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PREVENTION OF AIR VOID FORMATION IN POLYMER-MODIFIED CEMENT MORTAR BY PRE-WETTING

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ABSTRACT

The air voids that form when cement and aggregates are mixed with an aqueous polymer solution are not easily removed because they tend to be stabilized by the polymer. Antifoaming agents can be used to prevent air void formation, but they often cause problems of poor adhesion. An alternative approach is suggested for reducing air void formation in polymer-modified mortar, which is to pre-wet the cement and sand with water, and then add a concentrated polymer solution. The air content of a PVA-modified cement mortar prepared in this way was as low as 6%, which was lower than the 13% air content of the PVA-modified mortar with an antifoaming agent, and it was much lower than the 32% air content when a PVA solution was mixed with dry cement and sand. © *1997 Elsevier Science Ltd*

Introduction

Water soluble polymers and aqueous polymer dispersions are often used to improve the properties of mortar, concrete, and cement-based composites (1-4). But when the cement mixtures are mixed with these polymer admixtures, a large volume of air voids often forms. To prevent this, various antifoaming agents can be added to the mixtures (2). These antifoaming agents, however, often cause a problem of their own, viz., poor adhesion between the cement and the reinforcements (5, 6).

The purpose of this report is to describe an alternative to the use of antifoaming agents for reducing the volume of air voids when water-soluble polymers or aqueous polymer dispersions are added to mortar, concrete, and cement-based composites. The alternative is a mixing technique that was suggested by examining the mechanism of air void formation. The technique involves pre-wetting the cement and sand with plain water before adding the polymer solution or dispersion. A comparison of this technique with the use of antifoaming agents is described in the following.

Experimental

A commercial ASTM Type I ordinary portland cement and ASTM graded sand (ASTM C778, U.S. Silica Co.) were mixed with water or polymer solutions with a cement : sand :

water ratio of 1 : 2 : 0.5. The polymer used in this test was poly(vinyl alcohol) (PVA) (Airvol 203, Air Products and Chemicals, Inc.), as 87-89% hydrolyzed poly(vinyl acetate) in granular form. The PVA powder was dispersed in cold water at 20 wt% concentration, which was then heated to 90°C with stirring to completely dissolve the polymer. The solution was cooled to room temperature and diluted with water to the desired concentrations. The polymer content in the mortars was 1.0 wt% with respect to cement. When an antifoaming agent was used, 1% (with respect to polymer) of Foamaster V (Henkel Co.) was dispersed in the water before the PVA was added and dissolved, as described above. This is the concentration of Foamaster V suggested by Henkel.

Base specimens were prepared using both the ASTM and a slower mixing. ASTM mixing for cement mortar, using a planetary mixer specified by ASTM C305, was used as the standard mixing procedure. ASTM C305 mixing consists of a sequence of mixings that amount to a total of 1.0 min agitation with a paddle speed of 140 rpm followed by a total of 1.5 min at a speed of 285 rpm. To determine the effect of agitation on air void formation, a slower mixing was also used, which consisted of a total of 6 min at a paddle speed of 30 rpm, using the same mixer. In this, water (or PVA solution) and cement were mixed together for 2 min, then sand was added over 1 min with continued mixing, and the whole was mixed for another 3 min. During this mixing, the mixing bowl was vibrated to minimize void retention.

For the specimen without PVA (Mortar W), 1 part of cement (500 g) and 2 parts of sand (1000 g) were mixed with 0.50 parts (250 g) of plain water. The specimen with PVA (Mortar P) was prepared by mixing the same amounts of cement and sand with 0.5 parts of 2% PVA solution, which results in 1.0% PVA based on the weight of cement. For the specimen with PVA and antifoaming agent (Mortar PA), cement and sand were mixed with 2% PVA solution containing the antifoaming agent.

To prepare specimens by pre-wetting (Mortar WP), cement and sand were mixed with 0.45 parts of plain water, using standard ASTM C305 mortar mixing. This was then vibrated for 2 min to remove large air voids. Finally, 0.05 parts of 20% PVA solution (to yield 1.0% PVA based on the cement) was mixed with the pre-wetted mortar at 30 rpm for 3 min. During the latter, the mixing bowl was vibrated to minimize void formation. To determine the effect of fast agitation on void formation, pre-wetted mortar and PVA solution were also mixed at 285 rpm for 1 min.

The air content of the fresh mortars was calculated from their densities, obtained by measuring the weight of mortar that filled a glass vessel having a volume of 475 ml (ASTM C185). The individual densities of the cement and sand were measured by displacement in water. After mixing, all mortar specimens were vibrated in the mixing bowl for 2 min to remove the larger air voids. After filling the glass vessel, the specimens were vibrated again for 1 min before their weights were measured.

For microscopic observation, some portion of each mortar was poured into a separate container with vibration. The containers were sealed and the mortar hydrated for 7 d. The hardened mortars were cut with a diamond saw, and the cut surfaces were examined with an optical microscope.

Results

The air contents of the different mortars are shown in FIG. 1. The reference mortar without PVA (Mortar W) prepared by ASTM mixing had 1.4% air content. The slower mixing of Mortar W yielded an air content of about 0.2%. The air contents shown were those after

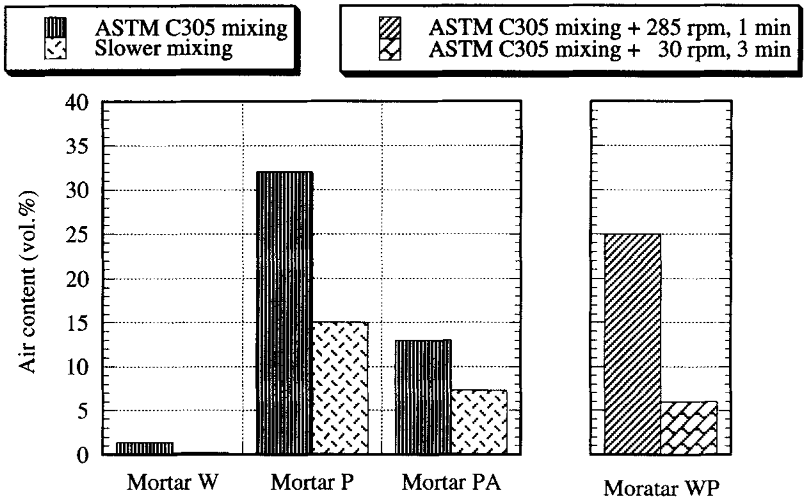

FIG. 1.
The air contents of mortars prepared without PVA (Mortar W), with PVA added with the initial water (Mortar P), with PVA and antifoaming agent added with the initial water (Mortar PA), and the specimen prepared by the pre-wetting technique (Mortar WP). Various mixing procedures were used for each (see text).

using vibration to remove the largest air bubbles or voids. The addition of PVA was found in all cases to increase the air content of mortar above that of the mortar without PVA. ASTM C305 mixing of cement and sand with a 2% PVA solution is seen to have yielded a 32% air content after vibration; slower mixing still yielded a 15% air content. The use of an antifoaming agent in the PVA solution is seen in FIG. 1 to have considerably reduced the air content with PVA. However, the air content still remained at 13% when the specimen was prepared by ASTM C305 mixing and at 7% when prepared by slower mixing. The use of the pre-wetting technique, in which the cement and sand were first mixed with plain water using ASTM C305 mixing and then mixed with concentrated PVA solution for 3 min at only 30 rpm, is seen in FIG. 1 to have yielded an air content of only 6%. When the pre-wetted mortar was vigorously mixed with concentrated PVA solution at high speed (285 rpm, 1 min), the air content was 25%.

The slower mixing is generally not recommended because it is not effective in breaking up the agglomerates of cement powder. Such agglomerates were observed in sections of the hydrated mortar specimens when mixed with a paddle speed of 30 rpm, especially those with PVA. This was true regardless of whether an antifoaming agent was used or not. With the pre-wetting technique, in which the cement, sand, and water were first mixed using ASTM C305 mixing, and then mixed with concentrated PVA solution at a slower speed, cement agglomerates were seldom seen.

Optical micrographs of sections through the mortars receiving ASTM C305 mixing are shown in FIG. 2. The micrographs show the distributions of air voids, which appear in these micrographs as the darker entities. Consistent with its minimal air content, relatively few air voids were seen to be trapped in the cement mortar obtained with plain water (Mortar W); those trapped were generally larger than 1 mm in diameter. In contrast, many air voids, broadly distributed in size with some of them approaching several millimeters in diameter, were trapped in the mortar prepared by adding PVA with the initial water (Mortar P). The

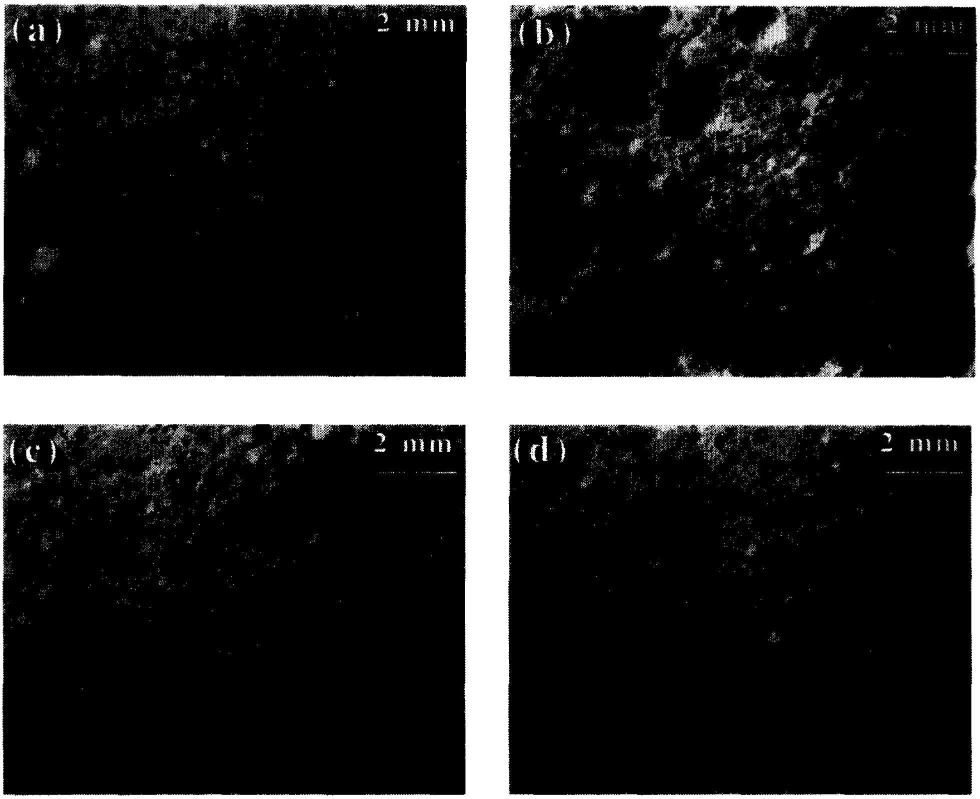

FIG. 2.
Optical micrographs of sections through the mortars receiving ASTM C305 mixing. (a) Mortar obtained with plain water (Mortar W), (b) mortar prepared by adding PVA with the initial water (Mortar P), (c) mortar prepared with an antifoaming agent (Mortar PA), and (d) mortar prepared by the pre-wetting technique, with the final additional mixing at 30 rpm (Mortar WP).

mortar prepared with an antifoaming agent (Mortar PA) had a relatively large number of smaller air voids. The air voids in the specimen prepared by the pre-wetting technique, with the final additional mixing at 30 rpm (Mortar WP), are similar in size to those formed with antifoaming agent (Mortar PA), but are fewer in number.

Discussion

The excessive air void formation in PVA-modified mortar prepared by mixing PVA solution with cement and sand could be substantially reduced by the pre-wetting technique. The air content of the PVA-modified mortar prepared by pre-wetting was lower even than that obtained by mixing PVA solution containing antifoaming agent with cement and sand. The size distributions of air voids of the two specimens were comparable.

Air voids can form in mortars in two ways. The first is by a nonuniform wicking of the liquid through the cement and sand, with the liquid advancing faster where the cement or

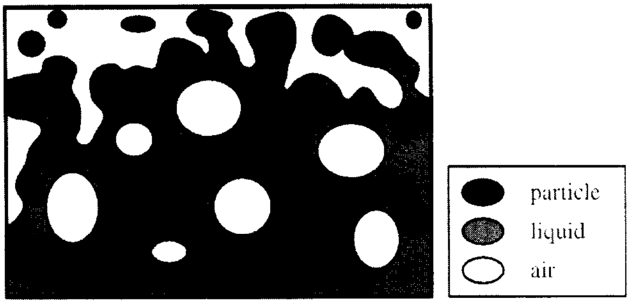

FIG. 3.
Void formation during wetting of powder with a liquid. Air voids are entrapped because of the nonuniform advancement of the liquid front caused by the irregular packing of particles.

sand particles are closer together (FIG. 3), occasionally trapping air left behind to create air voids. Air voids formed in this way are usually small. The second way by which air voids can form is by the whipping of air into the mix from the surface during mechanical mixing. This usually results in large air voids; however, these voids may be broken into smaller ones by the shear of continued mixing (7).

The contributions of the two mechanisms to air void formation in PVA-modified mortar can be estimated by comparing the air contents given in FIG. 1. Following the mixing of cement, sand, and water in the pre-wetting procedure, the air content was presumably similar to that of Mortar W, or about 1%. Hence, the increase to 6% air content after adding the PVA with slow mixing suggests that the slow mixing with PVA induced 5% air voids. On the other hand, fast mixing with PVA seems to have induced an additional 19% or so, to give a total of about 25% air voids. A similar 17% difference was found between fast and slow mixing with Mortar P. Also, the nonuniform wicking of PVA-solution through the dry cement-sand mixture seems to contribute about 8% air. This is deduced by comparing Mortars P and WP: the difference with fast mixing is 7%, and the difference with slow mixing is 9%.

The increased air voids content in mortars containing PVA arises from the enhanced stability of the air voids. Mechanical mixing both induces air voids and helps in their elimination, because it can bring small air voids together so they can merge to form bigger voids, which have an increased buoyancy and rise to the surface and rupture (7). But the tendency to merge depends on the surface energy gradient and viscosity (viscoelasticity) of the liquid membrane separating pairs of voids before they merge (8). Without PVA, there is minimal surface energy gradient and little film viscoelasticity, and small air voids merge rapidly and are eliminated. With PVA, which has mild surfactant properties, a surface energy gradient can develop as well as significant film viscoelasticity, causing a stabilization of small air voids. Antifoaming agents, which are usually very small droplets of liquid or very fine particles with very low surface energy, reduce the stability of air voids, even with PVA, thereby helping to eliminate the air voids (5). But as mentioned, antifoaming agents can cause unwanted effects, such as poor adhesion. Pre-wetting avoids the problem of air void stability enhancement by minimizing the creation of air voids when PVA is being incorporated.

The pre-wetting technique described is applicable to any foaming admixture and is especially useful where antifoaming agents can cause problems such as poor adhesion. However, the technique is limited to ratios of total water to cement (or water to solid) that are high enough for the amount of pre-wetting water to completely fill the voids between the particles and for the pre-wetted mixture to have enough fluidity to mix the polymer solution without serious void formation.

Conclusions

Air voids that form by non-uniform wetting and mechanical whipping when dry cement and aggregates are mixed with a polymer solution are not easily removed because of their stabilization by the polymer. However, air void formation can be effectively prevented without the use of antifoaming agents, as demonstrated for PVA-modified cement mortar, by pre-wetting the cement powder and sand first with water and then carefully mixing in a concentrated solution of the polymer.

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