eq.(2) and Eq.(3) show the mass equation of zone i in mortar and concrete after the bleeding. In the case of mortar, we ignored the cement content's change in the vertical direction, and in the case of concrete we supposed the cement and fine aggregate contents don't vary with the sample zone.

$$\begin{aligned} V_i\rho_i &= (V_{wi} + \Delta V_{wi})\rho_w + (V_{si} - \Delta V_{si})\rho_s + V_{ci}\rho_c \\ \Delta V_{wi} &= \Delta V_{si} \end{aligned} \tag{2}$$

$$\begin{aligned} V_i\rho_i &= (V_{wi} + \Delta V_{wi})\rho_w + (V_{gi} - \Delta V_{gi})\rho_g + V_{ci}\rho_c + V_{si}\rho_s \\ \Delta V_{wi} &= \Delta V_{gi} \end{aligned} \tag{3}$$

where V_{wi}, V_{ci}, V_{si}, and V_{gi} are respectively the volume of water, cement, fine aggregate, and coarse aggregate in zone i with the volume V_i (=1m^3) before the bleeding but the compaction effect of the bleeding is considered; ΔV_{wi}, ΔV_{si}, and ΔV_{gi} are respectively the volume change of water, fine aggregate, and coarse aggregate in zone i due to segregation; ρ_i is estimated density of sample in zone i; ρ_w, ρ_c, ρ_s, and ρ_g, are respectively density of water, cement, fine aggregate, and coarse aggregate.

Because part of air in the sample would escape during the bleeding, the V_{wi}, V_{ci}, V_{si}, and V_{gi} become greater than those before the bleeding. A coefficient α was used to take this compaction effect into account, as shown in Eq.(4). We ignored the variation of α in vertical direction.

$$V_{wi} = \alpha V_w,\ V_{ci} = \alpha V_c,\ V_{si} = \alpha V_s,\ V_{gi} = \alpha V_g \qquad (4)$$

where α is a ratio of mean density of concrete or mortar after to before the bleeding, and V_w, V_c, V_s, and V_g are respectively the volumes of water, cement, fine aggregate, and coarse aggregate in 1m^3 sample, which are known from the mix proportions.

Substituting Eq.(4) into Eq.(2) and Eq.(3), the volume change of water ΔV_{wi} in zone i can be obtained, as shown in Eq.(5).

$$\text{Mortar:}\quad \Delta V_{wi} = \frac{\alpha(V_w\rho_w + V_c\rho_c + V_s\rho_s) - V_i\rho_i}{\rho_s - 1}$$

Concrete:

$$\Delta V_{wi} = \frac{\alpha(V_w\rho_w + V_c\rho_c + V_s\rho_s + V_g\rho_g) - V_i\rho_i}{\rho_g - 1} \qquad (5)$$

Hence, the water-cement ratio $(W/C)_i$ in zone i can be calculated based on Eq.(5), as shown in Eq.(6).

$$(W/C)_i = \frac{(\alpha V_w + \Delta V_{wi})\rho_w}{\alpha V_c \rho_c} \qquad (6)$$

The standard deviation (σ_{wc}) of water-cement ratios of 8 zones is calculated by Eq.(7).

$$\sigma_{wc} = \sqrt{\frac{1}{7}\sum_{i=1}^{8}[(W/C)_i - (W/C)_m]^2} \qquad (7)$$

where $(W/C)_m$ is mean W/C of 8 sample zones.

4. Results and Discussion

4.1 Segregation degree and W/C distribution

Due to limitations of space, Fig. 6 shows the estimating results of the density at different heights for only three series of mortar and two series of concrete. The vibration times applied to the samples were 0s, 10s, and 30s, respectively. As shown in Fig.6, the density at the top zone is smaller. Except series M4 and C1, the lower the sample zone, the greater the density of mortar or concrete no matter how long the vibration time was. Series M4 and C1 had smaller W/C, their bleeding capacities were smaller. This maybe is the reason why the relationship between sample's height and density is in disorder. Because of the compaction of vibration and the bleeding, the estimated densities are greater than the initial densities shown in Table. 2.

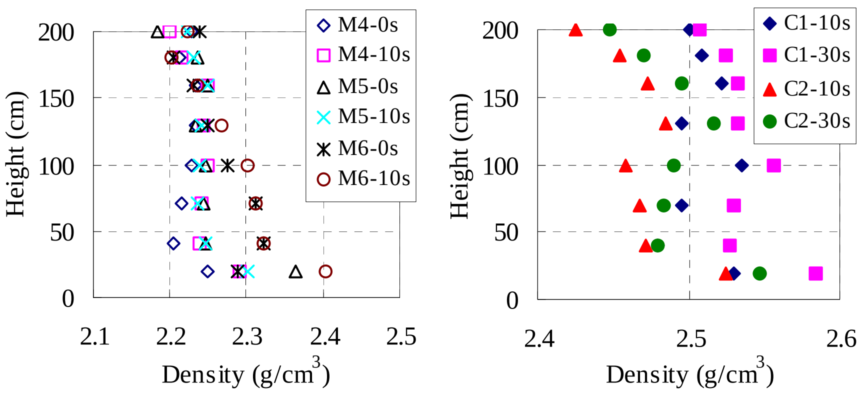

Fig.6 Examples of test results of variation of density with height

Based on the estimation results of density and Eq.(5)~(6), the W/C distributions in the vertical direction were estimated for all the samples. Fig.7 shows some of the results. As shown in this figure, because of the bleeding, the W/Cs of the mortars and concretes in the upper zones higher than 150cm were larger, the W/Cs in the zones lower than 50cm were smaller, but in the middle zones (50~150cm), the W/Cs didn't almost change with the height. Compared with the C2 that had a relative larger W/C, the variation of W/C of C1 was greatly affected by the vibration time. This is maybe because even if the C2 was not vibrated, it bled greatly. For the mortars, the variation degree of W/C in the upper and lower zones were different from the vibration time, but a consistent tendency of the vibration time's influence can't be found. This is maybe because these mortars with larger W/C had greater bleeding capacities, and the difference caused by the vibration time was too small.

4.2 S_i-B_c relationship

Fig.8 indicates the relationship between segregation indexes S_i and bleeding capacities B_c of series M4, M6, C1, and C2. As shown in this figure, except series C1, there is a close correlation between the S_i and the B_c. The greater the B_c, the larger the S_i. Maybe because of the bleeding capacity of series C1 with a smaller W/C was a little, the change of density resulted from the bleeding was so smaller that it couldn't be properly estimated due to the existence of the estimation error of density. According to this result, the segregation degree of placed concrete would be estimated through its final bleeding capacity.

4.3 σ_{wc} - B_c relationship

Fig.9 shows the relationship between the standard deviation of W/C (σ_{wc}) and the bleeding capacity for the mortars and the concretes. We can see from this figure that the greater the B_c when the bleeding capacity was more than 0.04 cm^3/cm^2, the larger the σ_{wc}. The relationship between the σ_{wc} and the B_c is roughly linear. This correlation could not be observed from series C1. Because the C1 had a smaller bleeding capacity (<0.03 cm^3/cm^2) as shown in Fig.8, the change of density in vertical direction was smaller, and thus the estimation error of density makes the calculation of W/C of each sample zone inaccurate. According to this experimental result, when the bleeding capacity was more than 0.04 cm^3/cm^2, the standard deviation of W/C of concrete, which is useful information to evaluate the heterogeneity, would be estimated through the measurement of bleeding capacity.

5. Conclusions

In order to evaluate non-uniformity of concrete, in this study, a non-destructive measuring method of water-cement ratio distribution of concrete was developed, following by a series of experiments to examine the relationships between the bleeding capacity (B_c) and the segregation degree, standard deviation (σ_{wc}) of actual W/C of freshly mixed mortar and concrete. Main conclusions are as follows:

(1) The actual W/C of placed concrete is inconsistent in vertical direction. The W/C in the upper zone is greater than in the middle zone, conversely, the W/C in the lower sample zone is smaller.

(2) The bleeding capacity is greatly related to the segregation degree of fresh concrete regardless of vibration time. When the bleeding capacity is more than 0.04cm^3/cm^2, the segregation index, evaluated by the density deviation method, increases linearly with the bleeding capacity.

(3) There is a close correlation between the bleeding capacity and the standard deviation of W/C of fresh concrete. The greater the B_c, the greater the σ_{wc}, and the closer the correlation between B_c and σ_{wc}. In case that the bleeding capacity is more than 0.04cm^3/cm^2, the estimating result of σ_{wc} increases linearly with the B_c.

One of future works is to investigate the effect of sample's size on the σ_{wc}-B_c relationship.

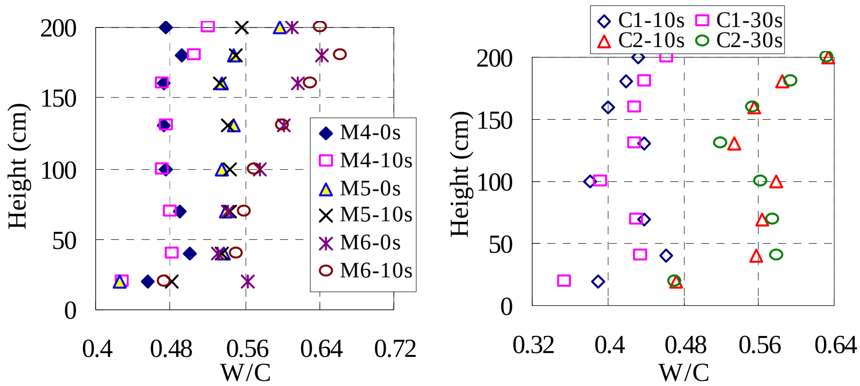

Fig.7 Examples of test results of W/C distribution in the vertical direction

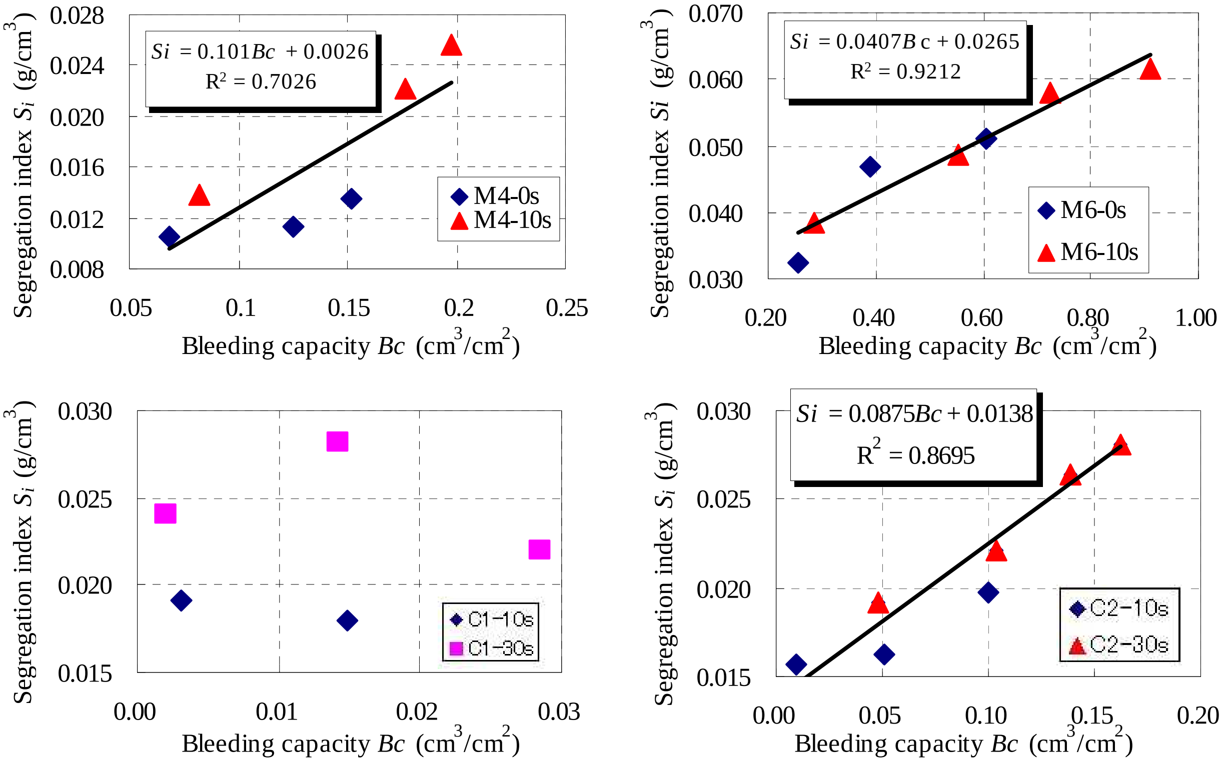

Fig. 8 Relationship between Segregation degree and bleeding capacity

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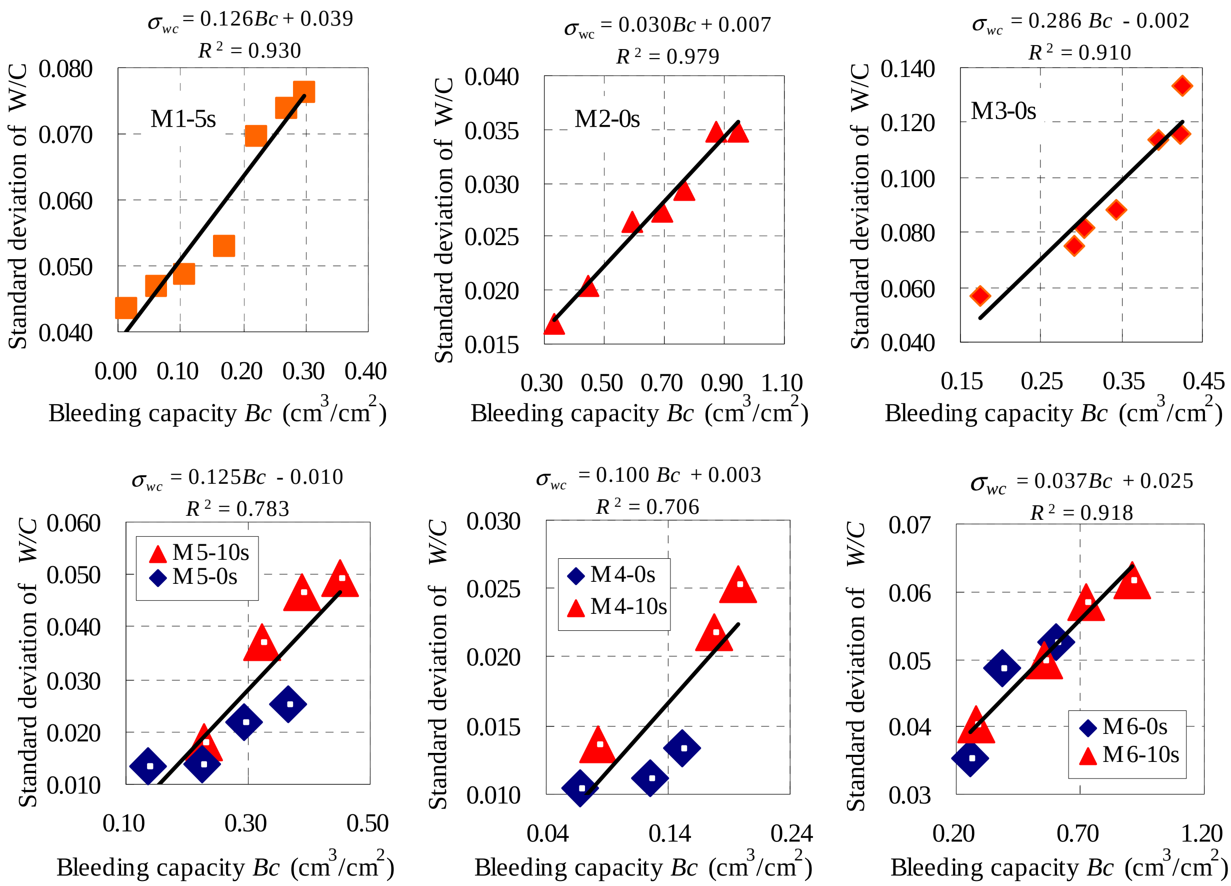

Fig. 9 (a) Relationship between the standard deviation of W/C and bleeding capacity (Mortar)

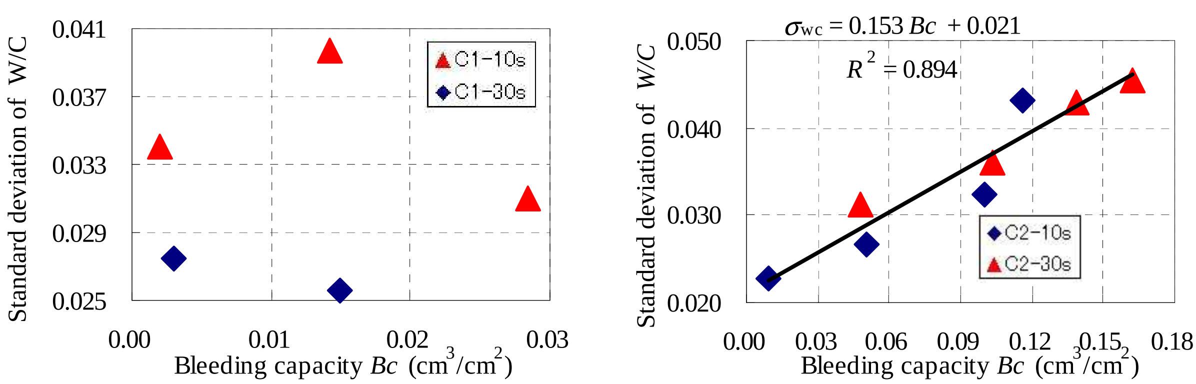

Fig. 9(b) Relationship between the standard deviation of W/C and the bleeding capacity (Concrete)