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Water Retention and Adhesion of Powdered and Aqueous Polymer-Modified Mortars

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Abstract

This paper evaluates and compares the water retention in the fresh state and adhesion or bond strength in the hardened state of powdered and aqueous polymer-modified mortars. The polymer-modified mortars using various powdered and aqueous cement modifiers were prepared with different polymer–cement ratios, and tested for water retention in the fresh state and adhesion in tension in the hardened state. In conclusion, the powdered as well as aqueous polymer-modified mortars show markedly improved water retention and adhesion in tension, which increase with a rise in the polymer–cement ratio regardless of the type of cement modifiers used. The magnitude of improvement in the water retention and adhesion in tension of the powdered and aqueous polymer-modified mortars, however, depends upon the type of cement modifiers used, polymer–cement ratios or both. Moreover, the failure mode distribution of the powdered and aqueous polymer-modified mortars depends on the type of cement modifiers used, polymer–cement ratio, or both.

Keywords: Polymer-modified mortars, powdered polymer-modified mortars, aqueous polymer-modified mortars, powdered cement modifiers, aqueous cement modifiers, polymer–cement ratio, water retention, adhesion.

INTRODUCTION

Polymer-modified mortars are being widely used as high-performance, low-cost construction materials, particularly for finishing and repairing works because of their excellent performance and durability. To produce polymer-modified mortars, mostly aqueous polymer dispersions (aqueous cement modifiers), like styrene–butadiene rubber (SBR) latex, ethylene–vinyl acetate (EVA) and polyacrylic ester (PAE) emulsions, are added to ordinary cement mortar during mixing.[1] However, at the job-site, problems are sometimes faced in preparing mixes from the aqueous cement modifiers because of the complex mix calculations. To overcome the problems, a more recent advance is the advent of powdered emulsions (powdered cement modifiers) with improved qualities.[2] Almost no data are available on the properties of the mortars modified by such powdered cement modifiers except the studies of Ohama & Shiroishida[2] and Hackel *et al.*[3]

The objective of this study is to evaluate and compare the water retention in fresh state and adhesion or bond strength in hardened state of powdered and aqueous polymer-modified mortars. These properties are important to study because they are the basic requirements of any finishing and repairing construction materials.

In this paper, polymer-modified mortars using four types of commercially available powdered cement modifiers and two types of commercially available aqueous cement modifiers were prepared with various polymer–cement ratios, and tested for water retention in fresh state and adhesion or bond strength in hardened state.

MATERIALS

Cement and fine aggregate

Ordinary Portland cement and Toyoura standard sand as specified in JIS (Japanese Industrial Standard) were used in all mixes. The chemical compositions and physical properties of the cement are listed in Table 1.

Cement modifiers

Four powdered and two aqueous cement modifiers, all commercially available, were used in this study. The powdered cement modifiers used include one brand of poly(vinyl acetate–vinyl carboxylate) (VA/VeoVa) type and three brands of poly(ethylene–vinyl acetate) (EVA) type. The aqueous cement modifiers used were one brand of EVA emulsion and one brand of SBR latex type. Their basic properties are given in Table 2. Before mixing, a silicone emulsion type antifoamer, containing 30% silicone solids, was added to the cement modifiers in a ratio of 0·7% of the silicone solids in the antifoamer to the total solids in the powdered and aqueous cement modifiers.

TESTING PROCEDURES

Preparation of mortars

Polymer-modified mortars were mixed according to JIS A 1171 (Method of Making Test Samples of Polymer-Modified Mortar in Laboratory) as follows: cement:standard sand=1:3 (by weight); polymer–cement ratios (P/C) (calculated on the basis of total solids in cement modifiers) of 0, 5, 10, 15 and 20%, and their flows were adjusted to be constant at 170 ± 5. The mix proportions of the polymer-modified mortars are given in Table 3.

Water retention test

After mixing, the fresh polymer-modified mortars were tested for water retention in accordance with the procedure of Ohama[4] and the water retention percentage was calculated from the water contents of the mortar sample before and after suction according to the following formulae:

$$\text{water retention}\% = \frac{\left(\begin{array}{l}\text{water content of sample in}\\ \text{receiving pan after suction}\end{array}\right)}{\left(\begin{array}{l}\text{water content of sample in}\\ \text{receiving pan before suction}\end{array}\right)} \times 100$$

Adhesion test

Mortar substrates $70 \times 70 \times 20$ mm, as shown in Fig. 1, were first molded with ordinary mortar (cement:Toyoura standard sand=1:2; water–cement ratio=65·0%) in accordance with the JIS R 5201 (Physical Testing Methods

Table 1. Chemical compositions and physical properties of cement

(a) Chemical compositions (%)

Ig. loss	*Insol.*	*SiO_2*	*Al_2O_3*	*Fe_2O_3*	*CaO*	*MgO*	*SO_3*	*Total*
1·0	0·1	22·0	5·2	3·2	65·0	1·4	1·8	99·7

(b) Physical properties

Specific gravity (20°C)	*Fineness*		*Setting time*		*Flexural strength of mortar ($kgf\ cm^{-2}$)*			*Compressive strength of mortar ($kgf\ cm^{-2}$)*		
	Residue on sieve of 88 μm (%)	*Blaine's specific surface area ($cm^2\ g^{-1}$)*	*Initial set (h:min)*	*Final set (h:min)*	*3 days*	*7 days*	*28 days*	*3 days*	*7 days*	*28 days*
3·16	1·4	3250	2:31	3:32	34	50	73	150	251	417

Table 2. Typical properties of cement modifiers

Type of cement modifier	*Stabilizer type*	*Appearance*	*Specific gravity (20°C)*	*pH (20°C)*	*Viscosity solids (20°C, cP)*	*Total*
Powdered VA/VeoVa emulsion	Anionic	Milky-white powder without coarse particles	1·100	—	—	—
Powdered EVA-1 emulsion	Anionic	Milky-white powder without coarse particles	1·180	—	—	—
Powdered EVA-2 emulsion	Anionic	Milky-white powder without coarse particles	1·120	—	—	—
Powdered EVA-3 emulsion	Anionic	Milky-white powder without coarse particles	1·180	—	—	—
EVA emulsion	Anionic	Milky-white aqueous dispersion	1·056	5·2	1600	44·4
SBR latex	Anionic	Milky-white aqueous dispersion	1·019	8·5	155	45·8

Table 3. Mix proportions of polymer-modified mortars

Type of mortar	*Cement: sand (by weight)*	*Polymer–cement ratio (%)*	*Water–cement ratio (%)*	*Flow*
Unmodified	1:3	0	77·5	165
Powdered VA/VeoVa-modified	1:3	5	72·2	172
		10	75·5	172
		15	76·2	173
		20	75·0	168
Powdered EVA-1-modified	1:3	5	73·8	170
		10	75·2	173
		15	73·0	170
		20	73·8	172
Powdered EVA-2-modified	1:3	5	76·2	167
		10	76·5	168
		15	76·2	172
		20	76·2	168
Powdered EVA-3-modified	1:3	5	76·2	168
		10	76·5	170
		15	77·5	168
		20	77·5	169
EVA-modified	1:3	5	72·5	170
		10	66·8	167
		15	63·0	167
		20	59·8	168
SBR-modified	1:3	5	74·2	172
		10	70·6	168
		15	62·8	168
		20	57·7	168

for Cement), and then given a 1-day–20°C–80% RH-moist + 6-day–20°C-water + 7-day–20°C–50% RH-day cure. Then the bonding surfaces of the mortar substrates were rubbed by the AA-150 abrasive papers specified in JIS R 6252 (Abrasive Papers), and compressed air was blown on them for removing dust. The polymer-modified mortars 40 × 40 × 10 mm, as shown in Fig. 1, were placed on the mortar substrate to make specimens, and the specimens were subjected to a 2-day–20°C-80% RH-moist + 5-day–20°C–water + 21-day–20°C–50% RH-dry cure. The cured specimens were tested for adhesion in tension in accordance with JIS A 6915 (Wall Coatings for Thick Textured Finishes). The adhesion or bond strength of the specimens was calculated by dividing the maximum load (the load carried by the specimens at failure) by the area of the bonded surface as follows:

$$\text{Adhesion in tension (kgf cm}^{-2}) = P/A$$

where P is the maximum load (kg) and A is the area (cm^2) of the bonded surface. After the adhesion tests, the failed cross-sections of the specimens were observed for failure modes, which were classified into the following three types:

M cohesive failure in polymer-modified mortars
A adhesive failure (failure in the interface)
S cohesive failure in mortar substrate (ordinary cement mortar)

The respective approximate rates of *M*, *A* and *S* areas in the total area of 10 on the failed cross-sections are expressed as suffixes for *M*, *A* and *S*.

TEST RESULTS AND DISCUSSION

Water retention

Figure 2 illustrates the relationship between polymer–cement ratio and water retention of polymer-modified mortars in fresh state. Irrespective of the types of cement modifiers, both powdered and aqueous polymer-modified mortars show markedly improved water retention as compared to unmodified mortar. The water retention of the powdered and aqueous polymer-modified mortars increases with a rise in polymer–cement ratio; however, the magnitude of an improvement in the water retention depends upon the types of cement modifiers used, polymer–cement ratio or both. The reasons for the improvement in the water retention of the powdered and aqueous polymer-modified mortars with a rise in the polymer–cement ratio are considered as follows: (1) a gradual increase in the viscosity of the mixing water, with increasing polymer–cement ratio, makes the movement of resulting high-viscosity aqueous phase gradually more difficult;[4] (2) the increases in the hydrophilic colloidal properties of the cement modifiers; (3) the inhibited water evaporation due to the filling and sealing effects of the impermeable polymer films formed in the polymer-modified mortars.[5] Overall, the water retention of all the powdered polymer-modified mortars is comparable to that of the aqueous polymer-modified mortars.

Adhesion

Figure 3 shows the relationship between the polymer–cement ratio and adhesion in tension of polymer-modified mortars. Irrespective of

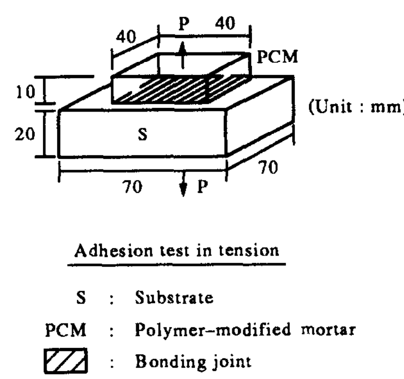

Fig. 1. Test method for adhesion in tension.

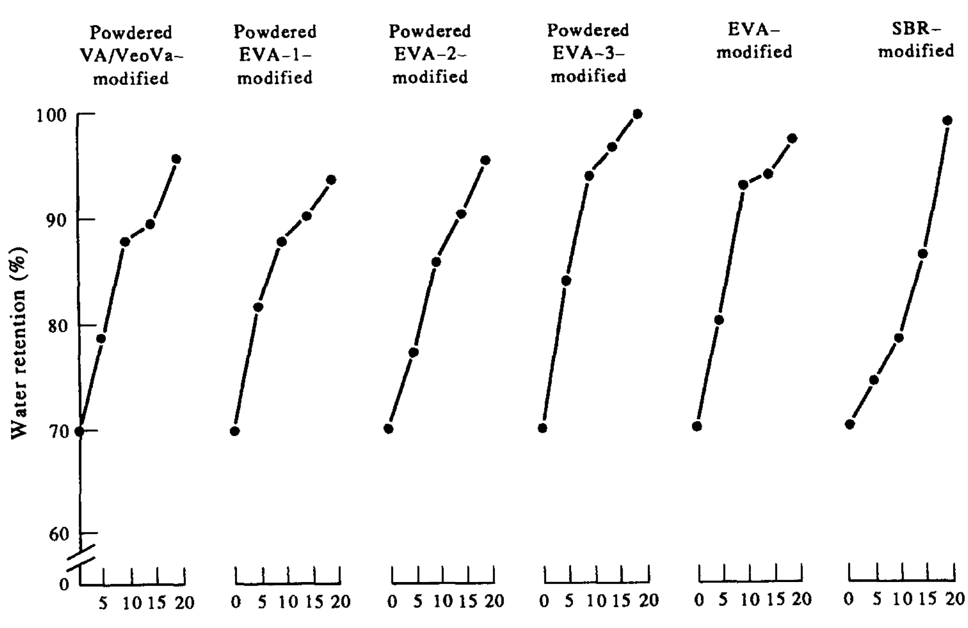

Fig. 2. Polymer–cement ratio vs water retention of polymer-modified mortars.

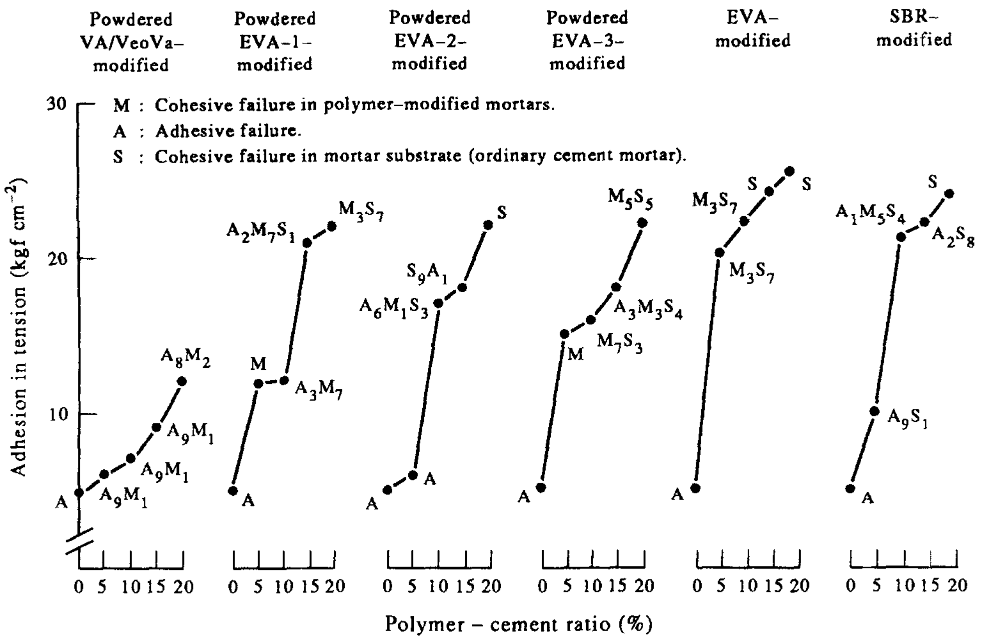

Fig. 3. Polymer–cement ratio vs adhesion in tension of polymer-modified mortars.

the types of cement modifiers, both powdered and aqueous polymer-modified mortars show remarkably improved adhesion as compared to unmodified mortar. The higher adhesion of the powdered and aqueous polymer-modified mortars is found to be due to higher adhesion of cement modifiers present in them.[6,7] The adhesion of the powdered and aqueous polymer-modified mortars increases with increase in the polymer–cement ratio; however, the magnitude of an improvement in the adhesion depends upon the types of the cement modifiers used, polymer–cement ratio, or both. Among the powdered polymer-modified mortars, powdered EVA-1-modified, powdered EVA-2-modified and powdered EVA-3-modified mortars provide a higher adhesion than powdered VA/VeoVa-modified mortars. Among the aqueous polymer-modified mortars, EVA-modified mortars have a slightly higher adhesion than SBR-modified mortars. Generally, the adhesion of the powdered EVA-1-modified, powdered EVA-2-modified and powdered EVA-3-modified mortars is almost comparable to that of the aqueous polymer-modified mortars. In general, the failure modes in adhesion in tension of 22 kgf cm^{-2} or more are purely cohesive failure in mortar substrate for powdered EVA-2-modified mortars and most of the aqueous polymer-modified mortars, and a mixture of cohesive failure in the polymer-modified mortars and cohesive failure in the mortar substrate for powdered EVA-1-modified and powdered EVA-3-modified mortars.

Figure 4 exhibits the failure mode distribution of polymer-modified mortars in adhesion test in tension. The failure mode distribution of the powdered as well as aqueous polymer-modified mortars depends upon the types of cement modifiers used, polymer–cement ratio, or both. In both powdered and aqueous polymer-modified mortars, generally the percentage of cohesive failure in mortar substrate increases with a rise in polymer–cement ratio, and at the same time, the percentages of adhesive failure and of cohesive failure in the polymer-modified mortars decrease. At a polymer–cement ratio of 20%, powdered EVA-2-modified, EVA-modified and SBR-modified mortars show purely cohesive failure in the mortar substrate, while powdered EVA-1-modified and powdered EVA-3-modified mortars show a mixture of cohesive failure in the polymer-modified mortars and cohesive failure in the mortar substrate. The powdered VA/VeoVa-modified mortars, however, provide a slight variation in the failure mode distribution relative to the rest of the powdered and aqueous polymer-modified mortars as they did not show any cohesive failure in the mortar substrate up to a polymer–cement ratio of 20%. The failure mode distribution of powdered VA/VeoVa-modified mortars is a mixture of adhesive failure and cohesive failure in the polymer-modified mortars.

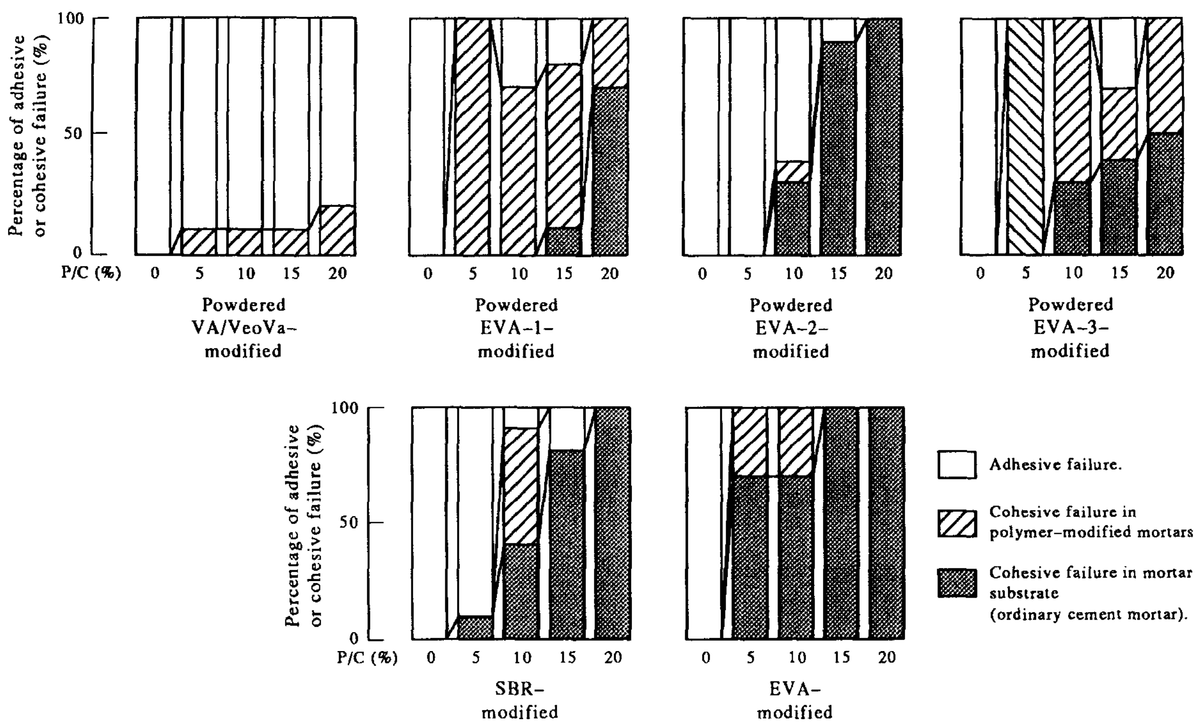

Fig. 4. Failure mode distribution of polymer-modified mortars in adhesion test in tension.

CONCLUSIONS

(1) Powdered and aqueous polymer-modified mortars show a comparable marked improvement in water retention. The water retention of the powdered and aqueous polymer-modified mortars increases with a rise in polymer–cement ratio, however, the magnitude of the improvement depends upon the types of cement modifiers used, polymer–cement ratio, or both.

(2) Powdered and aqueous polymer-modified mortars provide a remarkable improvement in adhesion in tension to ordinary cement mortar. The adhesion of the powdered and aqueous polymer-modified mortars increases with a rise in polymer–cement ratio, however, the magnitude of the improvement depends upon the types of cement modifiers used, polymer–cement ratio, or both. Powdered EVA-1-modified, powdered EVA-2-modified and powdered EVA-3-modified mortars have almost comparable adhesion to that of the aqueous polymer-modified mortars, whereas the adhesion of powdered VA/VeoVa-modified mortars is comparatively less than that of the aqueous polymer-modified mortars.

(3) The failure mode distribution in adhesion test in tension depends upon the types of cement modifiers used, polymer–cement ratio, or both.

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