- Technical Paper –

AN EFFECTIVE AND EFFICIENT MIXING METHOD FOR CONTROLLING INITIAL AIR CONTENT WITH STABILITY OF ENTRAINED AIR IN FRESH MORTAR OF SELF-COMPACTING CONCRETE

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ABSTRACT

The purpose of this study is to introduce a mixing method which is efficient in adjusting initial air content with a stable air entrainment and is effective in enhancing self-compactability of a new type self-compacting concrete (**airSCC**). Four types of mixing method of mortar were tested. A mixing method in which superplasticizer was poured at first then followed by air entraining agent, was effective in assuring the stability of entrained air. With this mixing method, longer mixing time with air entraining agent or shorter mixing time with superplasticizer resulted in higher initial air content.

Keywords: self-compacting concrete, fresh mortar, mixing method, entrained air, stability

1. INTRODUCTION

The author has developed new type of SCC in order to reduce unit cost by reducing cement content. So, the water to cement ratio (W/C) was increased to 45% by mass and the fine aggregate to mortar ratio (s/m) was increased to 55% by volume. For this proportion, the interaction between coarse aggregate particles and mortar will also be increased resulting in a poor self-compactability of SCC. With a new type of superplasticizer (SP, high range water reducing agent) containing viscosity agent, this problem can be mitigated but was not sufficient to achieve the current level of self-compactability specified by JSCE (R_1) [1]. Therefore, a higher entrained air content of around 10% was aimed to introduce in SCC, named as **airSCC**. AirSCC is a new type SCC containing higher air content which is able to enhance the self-compactability of SCC of W/C 45% by weight and s/m 55% by volume. The mix proportion of airSCC is shown in Table 1 which uses the same materials used for mortar as shown in Table 2. Coarse aggregate used in airSCC is 30% by volume. Therefore, to achieve the air content of around 10% in airSCC, the air content in mortar has to be around 15%. So, it is indispensable to control the quality of entrained air.

Table 1 Mix-proportion of airSCC of air content around 10% (kg/m^3)

Water	SP	AE	Cement	Fine aggregate	Coarse aggregate
123	2.8	0.4	280	1032	804

Entrained air is small air bubbles uniformly distributed throughout the cement paste. It is said that the majority of bubbles in air-entrained concrete are between 10 μm and 100 μm in diameter [2]. According to previous studies, tiny air bubbles improved the workability of fresh concrete while controlling both segregation and bleeding. The bubbles of entrained air are to be formed by the shearing action of the mixer blades, which breaks up the air into a fine system of bubbles. Air entraining admixtures are then employed to stabilize these air bubbles [2]. However, to fully understand air entrainment and its stability in fresh concrete may be complicated [3]. Moreover, the high flow characteristics of SCC may cause difficulty in achieving a proper air void system. Previous studies mentioned that air bubbles can move more freely in highly fluid concrete, thus increasing bubble fusion and rupturing [4, 5].

With a simple mixing method, initial air content was dramatically increased with increase dosage of air entraining agent (AE) (Fig. 1); however, there was a dramatic loss of air content in 2 hours after mixing (Fig. 2). In the simple mixing method, water, SP, and AE were simply added and mixed at the same time. This result showed that the simple mixing method produced a poor quality of entrained air. These two figures are further explained in following experiment.

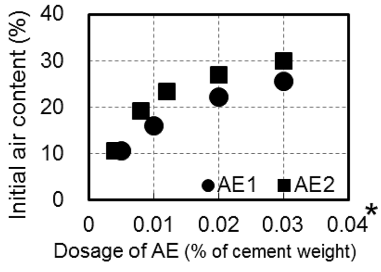

Fig. 1 Increase of initial air content by dosage of AE, * means x4 in case of AE2

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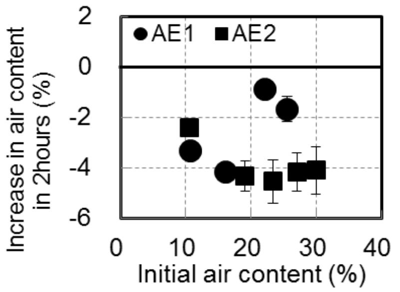

Fig. 2 Decrease in air content in 2 hours

Employment of both superplasticizer and air-entraining agent in mix may cause a complicated situation to produce a better air entrainment. Thus, mixing procedure may be an interesting parameter to be considered.

The purpose of this study is to improve mixing method so that it may be effective and efficient in improving the quality of air entrainment for the self-compactability of fresh concrete. Once such a mixing method has been achieved, airSCC, a new type SCC with higher entrained air content may be produced for a lower unit cost with all satisfied characteristics required.

2. EFFECT OF WATER DIVIDING MIXING METHOD ON STABILITY OF ENTRAINED AIR

2.1 Mixing method

Mixing method is one of many possible parameters to improve the quality of air entrainment. In mortar, a dramatic loss of air content in 2 hours after mixing was observed with the simple mixing method. Therefore, a modification on the mixing procedure was conducted in this study. In this chapter, two different types of mixing method, as shown in Fig. 3, were conducted. Water dividing mixing method (W. D.) was developed to compare its air entrainment performance on the stability of air content in 2 hours after mixing to that of the simple mixing method (Simple). In this experiment, the mixing machine with a rotation speed of 140±5 rpm was used. The capacity of the bowl is 5 liters and the shape of the blade is like a paddle.

In the simple mixing method, after the fine aggregate and cement were mixed for 0.5 minute, mixing water, superplasticizer (SP), and air entraining agent (AE) were added at the same time and mixed for 2 minutes.

The water dividing mixing method is different from the simple mixing method in which mixing water was separated into two parts. The first part, W_1 was fixed to 20 % of the weight of cement and the second part, W_2 was the remaining mixing water. In this mixing method, after the fine aggregate and cement were mixed for 0.5 minute, W_1 and SP were added and mixed for 1 minute and finally W_2 and AE were added and mixed for another 1 minute. In this mixing procedure, the mixture required higher energy input for the first 1 minute after adding water comparing to the simple mixing method. Also, in this first 1 minute, the mixture was already dispersed by the action of SP before adding AE and the remaining water. This action resulted in a reduction in friction of the mixture before introducing AE.

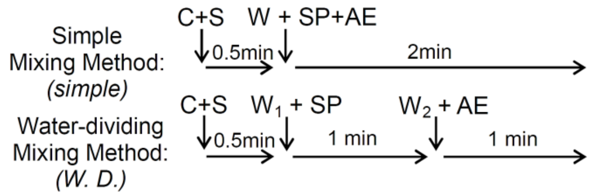

Fig. 3 Mixing procedure of simple mixing method and water dividing mixing method of mortar; S: fine aggregate, C: cement, W: water, SP: superplasticizer, AE: air entraining agent, $W = W_1 + W_2$, W_1 = 20 % of cement weight

2.2 Materials and mix-proportion

All materials shown in Table 2 were kept in a room where experiments were conducted with a constant temperature of 20°C. The main components of mortar in this study were ordinary Portland cement, crushed limestone sand, water, superplasticizer (SP), and air entraining agent (AE). A retarding type superplasticizer containing viscosity agent (SP1) and two types of air entraining agent (alkyl ether-based anionic surfactants (AE1) and vinsol resin (AE2)) were used in this section. The mix-proportion of mortar in this chapter is shown in Table3.

Table 4 shows a trial mix-proportion of $1m^3$ self-compacting mortar excluding air content.

Table 2 Materials used for mortar

Cement (C)		Ordinary Portland cement ($3.15g/cm^3$)
Fine aggregate (S)		Crushed limestone sand ($2.68g/cm^3$, F. M. 2.73)
Superplasti -cizer (SP)	SP1	Polycarboxylic based with viscosity agent and retarding type
Air entraining agent (AE)	AE1	Alkyl ether-based anionic surfactants
	AE2	Vinsol resin

Table 3 Mix-proportion of mortar

W/C	s/m	SP1/C	AE1/C	AE2/C
45% by weight	55% by volume	1.4% by weight	0.005%, 0.06% by weight	0.016%, 0.24% by weight

Table 4 Mix-proportion of self-compacting mortar (kg/m^3) (excluding air content)

W/C	s/m	Water	Cement	Fine aggregate	SP1
45%	55%	256	586	1474	8

2.3 Results and discussion

It can be seen from Fig. 4 that the water dividing mixing method (W. D.) produced lower initial air content than the simple mixing method (Simple) for both types of AE. With the water dividing mixing method and AE1, the initial air content reached the maximum of 13.3% only at the dosage of AE of 0.04% of the cement weight and was then slightly decreased with an increase in the dosage of AE. Similar phenomena occurred with AE2 in which the maximum initial air content of 14.9% was obtained at the dosage of AE of 0.05%.

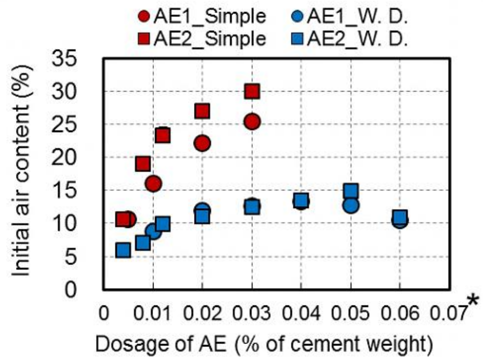

Fig. 4 Water dividing mixing method entraining lower initial air content; * means x4 in case of AE2

While the water dividing mixing method entrained lower initial air content, this type of mixing method lead to a satisfied stability of entrained air in 2 hours after mixing compared with that with the simple mixing method. It can be seen from Fig. 5 that with both types of AE, when using the water dividing mixing method, air content in 2 hours after mixing was slightly decreased at a low dosage of AE and was then mitigated with the increased dosage of AE. On the other hand, a dramatic decrease in air content in 2 hours after mixing was observed in both types of AE when using the simple mixing method. The increase in air content in 2 hours was mentioned instead of the total air content in 2 hours because the purpose of this study is to produce a stable air entrainment. So it is important to achieve qualified initial air content with little or no change in 2 hours.

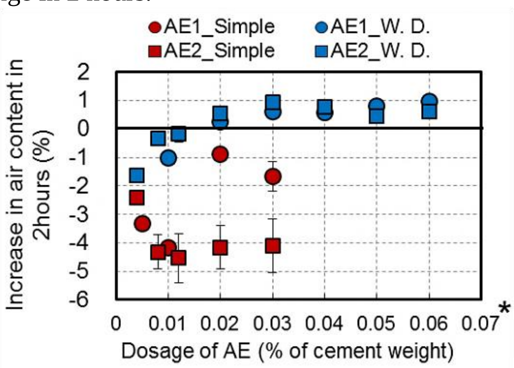

Fig. 5 Water dividing mixing method effective in stability of air content; * means x4 in case of AE2

It can be concluded from Fig. 6 that the water dividing mixing method improved the stability of air content in 2 hours after mixing. However, with this mixing method, initial air content reached a saturated zone at a very low value compared to the simple mixing method.

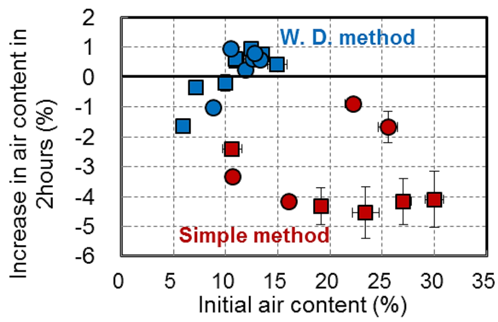

Fig. 6 Water dividing mixing method producing better air entrainment

3. EFFECTIVE MIXING METHOD FOR STABILITY OF ENTRAINED AIR

The aim of this chapter is to improve mixing method so that the stability of air content may be assured in a real construction site. As shown in the previous chapter, by employing the water dividing mixing method, there was no dramatic decrease in air content in 2 hours after mixing whereas this type of problem occurred with the simple mixing method. However, the water dividing mixing method, in which mixing water was divided into two parts, caused an inconvenience in the mixing process. That is why it is necessary to improve the process of mixing method to be more practical.

3.1 Mixing method

Four types of mixing method were set up and examined. The simple mixing method was referred to here as **Mixing Method A** and the water dividing mixing method was referred to here as **Mixing Method B**. The other two types of mixing method were **Mixing Method C** and **Mixing Method D** (Fig. 7). Each mixing procedure is shown in Fig. 7.

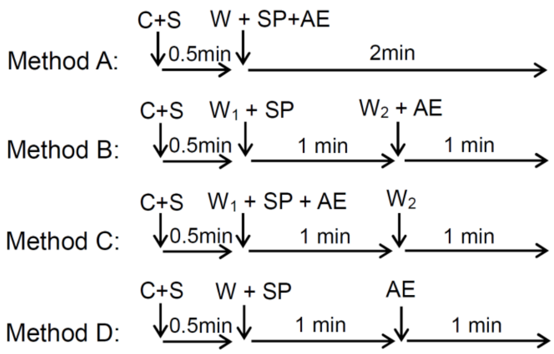

Fig. 7 Four types of mixing method for mortar; $W = W_1 + W_2$, W_1 = 20 % of cement weight

It can be summarized that the mixing method B and C were in which the mixing water was separated into two parts whereas there was no separation of the mixing water in method A and D. On the other hand, superplasticizer (SP) and air entraining agent (AE) were separated in the mixing method B and D but were not in method A and C. With these four types of mixing method, an effect of the water dividing and the separation of chemical admixture (SP and AE) were then clarified.

3.2 Materials and mix-proportion

Materials used for mortar experiments in this chapter are shown in Table 5. Chemical admixtures used were superplasticizer of polycarboxylic based with viscosity agent (SP2) and air entraining agent of alkyl ether-based anionic surfactants (AE1). The mix-proportion of mortar is shown in Table 6. The dosage of AE was selected for two cases of study. The interval of AE dosage 0.005% and 0.05% was chosen for the case of normal dosage. The AE dosage of 0.15% was for the case of excessive dosage as it was a possible maximum dosage that can be carried out.

Table 5 Materials used for mortar

Cement (C)		Ordinary Portland cement (3.15g/cm^3)
Fine aggregate (S)		Crushed limestone sand (2.68g/cm^3, F. M. 2.73)
Superplasticizer (SP)	SP2	Polycarboxylic based with viscosity agent
Air entraining agent (AE)	AE1	Alkyl ether-based anionic surfactants

Table 6 Mix-proportion of mortar

W/C	s/m	SP2/C	AE1/C
45% by weight	55% by volume	1.2% by weight	0.005%, 0.05% or 0.15% by weight

3.3 Results and discussion

(1) Normal dosage of air entraining agent

AE dosage was varied from 0.005% to 0.05% of the weight of cement. As shown in Fig. 8, the initial air content was dramatically increased with the increase in dosage of AE with the mixing method A or C whereas it was not the case with method B or D. It is possible that the higher initial air content with the mixing method A or C was due to the longer mixing time with AE in the mixing process. On the other hand, it is also possible that introducing SP prior to AE in the mixing method B or D may have restrained the initial air content due to a reduction in friction when AE was introduced.

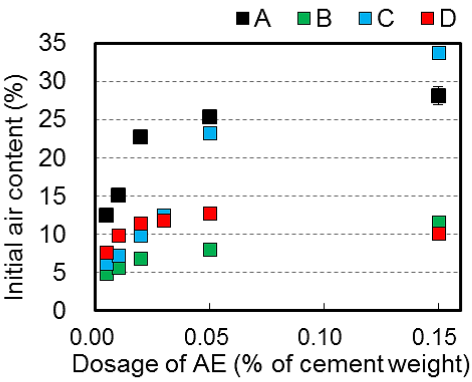

Fig. 8 Effect of mixing methods on initial air content

It is shown in Fig. 9 that the mixing method B or D produced a satisfied stability of air content in 2 hours after mixing even with lower dosage of AE and was then mitigated with the increased dosage of AE. On the other hand, the mixing method A or C produced a poorer stability of air content compared to method B or D. The slightly increase in air content in 2 hours after mixing occurred in case of the mixing method B or D may have been caused by remixing the mixture before the test. This reason proved the mixing method B or D to be more favorable than method A or C in assuring the stability of air content.

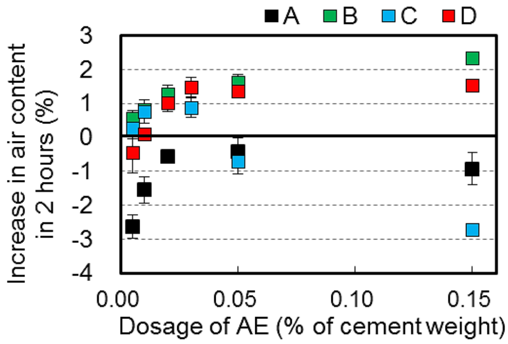

Fig. 9 Effect of mixing methods on stability of air content in 2 hours after mixing

The effect of the four types of mixing method on the stability of air content in 2 hours after mixing was summarized in Table 7. The mixing method A or C produced a poor stability of air content. On the other hand, there was no considerable decrease in air content in 2 hours after mixing with the mixing method B or D even with lower dosage of AE. It can be concluded that the mixing method in which superplasticizer was poured at first then followed by air entraining agent, was more effective in assuring the stability of air content than dividing mixing water.

Table 7 Effect of mixing methods on stability of air content in 2 hours after mixing

Mixing method	**A**	**C**	**B**	**D**
Mixing water	at once	dividing	dividing	at once
SP+AE	at once		separating	
Mixing time with AE	longer		shorter	
No decrease in air content in 2 hours	×	×	○	○

Fig. 10 represents the relationship between initial air content and its increase in 2 hours after mixing. It shows the results of four types of mixing method by increasing the dosage of AE. It is proved that the order of pouring materials in the mixing process had a significant effect on the initial air content and also its stability in 2 hours after mixing. The mixing method B or D, in which there was no decrease in air content in 2 hours after mixing, was not able to entrain higher initial air content as method A or C. Since the slightly increase in air content was more favorable, the mixing method B or D was more considerable. However, the mixing method B was not practical because of its process in dividing water. Therefore, the mixing method D was chosen for further experiment.

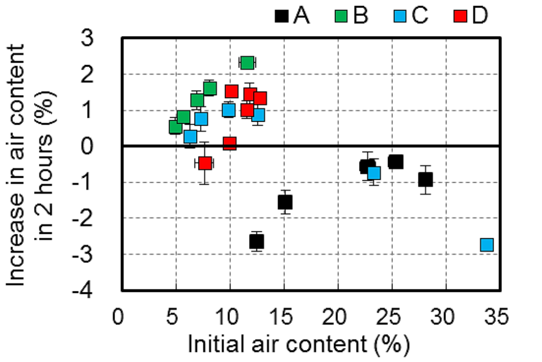

Fig. 10 Mixing method B or D producing lower initial air content without decrease in 2 hours

(2) Excessive dosage of air entraining agent

Since there was a difficulty in entraining higher initial air content using the mixing method B or D, an excessive dosage of AE of 0.15% of the cement weight was then conducted with the four types of mixing method above. As shown in Fig. 8, the initial air content, produced by the mixing method B or D, with the excessive dosage of AE was similar to that with the normal dosage of AE. The initial air content produced by the mixing method B or D was 11.6% or 10.1% respectively. On the other hand, the mixing method A or C produced the initial air content of 28.1% or 33.8% respectively. Regarding the stability of air content, there was no decrease in air content in 2 hours after mixing with the mixing method B or D whereas it was not the case for method A or C (Fig. 9).

To sum up, with the mixing method B or D, the saturated zone of the initial air content reached at a lower dosage of AE. Thus, with a higher increase in the dosage of AE, the stability of air content may be improved instead of entraining higher initial air content.

4. EFFECT OF MIXING TIME WITH CHEMICAL ADMIXTURE

Among the four types of mixing method in the previous chapter, the mixing method B or D had a difficulty in entraining higher initial air content regardless of the satisfied stability of air content. As shown in Fig. 7, the mixing time with AE within the mixing method B or D was only 1 minute whereas it was 2 minutes in case of the mixing method A or C. It is possible that the higher initial air content with the mixing method A or C was due to the longer mixing time with AE. Therefore, a variation in the mixing time with chemical admixtures (SP or AE) was conducted with the mixing method D in order to clarify its effect.

4.1 Mixing method

The mixing method D was tested by varying the mixing time with chemical admixture (SP or AE). **Method D_{xy}** was defined as method D in which after the fine aggregate and cement were mixed for 0.5 minute, mixing water and SP were then added and mixed for x minutes; and finally AE was added and mixed for y minutes. The mixing procedure of this method is shown in Fig. 11. The previous mixing method D, which was conducted with the mixing time with SP of 1 minute and with AE of 1 minute, was named here as **Method D_{11}**. To clarify the effect of the mixing time with chemical admixture, x was varied by 0.5 minute, 1 minute, and 2 minutes; while y was varied by 1 minute, 2 minutes, and 4 minutes.

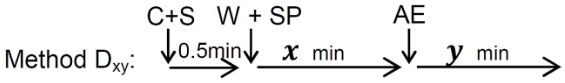

Fig. 11 Mixing procedure of method D_{xy} of mortar; $W = W_1 + W_2$, W_1 = 20 % of cement weight

4.2 Materials and mix-proportion

All materials used and the mix-proportion in this chapter were same as those in the previous chapter, (Tables 5 & 6). The excessive dosage of AE of 0.15% was selected in order to observe possible maximum initial air content reached when the mixing time with SP and AE were changed.

4.3 Results and discussion

As shown in Fig.s 12 & 13, the initial air content was increased with the increase in mixing time with AE or the decrease in mixing time with SP. For example, the initial air content of 10.1% with the mixing method **D_{11}** was increased to 17.2% by decreasing the mixing time with SP to 0.5 minute and increasing the mixing time with AE to 4 minutes (**D½ 4**). The longer mixing time with AE prolonged the shearing action of the mixer blade on the mixture which lead more air bubbles to be broken up and then stabilized by AE. The increase in the initial air content with the shorter mixing time with SP was possibly caused by an increase in friction of the mixture due to a less dispersing action of SP. However, it is shown in Fig. 13 that there was no significant difference in initial air content with the change of mixing time with SP from 1 minute to 2 minutes.

Fig. 14 shows that the longer mixing time with AE lowered the increase in air content in 2 hours after mixing. On the other hand, Fig. 15 shows that there was no linear correlation between the mixing time with SP and the increase in air content in 2 hours after mixing.

From the results mentioned above, with the mixing method D, the mixing time with AE or SP was the important parameter to achieve the target initial air content especially at a zone in which initial air content could not be increased by the additional dosage of AE.

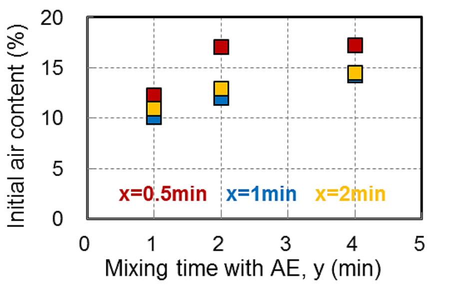

Fig. 12 Effect of mixing time with air-entraining agent (AE) on initial air content of fresh mortar

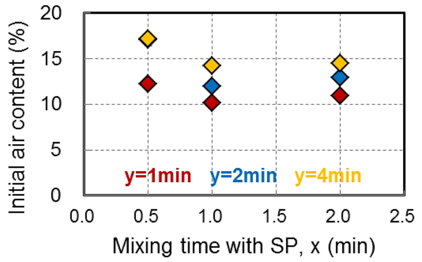

Fig. 13 Effect of mixing time with superplasticizer (SP) on initial air content of fresh mortar

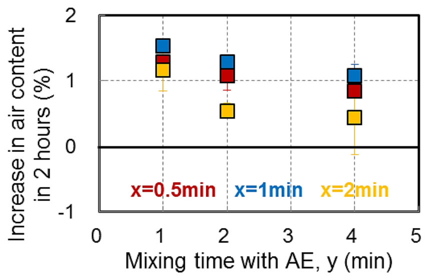

Fig. 14 Effect of mixing time with air-entraining agent (AE) on stability of air content of fresh mortar

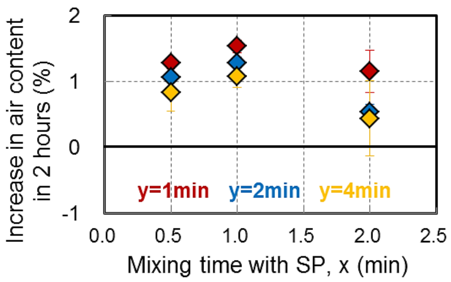

Fig. 15 Effect of mixing time with superplasticizer (SP) on stability of air content of fresh mortar

5. CONCLUSION: PROPOSAL OF SUITABLE MIXING METHOD FOR AIR SCC

According to the experimental results and discussions in the previous chapters, conclusion can be written as follows:

1) Mixing method has a significant influence on initial air content and its stability of fresh mortar.
2) A mixing method, in which superplasticizer (SP) was poured at first and then followed by air entraining agent (AE), resulted in a satisfied stability of air content in 2 hours after mixing even with a lower dosage of AE. However, this type of mixing method resulted in lower initial air content.
3) With mixing method in which superplasticizer (SP) was poured at first and then followed by air entraining agent (AE), a zone in which additional dosage of AE did not increase initial air content, so called "saturated zone" of initial air content, existed.
4) A mixing method in which superplasticizer (SP) was poured at first and then followed by air entraining agent (AE) without dividing water was recommended for practical usage. The following items are summaries on the mixing method:
5) Shorter mixing time with SP resulted in higher initial air content. On the other hand, longer mixing time with AE resulted in higher initial air content and lower increase in air content in 2 hours after mixing.
6) In the saturated zone of initial air content, increase in dosage of AE resulted in no change in initial air content or in increase in air content in 2 hours after mixing.

With the mixing method in which SP was poured at first and then followed by AE, when the initial air content reached its saturated zone in which it cannot be more increased with additional dosage of AE, varying of the mixing time with SP or AE was necessary to reach a desirable initial air content and achieve stability of air content (Fig.s 16 & 17).

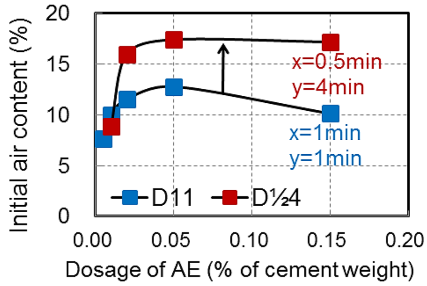

Fig. 16 Improvement of initial air content by adjusting mixing time with SP and AE

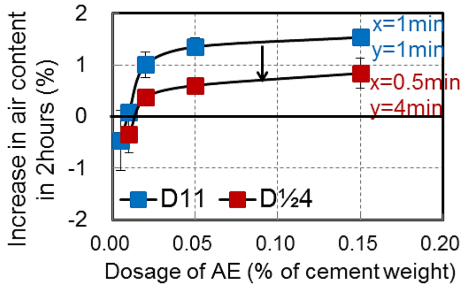

Fig. 17 Improvement of stability of air content by adjusting mixing time with SP and AE

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