Experimental Investigations on Bleeding of Fly Ash Concrete

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Abstract

This article outlines the experimental studies on bleeding of fly ash concrete. Bleeding is a form of segregation occurring from rising of some water in the mix to the surface of freshly placed concrete. Bleeding in concrete causes low abrasive resistance and high porosity of the top surface of concrete. This experimental program was designed to clarify the mechanisms of bleeding of fly ash concrete. The mix proportion of concrete was designed based on variation of ratio of paste volume to void volume of aggregate phase, water to binder ratio, type and replacement percentage of fly ash in order to investigate the effect of these parameters on bleeding. Moreover, the amount of free water and effective contact surface area of solid particles were computed and investigated for their effects on bleeding.

1. Introduction

Properties of fresh concrete are important for durability of concrete in long term state. One of the problems of fresh concrete causing the durability problem is bleeding. Bleeding is a form of segregation in which some water in the mix rises to the surface of freshly placed concrete. This is caused by the inability of the solid constituents of the mix to hold all of the mixing water when they settle downwards [1].

In Thailand, fly ash has been used in concrete for a number of years; however, understanding about fly ash concrete properties is still not up to a satisfactory level. With this level of understanding, fly ash has been refused for being used in some construction projects. Low abrasive resistance and dusty surface of fly ash concrete are common problems heard during these days. These problems are considered to be caused by excessive bleeding which may be accompanied by the prolonged setting time of the fly ash concrete, especially when the fly ash concrete have high w/b ratio or high water content (relatively low strength concrete).

Helmuth R. [2] found that among the most important characteristics of fly ashes are those that affect the bleeding characteristic of the fresh cement pastes in concretes. Replacement of a part of the cement with fly ash may either increase or decrease the bleeding of fresh concrete.

Tangtermsirikul S. [3] studied the influencing factors of bleeding which are surface area of solid particles, water to cement ratio, and air content on bleeding rate and bleeding capacity and found that the larger the total surface area of solid particles in the fresh concrete mixture is, the lower permeability of the fresh concrete mixture will be. Therefore, smaller bleeding rate can be expected. With regard to the effect of water to cement ratio (w/c), cement pastes with higher w/c ratio give higher value of bleeding rate for cement pastes made from same cement. It can be expected that the cement paste with higher w/c ratio gives higher bleeding capacity than that with lower w/c ratio since cement paste with higher w/c ratio contains larger amount of water in the mixture. Bleeding capacity is also affected by the sample height. A larger sample height gives rise to a larger bleeding capacity [4].

Studies have not yet been done on bleeding of fly ash concrete and its solutions for proper mix design in Thailand. This study will be useful for the mentioned purpose.

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2. Experimental Program

The objective of this study is to conduct comprehensive experiments to clarify the mechanisms of bleeding of fly ash concrete.

The experiments are conducted to investigate the effect of paste content, water to binder ratio (w/b), chemical and physical properties of fly ash and fly ash content on bleeding of fresh concrete.

2.1 Mix Proportion of Concrete

A total of 35 mixtures were tested in this experiment. Fly ash 1 was used in mixes no. ci-1 to ci-20 and fly ash 2 was used in mixes no. ci-22 to ci-40 as shown in Table 1.

Table 1 Mix proportion of concrete

No.	γ	w/b	%r	C	FA	W	S	G
Fly ash1								
ci-1	1.2	0.5	0	325	0	163	1071	844
ci-2	1.2	0.5	10	287	32	159	1071	844
ci-3	1.2	0.5	30	214	92	153	1071	844
ci-4	1.2	0.5	50	147	147	147	1071	844
ci-5	1.2	0.6	0	290	0	174	1071	844
ci-6	1.2	0.6	10	256	28	171	1071	844
ci-7	1.2	0.6	30	192	82	165	1071	844
ci-8	1.2	0.6	50	132	132	159	1071	844
ci-9	1.4	0.4	0	435	0	174	1003	790
ci-10	1.4	0.4	10	382	42	170	1003	790
ci-11	1.4	0.4	30	284	122	162	1003	790
ci-12	1.4	0.4	50	194	194	155	1003	790
ci-13	1.4	0.5	0	382	0	191	1003	790
ci-14	1.4	0.5	10	336	37	187	1003	790
ci-15	1.4	0.5	30	251	108	179	1003	790
ci-16	1.4	0.5	50	172	172	172	1003	790
ci-17	1.4	0.6	0	340	0	204	1003	790
ci-18	1.4	0.6	10	300	33	200	1003	790
ci-19	1.4	0.6	30	225	96	193	1003	790
ci-20	1.4	0.6	50	155	155	186	1003	790
Fly ash2								
ci-22	1.2	0.5	10	288	32	160	1071	844
ci-23	1.2	0.5	30	216	92	154	1071	844
ci-24	1.2	0.5	50	149	149	149	1071	844
ci-26	1.2	0.6	10	257	29	171	1071	844
ci-27	1.2	0.6	30	193	83	166	1071	844
ci-28	1.2	0.6	50	134	134	161	1071	844
ci-30	1.4	0.4	10	383	43	170	1003	790
ci-31	1.4	0.4	30	286	123	164	1003	790
ci-32	1.4	0.4	50	197	197	157	1003	790
ci-34	1.4	0.5	10	337	37	187	1003	790
ci-35	1.4	0.5	30	253	108	181	1003	790
ci-36	1.4	0.5	50	175	175	175	1003	790
ci-38	1.4	0.6	10	301	33	201	1003	790
ci-39	1.4	0.6	30	227	97	194	1003	790
ci-40	1.4	0.6	50	157	157	188	1003	790

Note: γ denotes the ratio of paste content to the total void of compacted aggregate phase and w/b is water to binder ratio. Replacement percentage of fly ash denotes percentage of fly ash contained in the total binder. C, FA, W, S, G denote weight of cement, fly ash, water, sand, and coarse aggregate in 1 m^3 of concrete (kg/m^3).

2.2 Sources and Properties of Materials

(i) Cementitious Materials

1. Ordinary Portland cement type 1 conforming to ASTM C150-92 type 1 was used. The chemical composition and physical properties of the cement are shown in Table 2.
2. Two lignite fly ash samples were collected from Mae-Moh electric power plant. The two fly ashes differ mainly in the CaO and SiO_2 contents. The chemical composition and physical properties of fly ash are shown in Table 2.

Table 2 Properties of Materials

	Cement	Fly ash 1	Fly ash 2
Chemical composition (%)			
Silicon dioxide	20.99	45.88	33.13
Aluminum oxide	5.18	26.20	26.89
Iron oxide	3.20	10.94	11.96
Calcium oxide	64.63	8.28	15.07
Magnesium oxide	1.30	2.83	2.94
Sulfur trioxide	2.61	1.04	1.63
Insoluble residue	0.13	-	-
Sodium oxide	0.04	0.90	1.42
Potassium oxide	0.4	2.78	3.33
Titanium dioxide	0.25	0.51	0.52
Phosphorus pentaoxide	0.05	0.10	0.16
Free Lime	0.75	0.18	-
Gypsum Content	5.60	-	-
Physical Properties			
Specific gravity (g/cm^3)	3.15	2.03	2.13
Loss on ignition (%)	1.17	0.17	0.04
Blaine fineness (cm^2/g)	3150	3460	3430
Water retainability (β)	0.230	0.204	0.166

(ii) Aggregates

1. The natural river sand, passing sieves No.4, was used as fine aggregate. Specific gravity was tested in accordance with the ASTM C128 and equals to 2.57 and 2.59 in dry and SSD condition, respectively.
2. The crushed limestone aggregate with the maximum size of 25 mm from the single

source was used as coarse aggregate. Specific gravity was tested in accordance with the ASTM C127 and equals to 2.68 and 2.69 in dry and SSD condition, respectively.

3. The compacted void content of binary mixture of aggregates was performed according to the ASTM C29/C29M-91a. Sand to aggregate ratio of 0.45, resulting in a void ratio of 0.23, was selected for the mix proportions.

2.3 Experimental Investigation

Measurement of bleeding water was performed following ASTM C232-99 Method A (sample consolidated by tamping). In this test, a cylindrical container of approximately 14 liters capacity (as shown in Fig. 1), having an inside diameter of 255±5 mm and inside height of 280±5 mm was used. After casting concrete into the container, draw off (with pipet or similar instrument) the water that had accumulated on the surface, at 10 minutes intervals during the first 40 minutes and at 30 minutes intervals thereafter until bleeding stops.

Fig. 1 A cylindrical container and major apparatus for bleeding test

3. Results and Discussion

The experimental results of bleeding are shown in Fig. 2 to Fig. 18.

3.1 Effect of Type of Fly Ash

The effect of chemical composition of fly ash in term of CaO content was investigated. FA1 has lower CaO content than FA2. Fig. 2 to Fig. 6 indicate that though CaO content of FA2 was higher than that of the FA1, FA2 caused higher bleeding. This indicates that for bleeding, which is the phenomenon during fresh state, chemical composition of the fly ash is not an essential factor due to the yet unreacted fly ash. Physical property is more significant. Mixtures with FA2 tend to have higher bleeding due to lower water retainability of FA2 than FA1 (see Table 2).

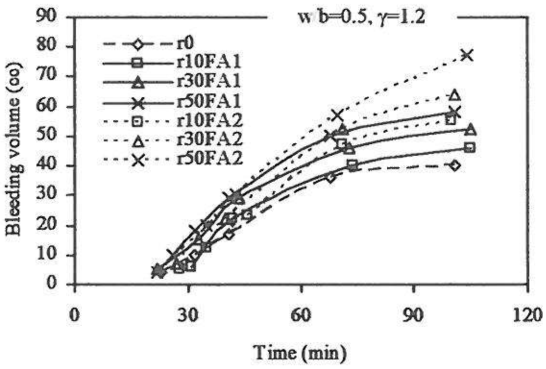

Fig. 2 Bleeding of concretes with FA1 and FA2 (w/b = 0.5, γ = 1.2, fly ash percentage = 0%, 10%, 30%, and 50%)

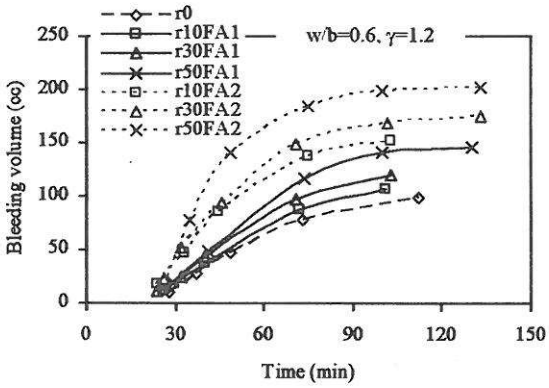

Fig. 3 Bleeding of concretes with FA1 and FA2 (w/b = 0.6, γ = 1.2, fly ash percentage = 0%, 10%, 30%, and 50%)

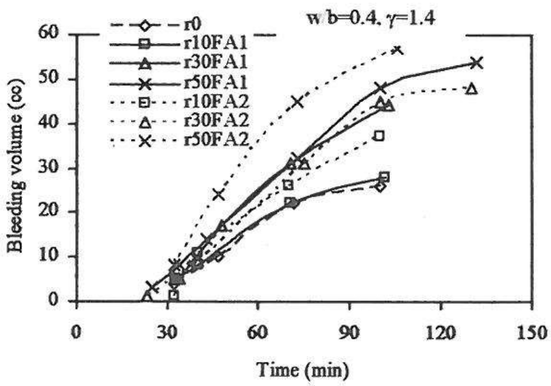

Fig. 4 Bleeding of concretes with FA1 and FA2 (w/b = 0.4, γ = 1.4, fly ash percentage = 0%, 10%, 30%, and 50%)

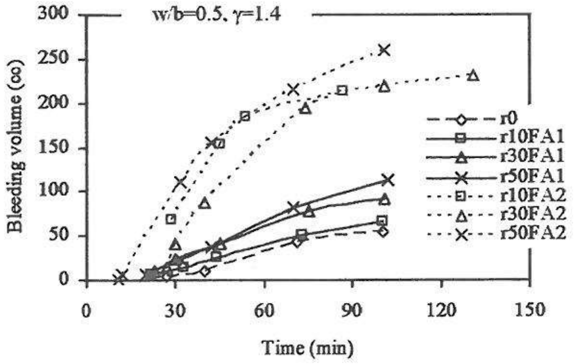

Fig. 5 Bleeding of concretes with FA1 and FA2 (w/b = 0.5, γ = 1.4, fly ash percentage = 0%, 10%, 30%, and 50%)

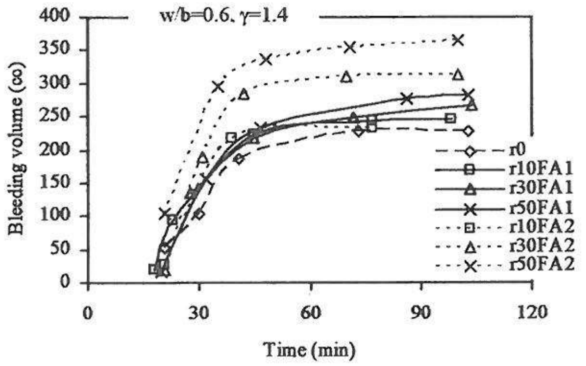

Fig. 6 Bleeding of concretes with FA1 and FA2 (w/b = 0.6, γ = 1.4, fly ash percentage = 0%, 10%, 30%, and 50%)

3.2 Effect of Replacement Percentage of Fly Ash

Increasing the replacement percentage of fly ash in the mixtures tends to increase the bleeding as can be observed from Fig. 7 to Fig. 10. The reason of increasing of bleeding is that fly ash has smaller water retainability than cement. And with the spherical shape, the drag force between water and fly ash particles is smaller.

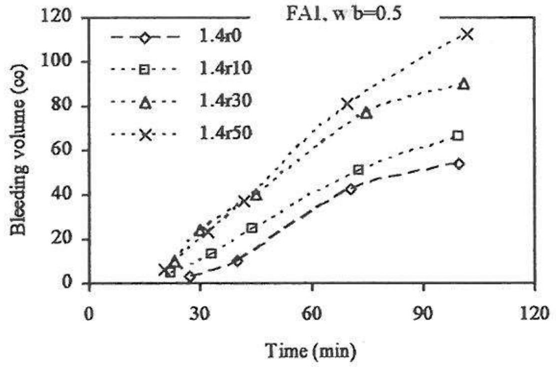

Fig. 7 Bleeding of concrete with fly ash percentages of 0%, 10%, 30%, and 50% (Fly ash FA1, w/b = 0.5, γ = 1.4)

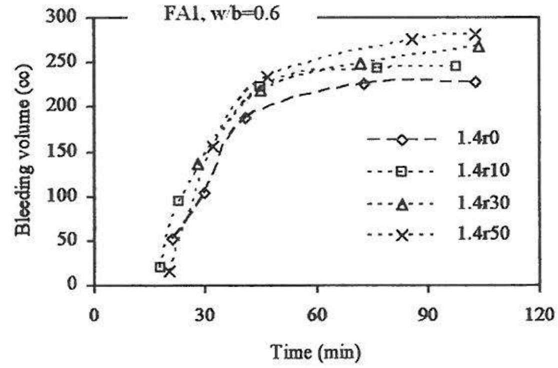

Fig. 8 Bleeding of concrete with fly ash percentages of 0%, 10%, 30%, and 50% (Fly ash FA1, w/b = 0.6, γ = 1.4)

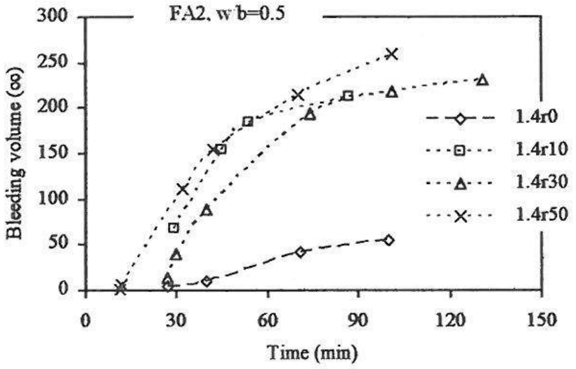

Fig. 9 Bleeding of concrete with fly ash percentages of 0%, 10%, 30%, and 50% (Fly ash FA2, w/b = 0.5, γ = 1.4)

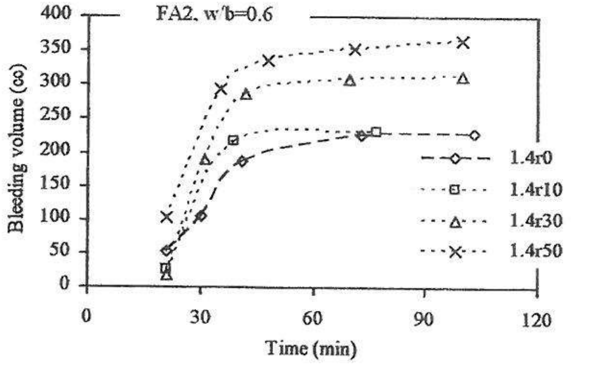

Fig. 10 Bleeding of concrete with fly ash percentages of 0%, 10%, 30%, and 50% (Fly ash FA2, w/b = 0.6, γ = 1.4)

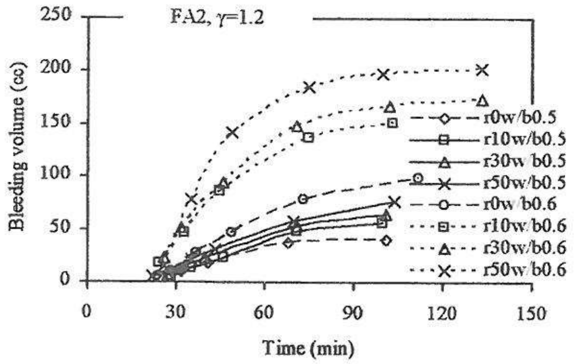

Fig. 12 Bleeding of concretes with water to binder ratios of 0.5 and 0.6 (Fly ash FA2, γ = 1.2, replacement percentage of FA2 = 0, 10, 30, and 50%)

3.3 Effect of Water to Binder Ratio

To investigate the effect of water to binder ratio on bleeding, mixtures with water to binder ratio of 0.5 and 0.6 and ratio of paste volume to void volume of aggregate phase of 1.2 with varied replacement percentages of FA1, FA2 at 0%, 10%, 30%, and 50% were tested. Increasing water to binder ratio caused an increase in bleeding volume as can be seen from Fig. 11 and Fig. 12 due to larger amount of free water content in the mixtures with higher w/b.

3.4 Effect of Ratio of Paste Volume to Void Volume of Aggregate Phase

Increasing the ratio of paste volume to void volume of aggregate phase (γ) caused an increase in bleeding due to a higher paste content in the mixture. This led to the higher amount of water for bleeding. The effect of the ratio of paste volume to void volume of aggregate phase (γ) is shown in Fig. 13 to Fig.16.

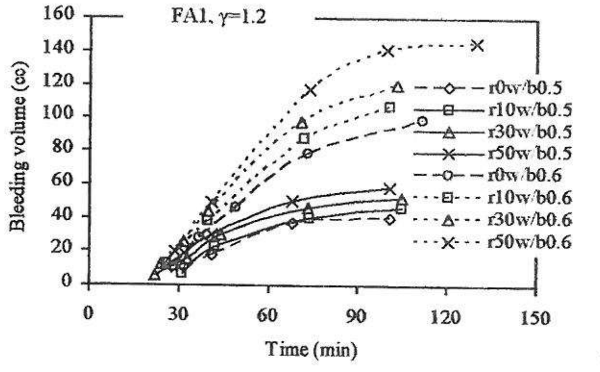

Fig. 11 Bleeding of concretes with water to binder ratios of 0.5 and 0.6 (Fly ash FA1, γ = 1.2, replacement percentage of FA1 = 0, 10, 30, and 50%)

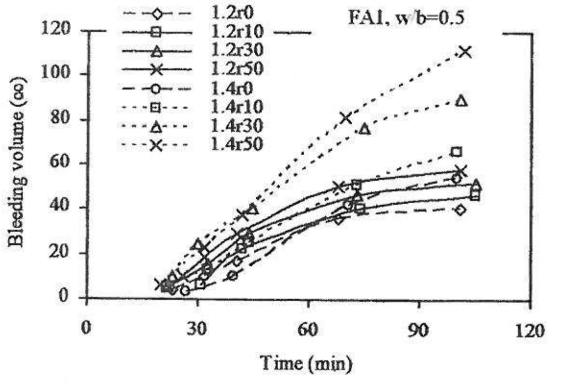

Fig. 13 Bleeding of concretes with γ of 1.2 and 1.4 (Fly ash FA1, w/b = 0.5, replacement percentage of fly ash = 0%, 10%, 30%, and 50%)

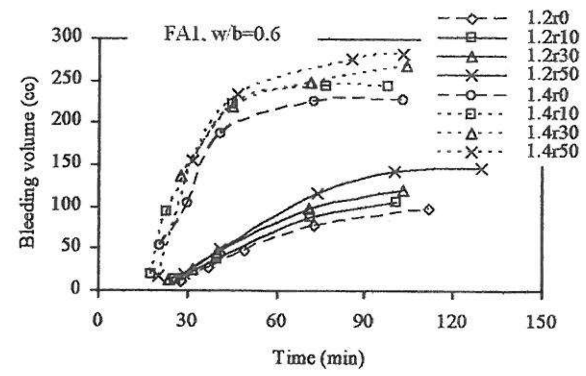

Fig. 14 Bleeding of concretes with γ of 1.2 and 1.4 (Fly ash FA1, w/b = 0.6, replacement percentage of fly ash = 0%, 10%, 30%, and 50%)

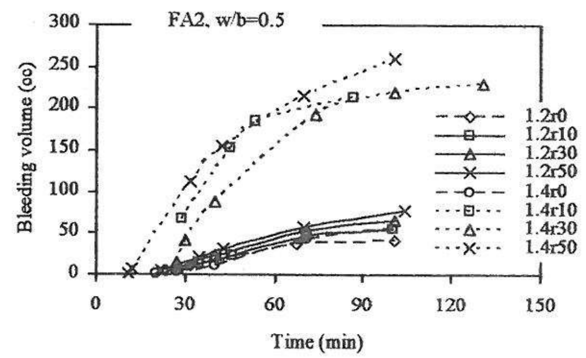

Fig. 15 Bleeding of concretes with γ of 1.2 and 1.4 (Fly ash FA2, w/b = 0.5, replacement percentage of fly ash = 0%, 10%, 30%, and 50%)

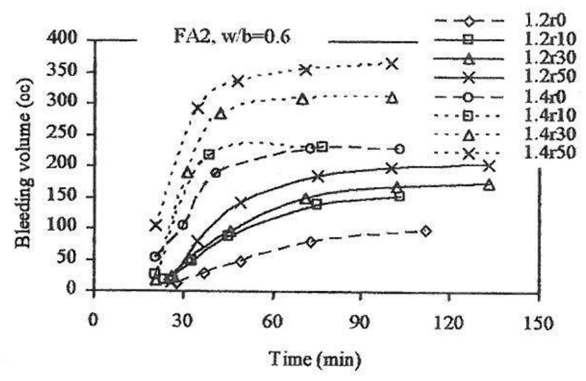

Fig. 16 Bleeding of concretes with γ of 1.2 and 1.4 (Fly ash FA2, w/b = 0.6, replacement percentage of fly ash = 0%, 10%, 30%, and 50%)

3.5 Analytical Parameters Affecting Bleeding

In this study, free water and effective surface area of solid particles have been considered as analytical parameters affecting bleeding.

3.6 Determinations of Bleeding Rate and Bleeding Capacity

Bleeding rate was calculated by plotting the amount of bleeding water from the exposed concrete surface of the testing container with time and finding the slope of the initial linear portion of the curve. The bleeding rate was expressed in cc. per minute. The bleeding capacity is the total bleeding volume which is expressed in cc.

3.7 Effect of Free Water on Bleeding Rate and Bleeding Capacity

Free water has been defined as the amount of water that is free, by any means, from being restricted by all solid particles in the fresh concrete. Moreover, it has been found that very fine powder particles could fill in the voids among cement particles and drive out water entrapped in these voids. This driven out water becomes available as additional free water. So, free water can be determined as :

$$W_{fr} = W_u - W_{rp} - W_{ra'} + W_{aa} \quad (1)$$

where W_u is unit water content of mix (kg/m^3 of concrete); W_{rp} is water restricted by powder materials (kg/m^3 of concrete); $W_{ra'}$ is restricted water at the surface of aggregates (kg/m^3 of concrete) and W_{aa} is additional free water due to filling effect of fine powders. The method for deriving the free water content was proposed by Tangtermsirikul S. and Khunthongkeaw J. [5].

Increasing the amount of free water increased the bleeding rate and bleeding capacity. The effects of free water to bleeding rate and bleeding capacity are shown in Fig. 17 and Fig. 18.

3.8 Effect of Effective Surface Area of Solid Particles on Bleeding Rate, Bleeding Capacity, and Free water

The effective surface area of solid particles has been defined as the surface area of solid particles that have the possibility to be in contacts. It has been derived as :

$$S_{eff} = \eta_a . S_{ta} + \eta_p . S_{tp} \quad (2)$$

$$S_{tp} = 1000 \sum_{i=1}^{n} S_{pi}\, w_{pi} \qquad (3)$$

$$S_{ta} = 1000\,(S_s\, w_{s'} + S_g\, w_{g'}) \qquad (4)$$

where S_{ta} and S_{tp} are surface area of total aggregates and total powder materials in mix, respectively (cm^2/m^3 of mix); $w_{s'}$, $w_{g'}$ and w_{pi} are the saturated surface dry weight of fine aggregate, coarse aggregate and the absolutely dry weight of powder material type i, respectively (kg/m^3 of mix); S_s, S_g and S_{pi} are the specific surface area of fine aggregate, coarse aggregate and powder material type i, respectively (cm^2/g); n is the total number of kind of powder materials used in the mix; η_a and η_p are the effective contact area ratio of aggregate and powder, respectively. The details of method for deriving the value of effective surface area of solid particles can be found in ref. [5].

Increasing the effective surface area of solid particles caused a decrease in the bleeding rate and bleeding capacity due to the increase of frictional contact area of the solid particles. The effects of effective surface area of solid particles on bleeding rate and bleeding capacity are shown in Fig. 17 and Fig. 18.

The effects of free water content and effective surface area of solid particles on bleeding, shown in Fig. 17 and Fig. 18, can provide useful knowledge for establishing a prediction model for bleeding.

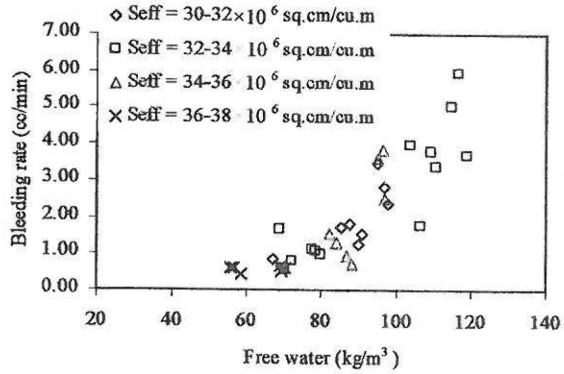

Fig. 17 Relationship between effective surface area of solid particles, free water and bleeding rate

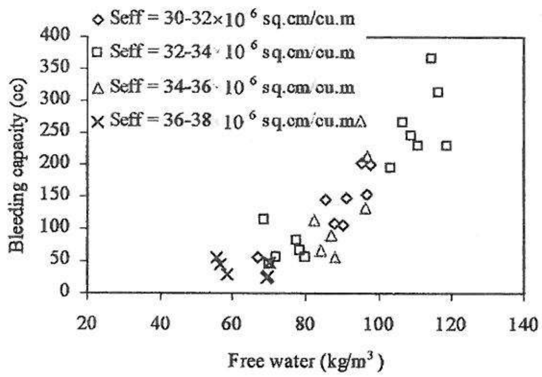

Fig. 18 Relationship between effective surface area of solid particles, free water and bleeding capacity

4. Conclusions

Based on the test results, the following conclusions were made.

1. Fly ash FA2 with lower water retainability caused higher bleeding than FA1.
2. Increasing replacement percentage of fly ash in cement caused an increase in bleeding of fresh concrete because fly ash has smaller water retainability than cement.
3. Increasing water to binder ratio caused an increase in bleeding due to the larger amount of free water in the mixture.
4. Increasing the ratio of paste volume to void volume of aggregate phase (γ) caused an increase in bleeding due to a higher paste content and so higher free water content in the mixture.
5. Increasing free water caused an increase in bleeding rate and bleeding capacity.
6. Increasing effective surface area of solid particles caused a decrease in bleeding rate and bleeding capacity.

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