

論文

[1166] ADHESION OF POLYMER-MODIFIED MORTARS TO REINFORCING BARS

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1. INTRODUCTION

In recent years, the rapid deterioration of reinforced concrete structures has become a serious problem in the world, and various repair and renovation techniques for damaged reinforced concrete structures have actively been developed. Polymer-modified mortars are widely used as repairing materials because of their superior durability and good adhesion to concrete surfaces[1]. However, the bond or adhesion of the polymer-modified mortars to reinforcing bars remains doubtful, because it is considered that the bond or adhesion depends on the type of polymer dispersion and the polymer-cement ratio[2].

In this research work, polymer-modified mortars using cationic, anionic and nonionic polymer dispersions are prepared with various polymer-cement ratios, and tested for bond strength through the pull-out of vertically embedded reinforcing bars in the mortars. Since the polymer-modified mortars are found to reduce their bond strength to some extent after water immersion, the retention of the bond strength of the polymer-modified mortars to the reinforcing bars through water immersion is also examined. Moreover, the bond or adhesion mechanism of the polymer-modified mortars to the reinforcing bars has been proposed with the help of model diagrams.

2. MATERIALS

2.1 CEMENT AND AGGREGATE

Ordinary portland cement and Toyoura standard sand were used for the mix proportions of unmodified and polymer-modified mortars.

2.2 POLYMER DISPERSIONS FOR CEMENT MODIFIERS

Commercial cement modifiers used were six types of polymer dispersions, and classified as follows:

- (1) Cationic polymer dispersions: Cationic polyacrylic ester emulsions, C-PAE-1 and C-PAE-2, and cationic styrene-butadiene latex, C-SBR.
- (2) Anionic polymer dispersion: Anionic styrene-butadiene latex, A-SBR.
- (3) Nonionic polymer dispersions: Nonionic ethylene-vinyl acetate emulsion

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N-EVA, and nonionic polyacrylic ester emulsion, N-PAE.

The properties of the polymer dispersions are listed in Table 1. Before mixing, a silicone-emulsion-type antifoamer was added to the polymer dispersions in a ratio of (the silicone solids of the antifoamer) to (the total solids of the polymer dispersions) of 0.7%.

Table 1 Properties of Polymer Dispersions.

Type of Polymer	Specific Gravity (20°C)	pH (20°C)	Viscosity (20°C, cP)	Total Solids (%)
C-PAE-1	1.04	9.5	34	38.8
C-PAE-2	1.02	8.5	6	30.4
C-SBR	1.02	8.3	7	30.1
A-SBR	1.02	8.9	125	45.1
N-EVA	1.06	4.7	1360	44.3
N-PAE	1.08	9.3	52	44.7

2.3 REINFORCING BARS

Reinforcing bars of 19 mm in diameter, having the qualities of SR30 (Hot Rolled Steel Bar) as specified in JIS G 3112 (Steel Bars for Concrete Reinforcement) were employed for bond strength test.

Table 2 Mix Proportions of Polymer-Modified Mortars.

3. TESTING PROCEDURES

3.1 PREPARATION OF SPECIMENS

According to JIS A 1171 (Method of Making Test Sample of Polymer-Modified Mortar in the Laboratory), polymer-modified mortars were mixed with the mix proportions given in Table 2. Cubic mortar specimens with each edge of 10cm, having a single reinforcing bar embedded vertically along a central axis in each specimen, were molded in

Type of Mortar	Cement : Sand (By Weight)	Polymer-Cement Ratio (%)	Water-Cement Ratio (%)	Air Content (%)	Flow
Unmodified	1 : 3	0	77.2	6.5	171
C-PAE-1-Modified	1 : 3	5	67.7	—	170
		10	65.3	10.1	166
		15	60.6	—	169
		20	54.4	10.4	170
C-PAE-2-Modified	1 : 3	5	59.7	—	172
		10	57.3	17.5	174
		15	54.2	—	171
		20	50.3	15.2	173
C-SBR-Modified	1 : 3	5	69.0	—	167
		10	65.7	11.9	166
		15	64.5	—	168
		20	62.2	12.4	166
N-SBR-Modified	1 : 3	10	68.1	6.5	170
		20	63.9	6.6	170
N-EVA-Modified	1 : 3	10	64.7	9.7	172
		20	57.5	4.0	168
N-PAE-Modified	1 : 3	10	46.8	22.0	170
		20	45.7	19.7	173

accordance with ASTM C 234 (Standard Test Method for Comparing Concretes on the Basis of the Bond Developed with Reinforcing Steel). The specimens were subjected to a 2-day-20°C-80% R.H.-moist, 5-day-20°C-water and 21-day-20°C-50% R.H.-dry cure.

3.2 BOND STRENGTH TEST

3.2.1 Measurement of Bond Strength

According to ASTM C 234, specimens were tested for bond strength in direct tension by the pull-out of the reinforcing bars embedded in the specimens at a no-load speed of the testing machine head of 1 mm/min. In order to measure the slip of the reinforcing bars, a strain gage-type displacement transducer was attached to the opposite side of each

vertically projecting reinforcing bar, and the slip of the reinforcing bars was measured by using a digital strain meter at a loading interval of 100 kgf.

3.2.2 Measurement of Retention of Bond Strength after Water Immersion

To measure the retention of bond strength, specimens were immersed in tap water at 20°C for 7 days. After water immersion, the specimens were tested for bond strength in the same manner as in 3.2.1. The retention of the bond strength of the specimens after water immersion was calculated as follows:

$$\text{Retention of bond strength (\%)} = (\bar{\sigma}_{b1} / \bar{\sigma}_{b0}) \times 100$$

where $\bar{\sigma}_{b0}$ and $\bar{\sigma}_{b1}$ are the bond strengths before and after water immersions respectively.

4. TEST RESULTS AND DISCUSSION

Fig. 1 shows the typical bond stress-slip curves for the reinforcing bars embedded in cationic polymer, C-PAE-2-modified mortars. The failure of the bond or adhesion between C-PAE-2-modified mortars and the reinforcing bars occurs at the maximum bond stress, followed by the pull-out of the reinforcing bars. With a raise in polymer-cement ratio, an increase in the maximum bond stress of the reinforcing bars in C-PAE-2-modified mortars is achieved. Moreover, the friction-controlled slip which occurs after the loss of the bond between C-PAE-2-modified mortars and the reinforcing bars is relatively higher than that of unmodified mortar. The debonding of the reinforcing bars from C-PAE-2-modified mortars takes place as a result of microcracking in the polymer-cement co-matrixes at the reinforcing bar-C-PAE-2-modified mortar interfaces[3]. The microcracking in the interfacial co-matrixes is retarded by the reinforcement by polymer films in them, which conduces to attain higher bond between C-PAE-2-modified mortars and the bars.

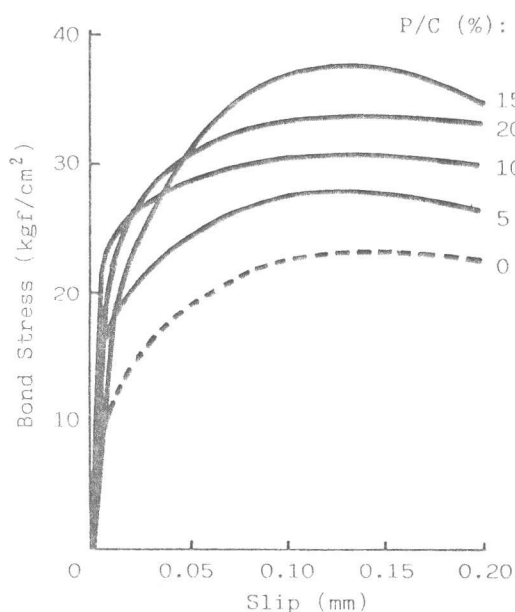


Fig. 1 Bond Stress-Slip Curves for C-PAE-2-Modified Mortars.

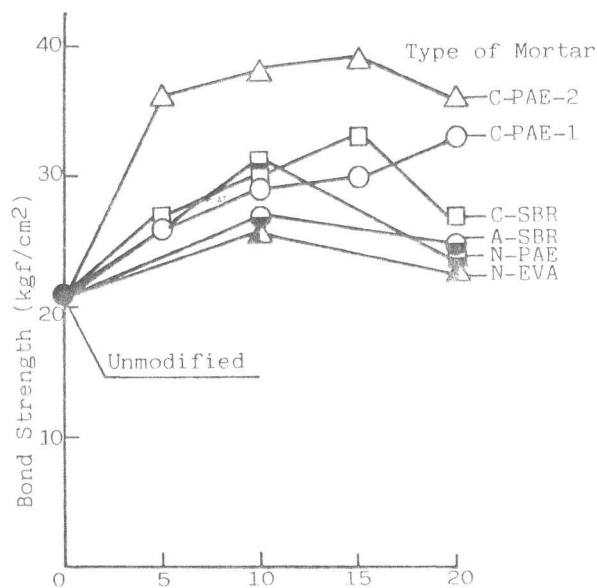


Fig. 2 Polymer-Cement Ratio (%)

Bond Strength of Polymer-Modified Mortars to Embedded Reinforcing Bars.

Fig.2 illustrates the bond strength of polymer-modified mortars to embedded reinforcing bars. Generally, the bond strength of cationic polymer-modified mortars to the embedded reinforcing bars is much higher than that of unmodified, anionic and nonionic polymer-modified mortars. In particular, the bond strength of the cationic polymer-modified mortars increases considerably with raising polymer-cement ratio. By contrast, the bond strength of the anionic and nonionic polymer-modified mortars tends to decrease with an increase in the polymer-cement ratio from 10 to 20%. The highest bond strength is obtained for cationic polymer, C-PAE-2-modified mortars with polymer-cement ratios of 10 and 15 %. In general, the bond strength of the polymer-modified mortars to the reinforcing bars is greatly influenced by the type of polymer dispersion used. In addition, the type of polymer dispersion drastically influences the water-cement ratio and air content of the polymer-modified mortars. However, in this research work, the relatively low water-cement ratio or high air content of the polymer-modified mortars hardly affect their bond strength to the reinforcing bars. This may be the result of the good compaction of the polymer-modified mortars and the vertical embedment of the reinforcing bars in them. The dominating effect of the type of polymer dispersion on the bond strength is the result of the differences in the physical properties of the polymer-cement co-matrixes which envelope the reinforcing bars and sand particles. Nakayama and Beaudoin[4] have studied on the morphology of the interfaces between the reinforcing bars and polymer-cement co-matrixes, and made clear the presence of a kind of interlocking mechanism of polymer films and calcium silicate hydrate crystals at the interfaces. The physico-chemical interactions at the interfaces of the reinforcing bars and the co-matrixes also influence the bond or adhesion of the polymer-modified mortars to the reinforcing bars. In addition, the intermolecular forces between the polymer-modified mortars and reinforcing bars contribute to the bond between them.

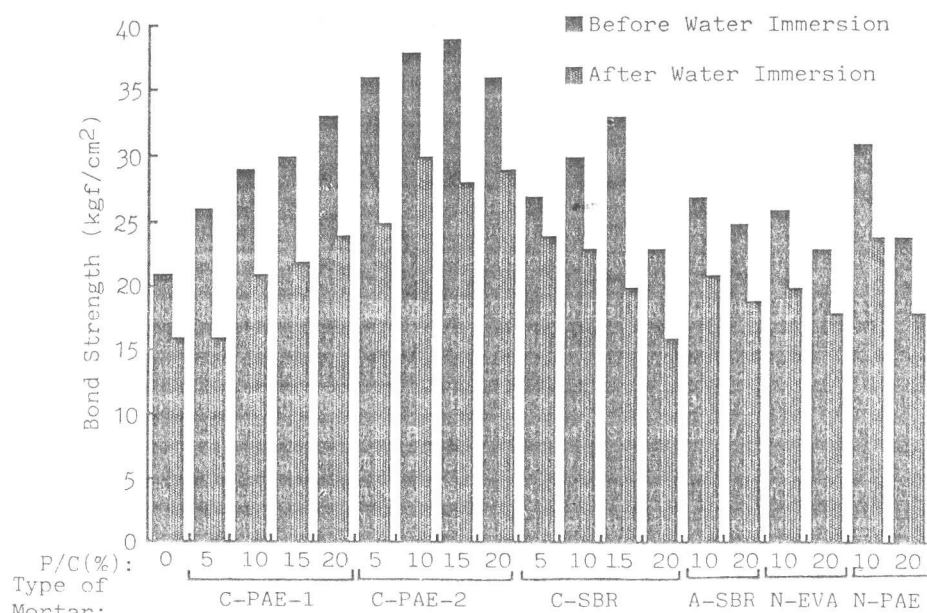


Fig. 3 Bond Strength of Polymer-Modified Mortars to Embedded Reinforcing Bars before and after 7-Day Water Immersions.

Fig.3 represents the bond strength of polymer-modified mortars to embedded reinforcing bars before and after 7-day water immersions. A similar tendency to the bond strength of the polymer-modified mortars to the embedded reinforcing bars before water immersion is observed after water immersion, i.e., the polymer-modified mortars having higher bond strength before water immersion have higher bond strength after water immersion. The bond strength of cationic polymer, C-PAE-2-modified mortars after water immersion is almost the same as or slightly higher than that of unmodified mortar before water immersion. A difference in the bond strength between the unmodified and polymer-modified mortars is about 10 to 15 kgf/cm².

Fig.4 shows the retention of bond strength of polymer-modified mortars to embedded reinforcing bars after 7-day water immersion. Except for a few cases, the retention of bond strength of the polymer-modified mortars to the reinforcing bars is 60 to 80% and is almost the same as that of the unmodified mortars.

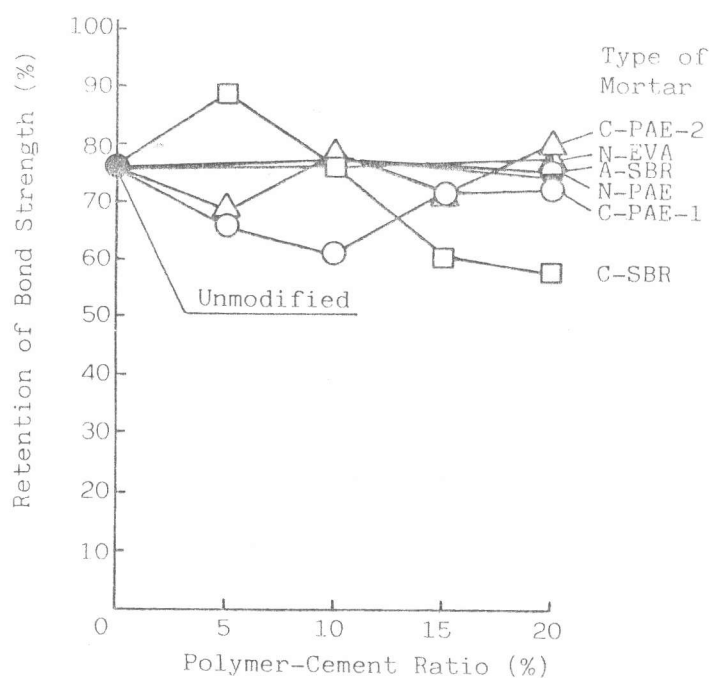
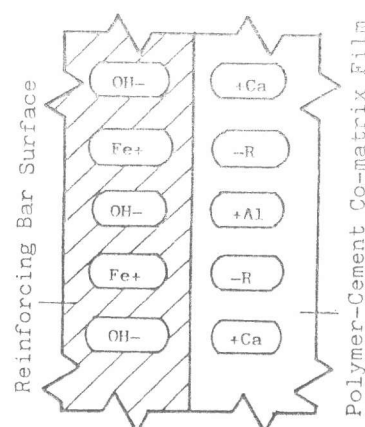


Fig. 4 Retention of Bond Strength of Polymer-Modified Mortars to Reinforcing Bars after 7-Day Water Immersion.



Notes, + and - indicate positive and negative charges respectively, and do not indicate valence. R- indicates organo-functional group.

Fig. 5 Formation of Electrical Double Layer with Mosaic Structure at Interface between Polymer-Cement Co-matrix and Reinforcing Bar.

5. BOND OR ADHESION MECHANISM OF POLYMER-MODIFIED MORTARS TO REINFORCING BARS

The bond or adhesion of polymer-modified mortars to reinforcing bars is a complex phenomenon as a result of the presence of heterogeneous microstructures of the polymer-cement co-matrixes at the interfaces. Accordingly, the type of polymer dispersions and their electrical charge largely influence the bond strength of the polymer-modified mortars to the reinforcing bars. A brief summary of the bond or adhesion mechanism of the polymer-modified mortars to the reinforcing bars is as follows:

- (1) The polymer dispersions in the polymer-modified mortars induce intermolecular bonds to the reinforcing bars[2]. In addition, the chemical interactions between the cement hydrates and reinforcing bars

also take place in both the polymer-modified and unmodified mortars. The combined effects of the polymer dispersions and cement hydrates in the polymer-modified mortars may result in the electrical double layers with mosaic structures at interfaces between the polymer-cement co-matrixes and reinforcing bars as shown in Fig. 5[5].

- (2) Furthermore, the presence of polymer films at the interfaces of the polymer-modified mortars and reinforcing bars helps to relax the stresses which occur under loading, as illustrated in Fig 6.
- (3) In addition, the friction-controlled slip between the polymer-modified mortars and reinforcing bars at the post-debonding stage is retarded by the presence of the polymer-films.

Polymer-cement co-matrix film between polymer-modified mortar and reinforcing bar, involved in bonding to reinforcing bar by intermolecular bonds and stress relaxation.

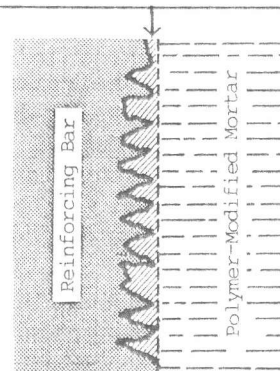


Fig. 6 Role of Co-matrix Film between Polymer-Modified Mortar and Reinforcing Bar in Improving Bond.

6. CONCLUSIONS

- (1) The bond strength of cationic polymer-modified mortars to reinforcing bars is much higher than that of unmodified, anionic and nonionic polymer-modified mortars. In particular, the bond strength of the cationic polymer-modified mortars increases considerably with raising polymer-cement ratio. In general, the type of electrical charge on the polymer particles in the polymer dispersions used and the polymer-cement ratio are the most dominant factors in the bonding of the polymer-modified mortars to the reinforcing bars.
- (2) Generally, the retention of the bond strength of polymer-modified mortars to reinforcing bars after water immersion is 60 to 80%, and is almost the same as that of unmodified mortar.
- (3) The bond or adhesion between polymer-modified mortars and reinforcing bars is the result of presence of electrochemically active polymer-cement co-matrixes at the interfaces which helps to relax stresses during loading and retards the friction-controlled slip of the reinforcing bars.

REFERENCES

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