

Effects of Materials and Mixing Procedures on Air Void Characteristics of Fresh Concrete

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ABSTRACT

The air void analyzer (AVA) was used to study the effects of concrete materials and mixing procedures on air void characteristics of fresh concrete. Twenty-seven batches of concrete were prepared with three mixes (with and without fly ash or water reducing agent), five mixing procedures (one-step mixing for one, two, or four minutes, two-step mixing for four minutes, and ASTM standard lab mixing procedures), and two sizes of pan mixers (0.5- and 1.5-cf capacity). The air content, size distribution, specific surface, and spacing factor of all the batch mixtures were examined. The results indicated that incorporating 15% fly ash replacement or the recommended dosage of water reducing agent into concrete generally reduced the spacing factor of air voids. The two-step mixing method (mixing mortar first, then adding coarse aggregate) produced a lower air void spacing factor than the one-step (four-minute) mixing method (mixing all concrete materials together at once) and the ASTM mixing method. For concrete mixed with the one-step mixing method, the air void spacing factor reduced with mixing time. For a given concrete mix and mixing procedure, use of different sizes of pan mixers provided the mixtures with different air contents and spacing factors.

Key words: air voids—fly ash—mixing—water reducing agent

INTRODUCTION

Mixing is important to achieve desirable concrete performance and homogeneity. Studying mixing is still difficult because to date there has been no consensus on evaluation criteria for concrete mixing quality, which depends primarily on mixing energy, time, and mixing sequence. The material and mixing systems usually mutually interact. Supplementary cementitious materials (SCMs), such as silica fume, fly ash, slag, natural Pozzolan, etc., have been used in concrete for many years because of the benefit to the environment and durability of the concrete. Some mixtures containing SCMs tend to be sticky and may need additional mixing time to reach uniformity. The requirements for mixing concrete with material-effect consideration, especially SCMs, have not been clearly established in the United States. Powers (1968) pointed out that the air void system is critical for concrete structures, such as pavement and bridge decks subjected to frost/thaw action and deicing salts. The air void system in concrete is generally formed during the mixing process and is significantly affected by both the material and the mixing method. For example, fly ash often contains carbon, which has a large surface area and absorbs the air-entraining agent (AEA); thus, it may impair the air void system. The mixing procedure (time) for normal concrete may not be appropriate for concrete mixing with SCMs.

The air void system in concrete is regarded to be the most significant factor in freeze-thaw resistant concrete (Powers 1968; Schlorholtz 1998). The pressure developed by water as it expands during freezing depends upon the distance the water must travel to the nearest air void. Smaller, closely spaced voids provide better protection by relieving the pressure than larger, more distant void spacing. Common test methods are only capable of measuring the volume of air voids, not the size or spacing of the voids. In the late 1980s, the air void analyzer (AVA) was developed to characterize the air void structure of fresh concrete (Magura 1996; AASHTO TIG 2003). The clear advantage of the AVA is its ability to obtain air void structure information on fresh concrete in less than 30 minutes. With this information, adjustments can be made in the production process to rectify any problems with the air void system during concrete placement.

RESEARCH SIGNIFICANCE

In this research, the AVA was first used as a tool to study the effect of mixing and material on the air void system of portland cement concrete in the laboratory. The correlation between Rapid Air 457 testing and AVA testing are presented to find a better way of measuring mixing quality.

MATERIALS, MIX PROPORTION, AND MIXING METHODS

The chemical properties of the cementitious materials used in this study are summarized in Table 1. Portland cement is an ASTM Type I cement and meets the requirements of ASTM C 150. Class C fly ashes meet the appropriate requirements of ASTM C 618. Concrete sand with a fine modulus of 2.92 and limestone with a nominal maximum size of one inch are used for all concrete mixes. An (AEA), Daravair 1000, is employed in all mixes to gain approximately 6% air content for the concrete. The water reducer (WR) from the same company is applied to selected concrete mixes.

As shown in Table 2, the C-4 mix proportion specified by Iowa DOT is used as the basis, and a total of three mix proportions are used. To determine the effect of the mixture, replacement with 15% of class C fly ash (C-3-C) and the addition of water reducer (C3-WR) are used for two other mix proportions as modifications of the standard C-4 mix.

Table 1. Chemical composition of raw materials

	Type I cement	Class C fly ash
CaO	64.77	24.95
SiO ₂	20.97	34.96
Al ₂ O ₃	5.59	19.86
Fe ₂ O ₃	2.27	5.4
K ₂ O	0.51	0.53
Na ₂ O	0.19	3.2
(Na ₂ O)eq.	0.53	-
SO ₃	2.99	-

Table 2. Nominal concrete mix proportions

Constituent	Absolute volume	Specific gravity	Pounds per yd ³
Cement	0.118	3.14	624
Water	0.159	1	268
Air	0.06	0	--
Fine aggregate	0.331	2.63	1478
Coarse aggregate	0.332	2.7	1482

Three mixing methods are used to prepare samples for AVA tests:

1. *Standard ASTM C192 lab mixing procedure.* The standard ASTM C192 lab mixing procedure is used as the reference. Coarse aggregate and a portion of the water with AEA are premixed for about 30 seconds. Then sand, cement, and the remainder of the water are added, after which the mixer runs for three minutes. The mixer is stopped for three minutes, after which the mixer runs for another two minutes.
2. *One-step mixing.* All materials, including coarse aggregate, sand, cement, and water, are loaded before mixing. One-, two-, and four-minute mixing times are applied to investigate the effect of mixing time on the air void system of fresh concrete.
3. *Two-step mixing.* Cementitious materials, sand, and half of the water are first mixed for two minutes. Coarse aggregate and the remainder of the water are then added and mixed together for another two minutes.

TESTING METHODS

The air content of fresh concrete is measured by the pressure method per ASTM C231, “Standard Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method.” The instrument is shown in Figure 1.



Figure 1. Pressure type B meter

The AVA test (see Figure 2) is performed on a sample of mortar from a cylinder specimen. The sample of mortar is extracted using a 20-ml syringe and vibrated into the fresh concrete with a percussion drill. This sample is injected into the bottom of the AVA testing device, a temperature-conditioned riser column assembly that contains a layer of analysis liquid under a column of water. The analysis liquid has specific properties that ensure that the air void system in the fresh mortar is released into it without affecting the quantity or sizes of the air voids.

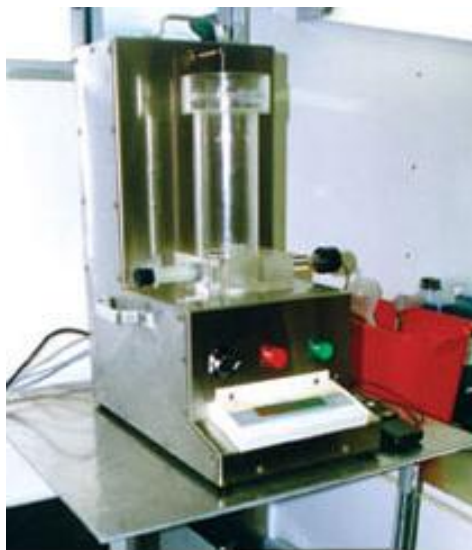


Figure 2. Air void analyzer (AVA)

RESULTS AND DISCUSSION

The air void system of concrete can be characterized by the total air content, the specific surface, and the spacing factor. Of these three parameters, the spacing factor is considered to be the most significant indicator of the durability of the cement paste matrix to the freezing and thawing exposure of the concrete. In this study, the AVA test method is used for air void characterization of fresh concrete. The air void distribution, based on paste air content rather concrete content, is used for the following reasons:

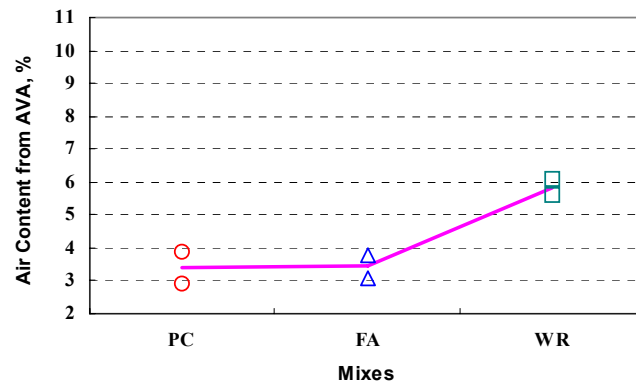
1. Paste content in concrete generally varies with the nominal maximum size of coarse aggregate. The paste needs to be protected by the air voids. Therefore, paste air content is more appropriate for use as an indicator of freeze-thaw resistance.
2. Only mortar samples extracted from the concrete are used in the AVA tests. The concrete air content is calculated from the mix proportion based on the mortar or paste air content. Additionally, the estimated air content is used for calculating the spacing factor, so using the paste air content would probably be more reasonable.

Effect of Concrete Materials on the Air Void System

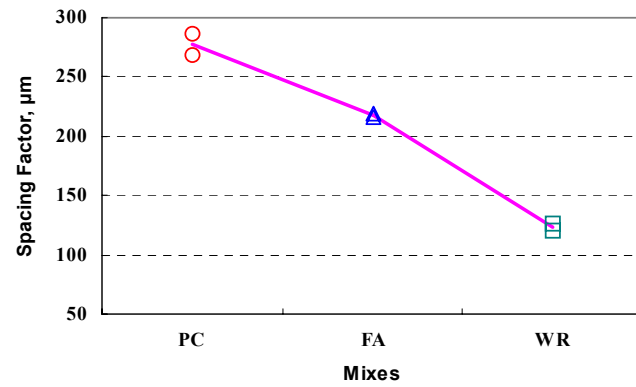
Three parameters measured from the AVA tests and air void distribution curves of three different mixes using the same standard ASTM lab mixing procedure are plotted in Figures 3 and 4, respectively. As observed from Figure 3, when compared with the portland cement mix, 15% fly ash replacement for portland cement does not change the total air content of concrete. It reduces the spacing factor and increases the specific surface. Addition of a water reducer dramatically increases the total air content, reduces the spacing factor, and increases the specific surface of the air voids.

Figure 4 indicates that, compared with the portland cement concrete mix, adding water reducer generated much smaller air voids (50–300 μm), desirable for freeze-thaw resistance while reducing the larger air voids (1,000–2,000 μm) in the paste system. Fly ash replacement produces a slightly smaller air void (125–500 μm) while significantly reducing the larger air voids (2,000 μm) in the paste. In terms of the total air content of the paste ($< 2,000 \mu\text{m}$), the water reducer mix has a much higher air content than the portland cement concrete and fly ash mixes, which show about the same total air content in this study. In Figure 4 (b), the accumulative distribution curve of water reducer moved upward and leftward, while the fly ash curve moved leftward from the portland cement concrete mix curve. This also indicates that the water reducer produces finer and a greater number of air voids, and fly ash produces finer air voids.

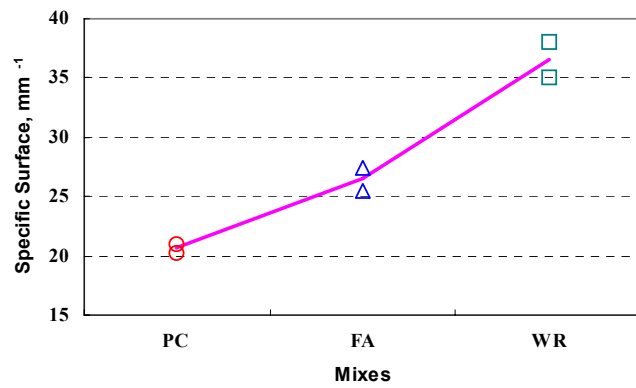
One-step two-minute and four-minute mixing methods show similar trends with the standard ASTM lab mixing, when comparing the effects of the mixture on the air void system.



(a)

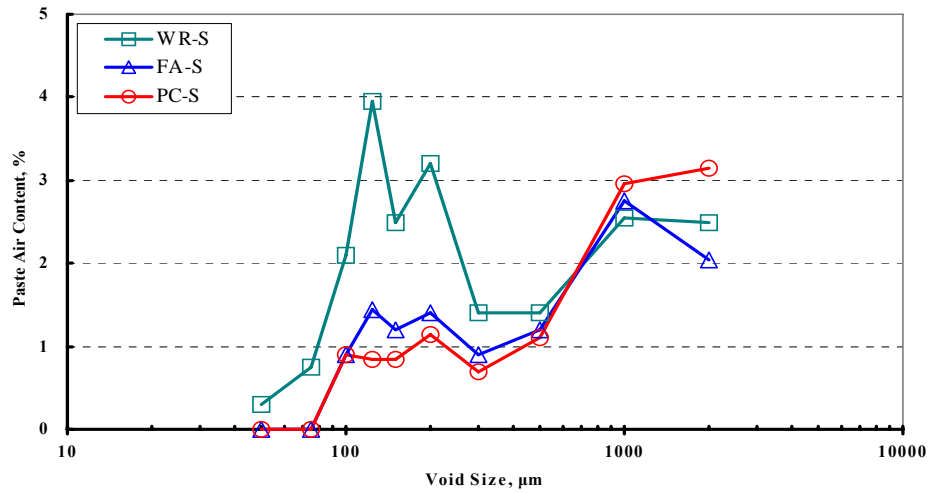


(b)

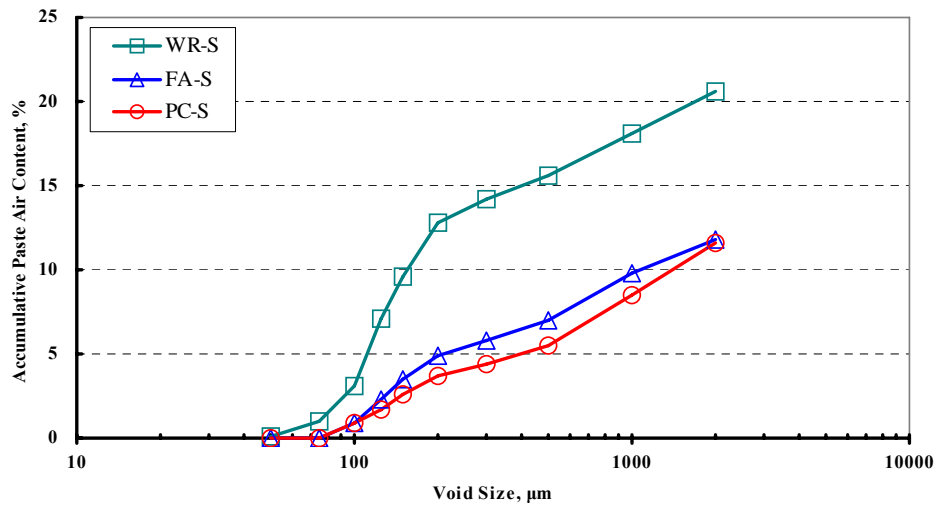


(c)

Figure 3 Effect of mixes on the AVA parameters (3-3-2 mixing)



(a)



(b)

Figure 4 Effect of mixes on paste air content distribution (3-3-2 mixing)

Effect of Mixing Procedure on Air Void Distribution

Figures 5 and 6 illustrate the AVA test results of concrete mixtures mixed with one-step and two-step methods for four minutes. Compared with the one-step mixing procedure, the two-step mixing procedure produces a slightly higher total concrete air content. The spacing factor is reduced and the specific surface is increased (see Figure 5).

Compared with the one-step mixing procedure, the two-step mixing procedure generates many more and smaller air voids (100–500 mm) while reducing the larger air voids (2,000 mm) in the paste, as shown in Figure 6. In terms of the total air content of the paste (< 2,000 mm), the two-step mixing procedure

generates a higher air content than the one-step mixing procedure. The accumulative distribution curve of two-step mixing moves up and leftward from the one-step mixing curve. This also indicates that two-step mixing produces finer and a greater number of air voids than one-step mixing.

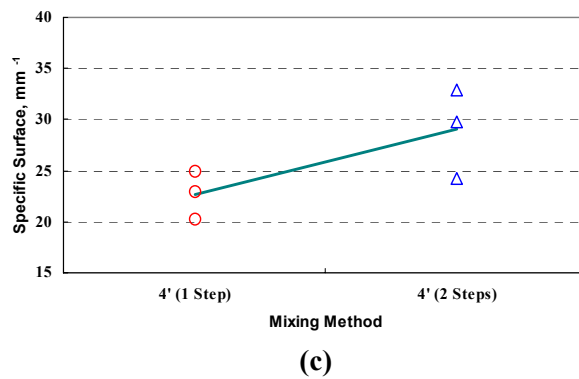
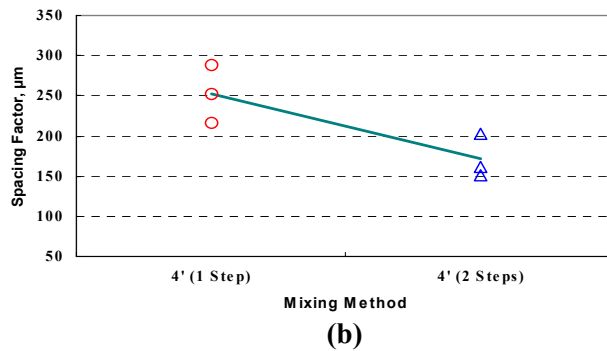
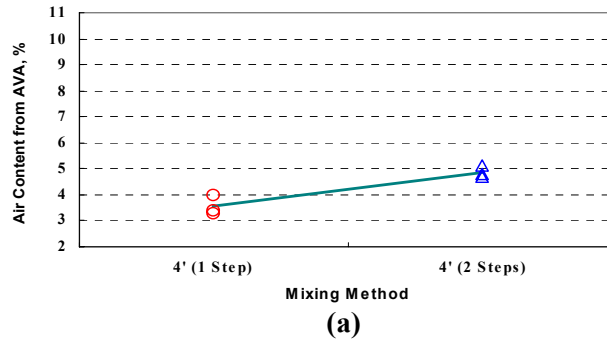
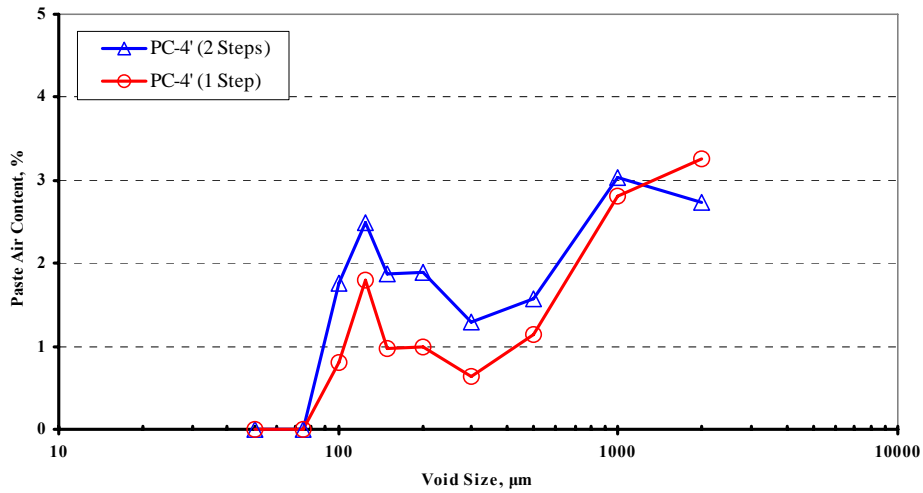
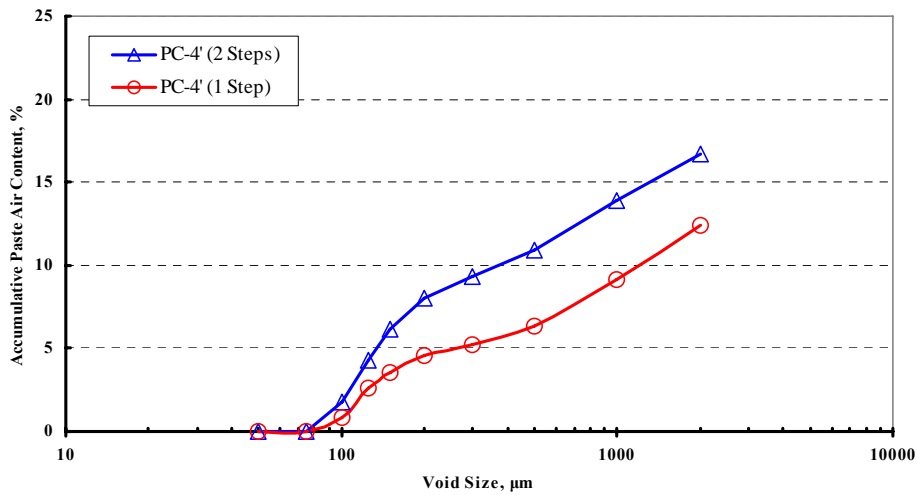


Figure 5. Effect of mixing sequence on AVA parameters (portland cement, four min. mixing)



(a)

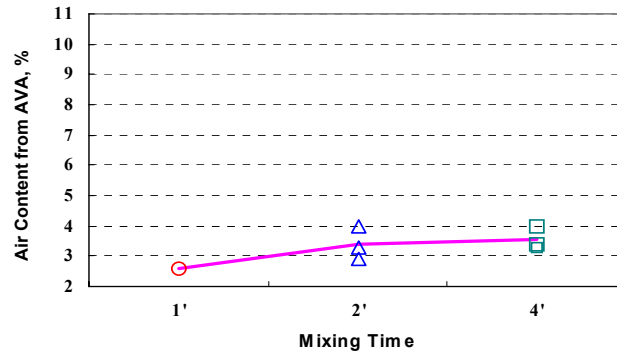


(b)

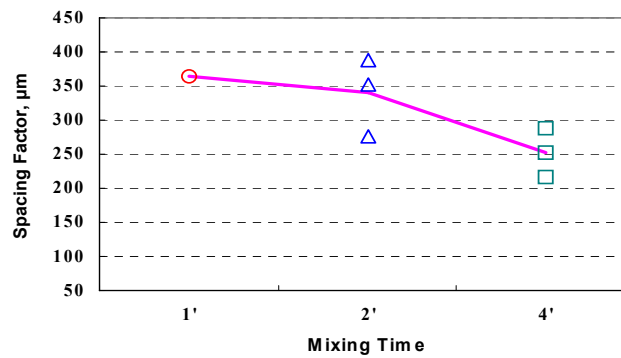
Figure 6. Effect of mixing sequence on air distribution (portland cement, four min. mixing)

Effect of Mixing Time on Air Void Distribution

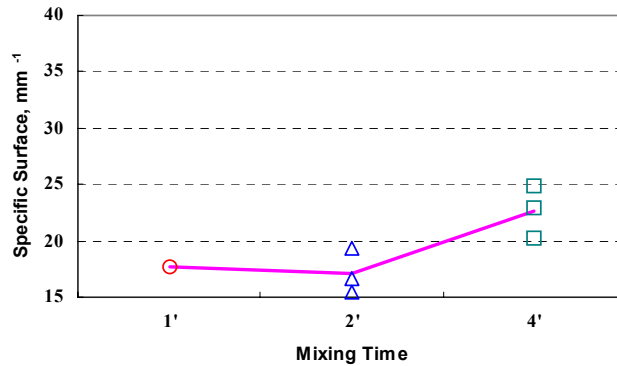
Figures 7 and 8 illustrate the effect of mixing time on AVA test results. Three mixing times (one minute, two minutes, and four minutes) are used for one-step mixing of a portland cement concrete mix. Compared to one-minute mixing, two-minute mixing increases the total concrete air content slightly, but has little influence on the specific surface. The spacing factor decreases a little when the mixing time is changed from one minute to two minutes. A four-minute mixing time does not increase the total concrete air content at all from the two-minute mixing time, but it does reduce the spacing factor and increases the specific surface greatly from the one-minute or two-minute mixing times (see Figure 7).



(a)



(b)

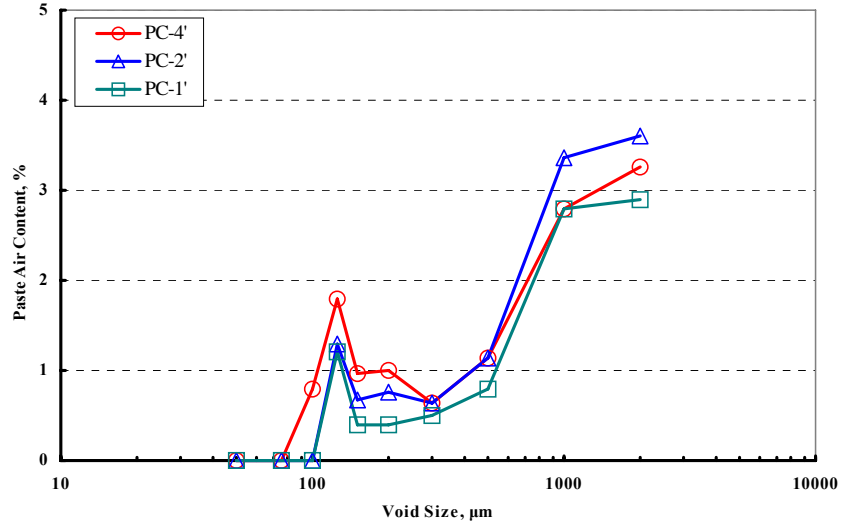


(c)

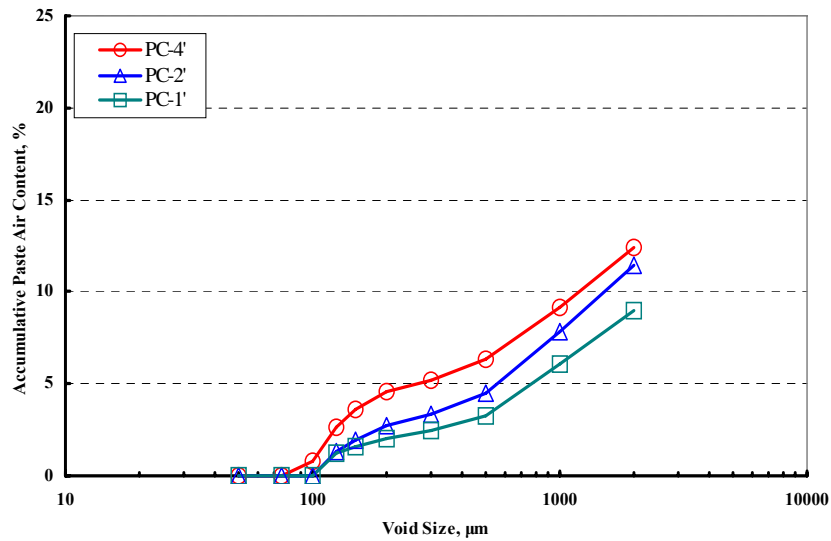
Figure 7. Effect of mixing time on the AVA results (portland cement one-step mixing)

Figure 8 shows the air void distribution curves for three different mixing times. It can be seen that one-minute mixing generates the lowest air content within all size ranges. A two-minute mixing time produces a few smaller air voids (150–500 μm) and the highest number of larger air voids (1,000–2,000 μm). Four-minute mixing increases the number of small air voids (100–200 μm) and produces fewer large air voids (1,000–2,000 μm). Based on Figure 8(b), one-minute mixing has lower total air content in the paste (<2,000 μm) than the two-minute and four-minute mixing. The four-minute mixing generates nearly the

same total air content compared with two-minute mixing, but four-minute mixing produces a more desirable air void distribution. The two-minute mixing curve moves leftward and upward from the one-minute mixing curve, and the four-minute curve continues to move leftward from the two-minute mixing curve. This indicates that as mixing time increases, the amount of small air voids in the concrete increase.



(a)



(b)

Figure 8. Effect of mixing time on air void curve (portland cement one-step mixing)

Effect of Mixer on Air Void Distribution

Two lab mixers with capacities of 0.5 and 1.5 ft³ are used in this study. Three numerical parameters measured from the AVA and the average air void distribution curves of two mixers using portland cement mix are plotted in Figures 9 and 10.

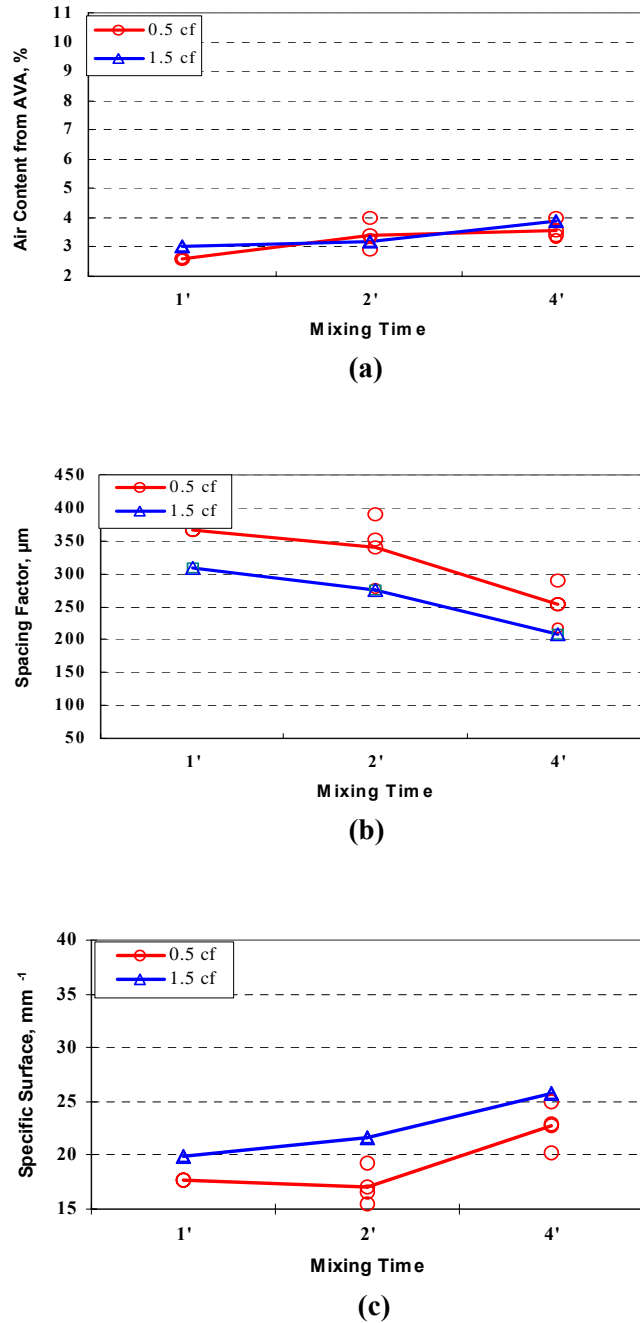
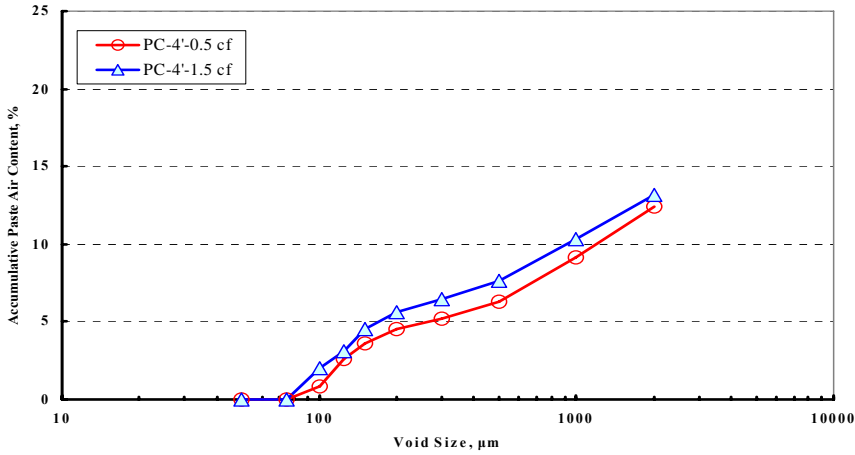


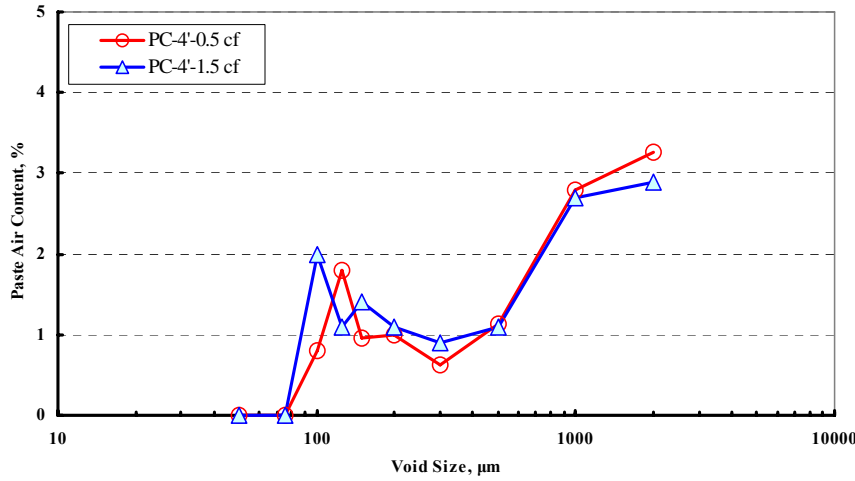
Figure 9. Effect of mixer on the AVA results (portland cement one-step four-min. mixing)

Based on Figure 9, the big mixer produces nearly the same total air content as the small mixer for the concrete at every mixing time, but it reduces the spacing factor and increases the specific surface of the concrete air void at every mixing time.

The air void distributions of the mixture mixed with two mixers are plotted in Figure 10. According to Figure 10(a), a larger mixer, with more mixing energy, made the distribution curve at smaller air void levels shift leftward. That is, there are more small air voids and fewer large air voids in the mixture. Figure 10(b) indicates that the total air contents of the mixture produced by the two mixers are close. The accumulative air void curve of the mixture made with the larger mixer moves leftward, which indicates more fine air voids in the mixture.



(a)



(b)

Figure 10. Mixer effect on air void distribution (portland cement one-step four-min. mixing)

RESEARCH FINDINGS

The major findings from this study are summarized in the following:

1. AVA tests indicate that 15 % fly ash replacement for portland cement reduces the spacing factor of the concrete. Addition of a water reducer also significantly reduces the spacing factor and increases the specific surface of concrete.
2. The two-step mixing method produces a higher spacing factor and increases the amount of small-size air voids while reducing the large air voids, when compared to the one-step mixing method.
3. When a small-pan lab mixer (0.5 cf) is used, mixing time less than four minutes seems insufficient to produce a desirable spacing factor. Two-minute mixing produces more air voids than one-minute mixing, but not as good as four-minute mixing, which produces a desirable air void distribution. Use of a large mixer appears to facilitate obtaining a normal air void system.

CONCLUSION

AVA testing can provide valuable information on the concrete air void system. This testing method is recommended for evaluating mixing and concrete quality control. Not only mixing methods, but also materials used in the concrete mixture, significantly influence concrete air void characteristics.

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