Pergamon

Cement and Concrete Research 32 (2002) 1877–1881

CEMENT AND CONCRETE RESEARCH

A way for improving interfacial transition zone between concrete substrate and repair materials

Guangjing Xiong*, Jinwei Liu, Gengying Li, Huicai Xie

Department of Civil Engineering, Shantou University, Shantou 515063, PR China

Received 3 March 2000; accepted 30 April 2002

Abstract

An attempt to modify the repair interfacial transition zone by introducing fly ash into a primer between concrete substrate and repair materials was proposed. A comparison test was carried out for five different bond interfaces coated with five kinds of primers, namely neat cement paste, expansive paste, cement mortar, water-dispersible epoxy resin, and fly ash-modified mortar. The test results showed that the fly ash-modified primer made the microstructure of the repaired interface zone more dense and uniform. As a result, the splitting bond strength of the interface coated with the fly ash-modified primer was significantly higher than those coated with the other kinds of primers.
© 2002 Published by Elsevier Science Ltd.

Keywords: Primer; Microstructure; Bond strength; Fly ash; Hydration products

1. Introduction

Good bonding between repair materials and in situ concrete substrate is of vital importance in the concrete repairs [1–3]. It was reported that many applications of concrete repairs were not reliable though the necessary measures were taken to obtain as perfect adherence as possible (such as roughing the in situ concrete, application of a bond coat, etc.) [1]. Noticing that the primer (bond coat) is one of the main factors influencing bond quality, an investigation aimed at studying the effect of several kinds of existing primers on repaired interfacial zone (namely, neat cement paste, expansive paste, cement mortar, and water-dispersible epoxy resin) was carried out as the first part of this research program. Test results showed that the bond strengths of the specimens were low because the use of the above primers led to weak repaired interface zones. In view of these facts and in the light of that fly ash can significantly modify the weak interfacial transition zone between cement paste and coarse aggregates of a concrete, a novel method to modify the weak interfacial zone by introducing fly ash into a primer was proposed. A comparison test as the second part of this research was carried out to examine the effect of the modified primer on microstructure and bond strength of repaired interface.

2. Experimental

2.1. Materials

Ordinary Portland cement (Chinese Standard GB175-1999, analogous with ASTM C 150 Standard specification) and a Class II fly ash (Chinese Standard GB15 96-91, analogous with ASTM C 618) were used in this research. The chemical analysis and physical properties of the cement and fly ash are presented in Table 1. Crushed stone with a maximum size less than 20 mm and medium sand (2.98 modulus fineness) were used for producing new and old concretes. Fine sand with a fineness modulus of 1.76 was used for making primers.

2.1.1. New and old concrete

The composition of the old concrete specimen mixes was 0.4:1:1.57:2.55 (water/cement/medium sand/stone). The only difference of mix ratios between old and new concretes was that 10 wt.% of U-type expansive agent (on cement weight) was added in the new concrete mixes to decrease the shrinkage difference between new and old concretes.

* Corresponding author. Tel.: +86-754-290-3242; fax: +86-754-290-2005.

E-mail address: gjxiong@stu.edu.cn (G. Xiong).

0008-8846/02/$ – see front matter © 2002 Published by Elsevier Science Ltd.
PII: S0008-8846(02)00840-2

Table 1
Chemical and physical properties of cement and fly ash

	Chemical analysis (%)								Specific surface, Blaine (m^2/kg)	28 days compressive strength (MPa)
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	LOI		
Cement	19.5	4.4	6.22	65.9	1.5	1.09	0.30	1.43	462	45.9
Fly ash	52.5	19.1	8.2	14.7	1.98	0.35	0.48	3.6	565	–

2.1.2. Existed primers

The W/C ratio for the unmodified ordinary Portland cement paste primer was 0.4. The expansive paste primer was made by adding 10 wt.% of U-type expansive agent (on cement weight) in the unmodified cement paste. The mix ratio for the cement mortar was 0.4:1:1 (water/cement/sand). Proprietary water-dispersible bicomponent and one-component epoxy primers, YJ-302 and YJ-303, were used as listed in Tables 2 and 3.

2.1.3. Fly ash-modified mortar primer

The mixture proportions in the proposed modified primer were 0.4:1:1:0.15 (water/cement/fine sand/fly ash).

2.2. Specimen preparation and repair procedures

2.2.1. Specimen preparation

For the first part of this research, 35 prisms (100×100×300 mm) and 35 cubes (100×100×100 mm) were cast for the slant shear test and splitting test (Chinese Standard GBJ 81-85, analogous with ASTM C 496), respectively (Fig. 1). According to different test parameters, they were divided into 14 groups as shown in Table 2 and each group had five specimens. The age difference between new and old concrete was 3 months.

For the second part of this research, 35 cubes (100×100×100 mm) were cast as shown in Fig. 1. They were divided into five groups as shown in Table 3. For each group, two specimens were used for microstructure observation and five specimens were used for splitting strength test as well as microstructure observation (after splitting test). Noticing that in field practice the old concrete had worked for a long time and could be thought to have completed hydration and shrinkage, cubes that were cast 2 years before were used as old concrete to simulate field practice better.

2.2.2. Repair procedures

A conventional repair technique was followed. The surface of the old concrete was hand-chiseled or split-broken (obtained by splitting test for cube specimens). Loose concrete and dust were removed, the surface was washed by tap water and then the surface was allowed to dry. The

Table 2
Test results of splitting and slant shear specimens with existed primers

Specimen group	Test item	Primer	Surface preparation	Mean strength (MPa)	Coefficients of variation (%)	Percentage of old concrete strength
1	splitting	–	split-broken	1.982	9.56	42.2
2		–	hand-chiseled	2.384	3.50	50.8
3		mortar	hand-chiseled	2.616	3.27	55.7
4		cement paste	hand-chiseled	2.691	3.94	57.3
5		expansive paste	hand-chiseled	2.768	4.92	59.0
6		YJ-302	hand-chiseled	2.424	6.07	51.6
7		YJ-303	hand-chiseled	2.407	4.53	51.3
8	slant shear	–	split-broken	23.54	7.13	52.2
9		–	hand-chiseled	31.09	3.12	69.0
10		mortar	hand-chiseled	30.95	7.36	68.67
11		cement paste	hand-chiseled	35.52	4.51	78.8
12		expansive paste	hand-chiseled	36.85	3.57	81.7
13		YJ-302	hand-chiseled	25.60	3.61	56.8
14		YJ-303	hand-chiseled	30.03	8.08	66.6

Table 3
Test results of splitting specimens with modified and existing primers

Specimen group	Primer	Surface preparation	Mean bond strength (MPa)	Old concrete strength (MPa)	Coefficients of variation (%)	Percentage of old concrete strength
1	–	split-broken	2.05	5.38	7.68	38.1
2	cement paste	split-broken	2.17	5.41	4.27	40.1
3	expansive paste	split-broken	2.39	5.32	6.21	45.0
4	YJ-303	split-broken	2.07	5.33	6.47	38.9
5	modified mortar	split-broken	3.21	5.03	4.42	63.8

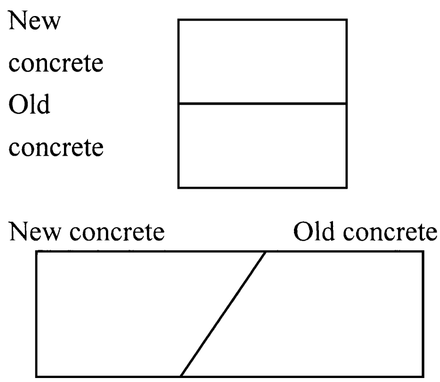


Fig. 1. Splitting and slant shear specimens.

specimens were then placed in molds. A layer (about 3 mm thick for cement-based primer and 300 μm for epoxy primer) of primer was brushed on the surface of the substrate and the repair concrete was applied after no more than 30 min. The repaired portions for all of specimens were wet-cured by covering with wet burlap for 28 days before testing (Chinese Standard GBJ 81-85, analogous with ASTM C 192).

3. Results and discussion

3.1. Influence of primers on bond strength

3.1.1. The first test

The splitting and slant shear test results are presented in Table 2. The interfaces coated with YJ-302 or YJ-303 water-dispersible epoxy showed a 8–15% drop in splitting strength and a 3–36% drop in slant shear strength compared to those coated with the other three kinds of primers. When

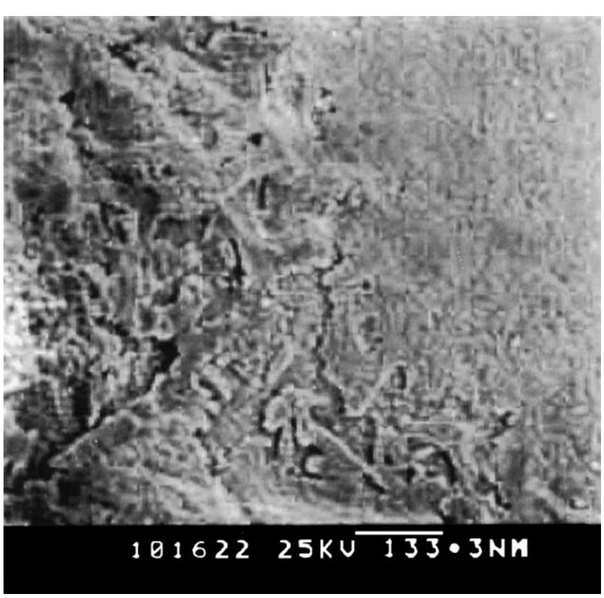


Fig. 2. SEM micrograph of fractured old concrete substrate using YJ-303 primer.

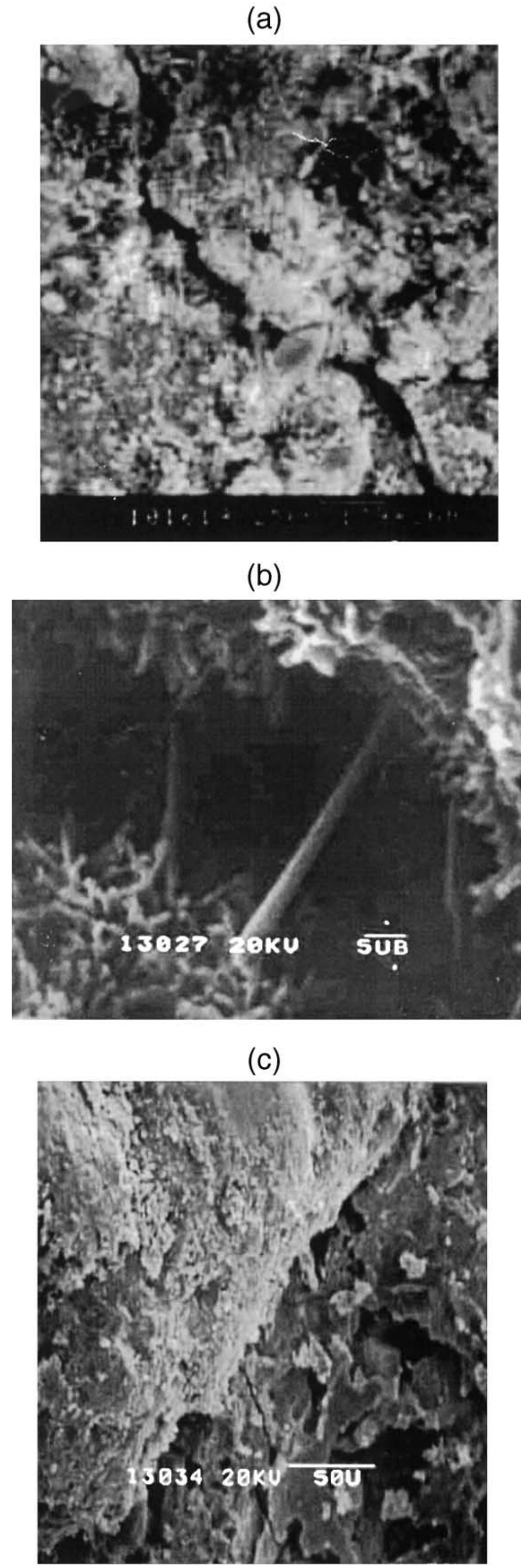


Fig. 3. SEM micrograph of repaired interface zone with (a) cement primer, (b) expansive paste primer, and (c) fly ash-modified mortar primer.

the old concrete surface was hand-chiseled, the water-dispersible epoxy did not exert any effect, which is similar to what has been reported elsewhere in repaired concrete [3]. One of main reasons is probably because some epoxy was accumulated at some lower parts of the rough surface of the concrete substrate, leading to the creation of a thicker polymer adhesive layer at these parts, thus causing a decrease of the bond strength.

3.1.2. The second test

As shown in Table 3, the interface splitting strength using the fly ash-modified primer was 34%, 48%, and 56% higher than those using the cement paste, expansive paste, and YJ-303 primer, respectively. It can be seen that when the old concrete surface was split-broken, the water-dispersible epoxy did not exert any effect as well. It should be noted that when the old concrete surface was smooth (obtained by cutting with a diamond saw), the water-dispersible epoxy showed a good bond effect probably because of its chemical structure [4].

3.2. Influence of primers on microstructure of interfacial transition zone

3.2.1. Water-dispersible epoxy

For water-dispersible epoxy-to-concrete bonding, all of the failures occurred at the bond line and the fractured old concrete substrate was covered by a layer of polymer membrane (Fig. 2). It can be assumed that the bond strength between the polymer membrane and the new concrete stems from intermolecular force (Van der Waals force) and this force is relatively weak. This is because the excess mixing water in the fresh concrete gradually accumulated near the polymer primer boundary, thus creating a higher W/C ratio and porous interfacial transition zone, and consequently compromising the adhesion [3,5]. For the other kinds of primer-to-concrete bonding interfaces, the failures took place in the concrete substrate and the fractured old concrete substrate was covered by a layer of hydration products.

3.2.2. Cement paste

Some obvious separations between substrate and primer induced by shrinkage could be observed with SEM as shown in Fig. 3a. The interface zone contained hydration products of cement with larger crystals of $Ca(OH)_2$ (the C/S ratio was the highest of the three interface zones as shown in Fig. 4, leading to the relatively lowest bond strength), but without any unhydrated cement particle. The significance of the above microstructure was twofold. First, the complete hydration of cement indicated that the W/C ratio at the interface zone was higher than elsewhere. Second, the presence of large crystals of $Ca(OH)_2$ indicated that the porosity at the interface zone was higher than elsewhere. As a result, the bond strength of the interfacial transition zone was lower than elsewhere. It was observed that some pores in the old concrete substrate had been penetrated by hydration products, which, by creating mechanical interlocking of interfacial zone in addition to intermolecular force, led to a higher interface bond strength than epoxy-to-concrete interface. Fig. 3a shows an evidence of a large crystal of $Ca(OH)_2$ in a pore.

3.2.3. Expansive paste

The interface zone contained hydration products of cement with more needle-like material, apparently ettrin-

Standardless, Elements
PEI Default Set : 1

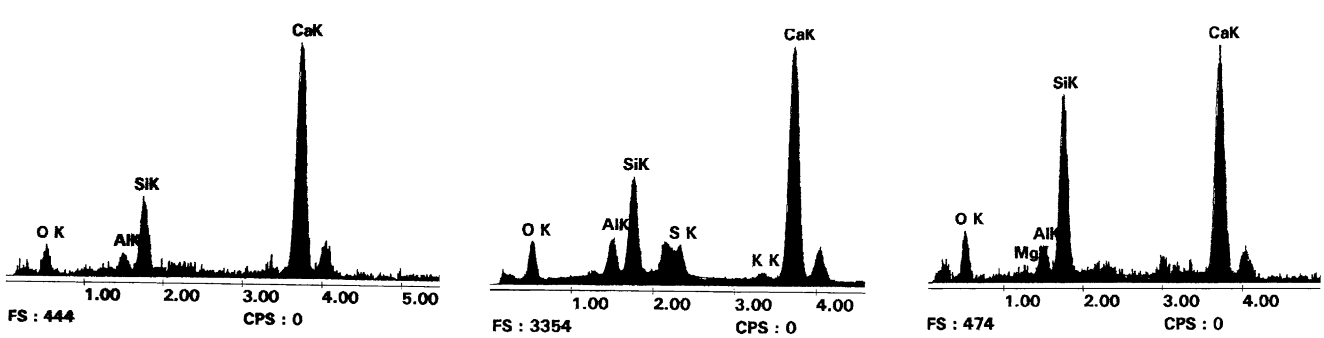
Element	K Ratio	Weight %	Atomic %
O K	0.1640	16.404	31.485
AlK	0.0303	3.031	3.450
SiK	0.1020	10.205	11.158
CaK	0.7036	70.360	53.907
Total		100.000	100.000

Standardless, Elements
PEI Default Set : 1

Element	K Ratio	Weight %	Atomic %
O K	0.2044	20.442	36.908
AlK	0.0441	4.411	4.722
SiK	0.1085	10.847	11.156
S K	0.0471	4.706	4.240
K K	0.0143	1.427	1.054
CaK	0.5817	58.166	41.920
Total		100.000	100.000

Standardless, Elements
PEI Default Set : 1

Element	K Ratio	Weight %	Atomic %
O K	0.2412	24.121	41.161
MgK	0.0091	0.914	1.026
AlK	0.0356	3.557	3.599
SiK	0.1916	19.161	18.625
CaK	0.5225	52.248	35.589
Total		100.000	100.000



(a) (b) (c)

Fig. 4. XRD pattern of repaired interfacial transition zone with (a) cement paste primer, (b) expansive paste primer, and (c) fly ash-modified mortar primer.

gite, but without any unhydrated cement. Fig. 3b shows an evidence of a crystal of ettringite penetrated in the old concrete substrate and a microcrack between substrate and primer. The microstructure of the expansive paste-to-concrete interface is denser than that of the cement paste-to-concrete interface because the expansive action compensated some shrinkage. In consequence, the interface zone had a higher strength than the cement paste-to-concrete interface.

3.2.4. Fly ash-modified mortar

The interface zone contained mainly C-S-H and no clear crystalline morphology could be observed. It can be seen (Fig. 3c) that the substrate and primer mingled each other and the distinction between the two materials could not be made. As shown in X-ray diffraction (XRD) pattern (Fig. 4), the C/S ratio of the interfacial zone was only 2.73. It was significantly lower than those of the interface zones using other kinds of primers. The improvement of the microstructure of the interface zone by using fly ash is not only the consequence of its pozzolanicity but also of the ability of the very small fly ash particles to "fit in" between cement particles. The noticeable improvement in the microstructure led to a significant increase of the intermolecular force and mechanical interlocking. Consequently, the bond strength increased greatly as shown in Table 3. The significant increase in strength may also partially result from the chemical reaction between the active silicon dioxide of fly ash in the primer and the $Ca(OH)_2$ in the old concrete to form C-S-H. It can be inferred that the microstructure of the interface zone can be improved further with time in consequence of a secondary reaction between the $Ca(OH)_2$ present there and pozzolana, thus leading to a even denser interface zone with a better durability.

4. Conclusions

1. Fly ash-modified primer made the repaired interfacial transition zone more dense and uniform, and consequently led to a significant increase of the bond strength.
2. The bond strength of epoxy-to-concrete interface results mainly from intermolecular force. The bond strengths of cement paste-to-concrete interface and expansive paste-to-concrete interface stem mainly from intermolecular force and mechanical interlocking. The bond strength of fly ash-modified paste-to-concrete interface results from intermolecular force, mechanical interlocking and chemical reaction.

Acknowledgements

The authors gratefully acknowledge the funding provided by the National Natural Science Foundation of China and Guangdong Provincial Natural Science Foundation.

References

[1] I. Uherkovich, Questions concerning the long-term behavior of concrete repairs, in: F.H. Wittmann (Ed.), Proceedings of International Conference for Adherence of Young on Old Concrete, AEDIFCATIO, Switzerland, 1994, pp. 177–181.
[2] J.S. Wall, N.G. Shrive, Factors affecting bond between new and old concrete, ACI Mater. J. 95 (2) (1998) 117–125.
[3] A.I. Abu-Tair, S.R. Rigdin, E. Burley, Testing the bond between repair materials and concrete substrate, ACI Mater. J. 93 (6) (1996) 553–558.
[4] A. Saccani, V. Magnaghi, Durability of epoxy resin-based materials for the repair of damaged cementitious composites, Cem. Concr. Res. 29 (1) (1999) 95–98.
[5] L. Tu, D. Kruger, Engineering properties of epoxy resins used as concrete adhesives, ACI Mater. J. 93 (1) (1996) 26–35.