- Technical Paper -

USE OF POLYMER-CEMENT PASTES AS BONDING AGENTS FOR PINNING RETROFITTING OF MASONRY CONSTRUCTION

Kshitij C. SHRESTHA[*1], Sanjay PAREEK [*2] and Yoshikazu ARAKI[*3]

ABSTRACT

A comprehensive experimental study was done to compare the workability and the bond strength of six different types of commercially available polymer-based admixtures, used as bonding agents for reinforcing bars in masonry. It was found that pretreatment agents, as water penetration barrier impregnants, largely affected the workability characteristics shown by polymer-cement pastes (PCPs). The best combination of PCP and pretreatment agent showing strong bond with minimum strength variation at different open times was determined experimentally through pull-out tests.

Keywords: polymer-cement paste, impregnant, masonry retrofitting, workability, bond strength

1. INTRODUCTION

Historical masonry constructions are vulnerable to earthquake excitations and hence require proper strengthening and retrofitting. Among various available retrofitting techniques [1-2], pinning retrofitting procedure practiced in Japan has strong potential in masonry retrofitting since in addition to strength and ductility improvements, this technique also causes minimal change in original appearance of structure. Extensive experimental [3] and numerical [4] studies have been done to prove robustness of this pinning retrofitting technique in masonry constructions. However retrofitting procedure involves use of epoxy resin for the bonding between masonry and reinforcing bar and epoxy resin, being an organic adhesive, has got its limitations -- low fire resistance, higher cost and poor bond to wet surfaces.

Use of ordinary mortar as bonding agent in place of epoxy resin largely affects the workability environment. During pinning retrofitting, a professional mason would normally require an open time limit up to 10 minutes between the injection of mortar and insertion of reinforcing bar, but with an ordinary mortar as bonding agent, it is very difficult to insert reinforcing bar. As an alternative, use of polymer-cement paste (PCP) as bonding agent has been proposed in this study with investigation on comparison of bond strengths of various commercially available polymer based admixtures in brick masonry.

Mechanical properties of polymer-based cementitious bonding agents as PCP and polymer-cement mortar (PCM) have already been reported as highly superior over normal conventional mortar [5-8]. Latex-modified PCM provide an improved workability over normal cement mortar and also with increase in polymer-cement ratio, there is subsequent reduction in water-cement ratio, which ultimately contributes to strength development and drying shrinkage reduction. In hardened state PCM shows an improved water-proofness and improved bond strength over ordinary cement mortar which makes it a potential bonding material as PCP and PCM in masonry retrofitting.

Application of PCP in masonry requires another important consideration regarding check in workability. If applied as masonry in its normal state, water from PCP gets absorbed by masonry making the paste poor in workability. For this purpose, there is need for pretreatment of masonry to create a water penetration barrier film so that there is minimum effect on workability of PCP after insertion. The present study involves comparison on various impregnants as pretreatment agent and their effect on workability of PCP in masonry.

The use of PCM for repair and restoration purpose of masonry structures has been limited to its use more as surface coating over grid of reinforcing bars [9-10] on unreinforced masonry walls. In this present study, we have examined and compared the effectiveness of PCPs prepared from various commercially available polymer admixtures as bonding adhesive between reinforcing bar used for pinning and masonry considering the effect of pretreatment using impregrnant.

2. TEST PROGRAMS

2.1 Materials

*1 Graduate Student, Dept. of Architecture and Architectural Engineering, Kyoto University, M Sc, JCI Member
*2 Assoc. Professor, Dept. of Architecture, College of Engineering, Nihon University, Dr. Eng., JCI Member
*3 Assoc. Professor, Dept. of Architecture and Architectural Engineering, Kyoto University, Dr. Eng., JCI Member

Table 1 Properties of polymer dispersion

Type of polymer	Chemical Constituent	Viscosity (mPa.s)	Mechanical properties of polymer-cement paste: E (MPa)	f_c (MPa)	υ
EVA2	Ethylene vinyl acetate copolymer emulsion	1000±200	1.82	43.19	0.24
ACL1	Acrylic resin	14	1.55	44.21	0.20
PAE2	Polyacrylic ester-methacrylate ester copolymer emulsion	300	1.29	35.29	0.21
SBR1	Styrene-butadiene rubber	200	1.76	49.78	0.22
SBR2	Styrene-butadiene rubber	50	1.97	50.10	0.20

E - Young's Modulus, f_c - Compressive Strength, υ - Poisson's ratio

(1) Polymer based admixtures

Five different types of polymer admixtures used in this study were -- EVA2, ACL1, PAE2, SBR1 and SBR2, representing the most popular commercially used polymers. The corresponding numerology and properties of above mentioned polymer dispersions are given in Table 1. Polymer-cement pastes (PCPs) for the above listed polymers were prepared using ordinary Portland-cement with polymer-cement ratio (P/C) of 20% and water-cement ratio (W/C) at 40% for all the mixes. The above mentioned proportions were attained after extensive sensitivity and trial and error studies on PCPs used.

(2) Water penetration barrier agents (Impregnants)

Three types of alkyl alkoxysilane based water penetration barrier agents were used -- BPA-I, BPA-II and BPC-I in this study. Additionally application of water and polymers as water penetration barrier agents in place of impregnants was also checked.

2.2 Laboratory procedure

(1) Workability test

First phase of experiment involved workability tests for different PCPs with pre-application of above mentioned impregnants. Each specimen, as shown in Fig. 1, first involved drilling of 8 mm diameter holes 100 mm deep on 100×105×60 mm^3 well-cut brick samples. Dusts in the holes were blown out by applying air pressure. Afterwards 25.13 cm^3 of impregnant was injected into the hole as shown in Fig. 2. After 60 minutes of impregnant injection, PCP was injected into the hole. A 6 mm diameter zinc plated full threaded steel bar (SS400) was inserted into the hole at three different open times -- 0 minute, 5 minutes and 10 minutes for each type of impregnant and PCP. The specimen was placed over digital weighing balance and the amount of force required for the insertion of pin was recorded to measure the workability.

Additional tests were also performed using polymer and water in place of impregnants for the pretreatment. In case of polymer, polymer used in corresponding PCP was used in two different ways. For Polymer-I, polymer was injected into the hole and PCP was poured out after 15/30 minutes. However in case of Polymer-II, PCP was injected into the holes after drying polymer for 5 days after pretreatment of the hole. For comparison, untreated specimens without application of any water penetration barrier agents, termed as untreated specimen here onwards, were also prepared. 63 specimens for each PCP type, with different pretreatment performed and at different open times, were prepared. Total of 315 specimens were prepared for all PCPs to test the workability.

(2) Pull-out test

Direct pull-out tests of steel bars were performed on each specimen as illustrated in Fig. 3 to compare the

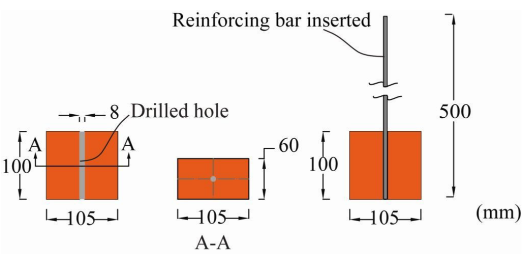


Fig. 1 Details of test specimen

Fig. 2 Application of impregnant (water penetration barrier agent)

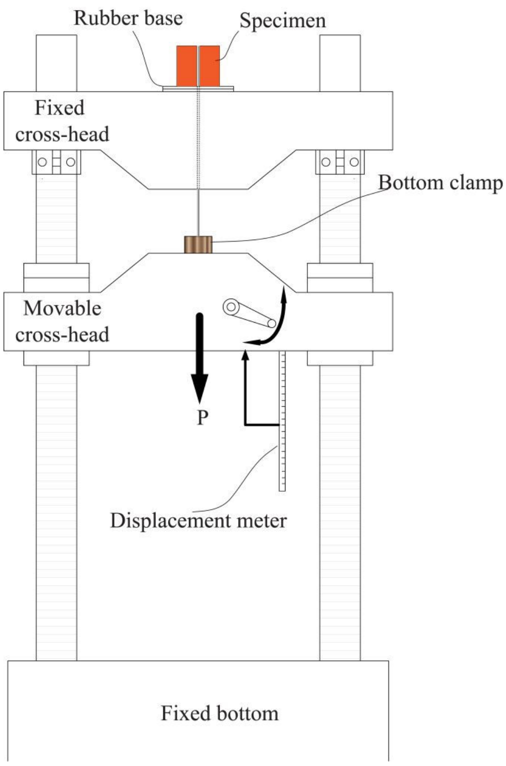


Fig. 3 Pull-out test set-up

bond strength of the PCP in brick masonry. Test specimen was mounted upside down on the testing machine as shown in Fig. 3 and the bar was clamped at the other end to the fixed grip at the bottom.

The following expression for a straight reinforcing bar inserted in masonry may be derived from the equilibrium of the forces:

$$A_\mathrm{r} f_\mathrm{r} = \tau_\mathrm{b} \pi d_\mathrm{r} l_\mathrm{b} \tag{1}$$

where, A_r and d_r are the area and diameter of reinforcing bar, l_b is the bond length, f_r is the stress developed in the bar, and τ_b is the average bond stress. The average bond stress can be obtained simplifying Eq. 1:

$$\tau_\mathrm{b} = \frac{f_\mathrm{r} d_\mathrm{r}}{4 l_\mathrm{b}} \tag{2}$$

3. RESULTS AND DISCUSSION

3.1 Workability tests

Fig. 4 shows results for the test of workability of PCPs with different pretreatments performed. At open time of 0 minute, all combination of pretreatments with PCPs used showed good workable response as shown in Fig. 4. With increment in open time up to 5 min with results given in Fig. 4(e), reinforcing bar could not be inserted in case of ACL1 PCP when pretreated with

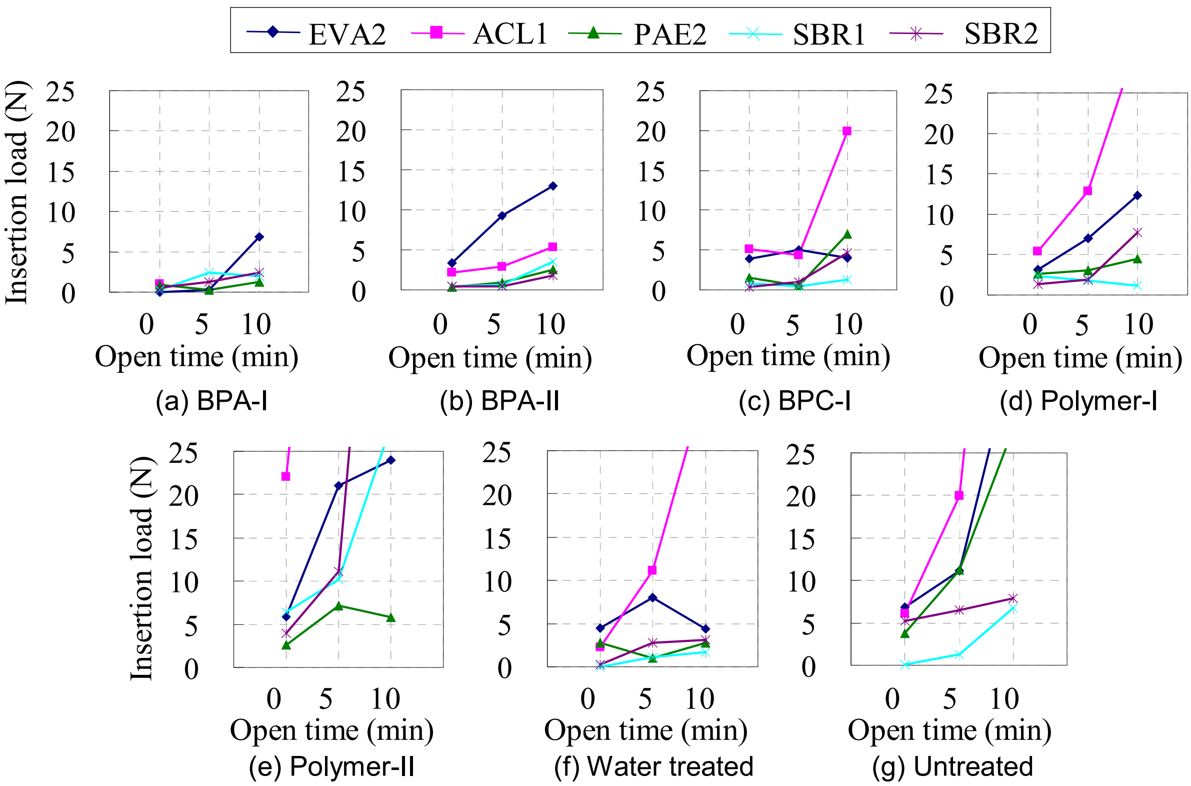


Fig. 4 Insertion load for combination of PCPs and impregnants at varying open times

Polymer-II. Finally, for open time of 10 min, Polymer-II pretreated ACL1 and SBR2 PCPs were not workable enough for pin insertion and additionally untreated ACL1 sample was also not workable.

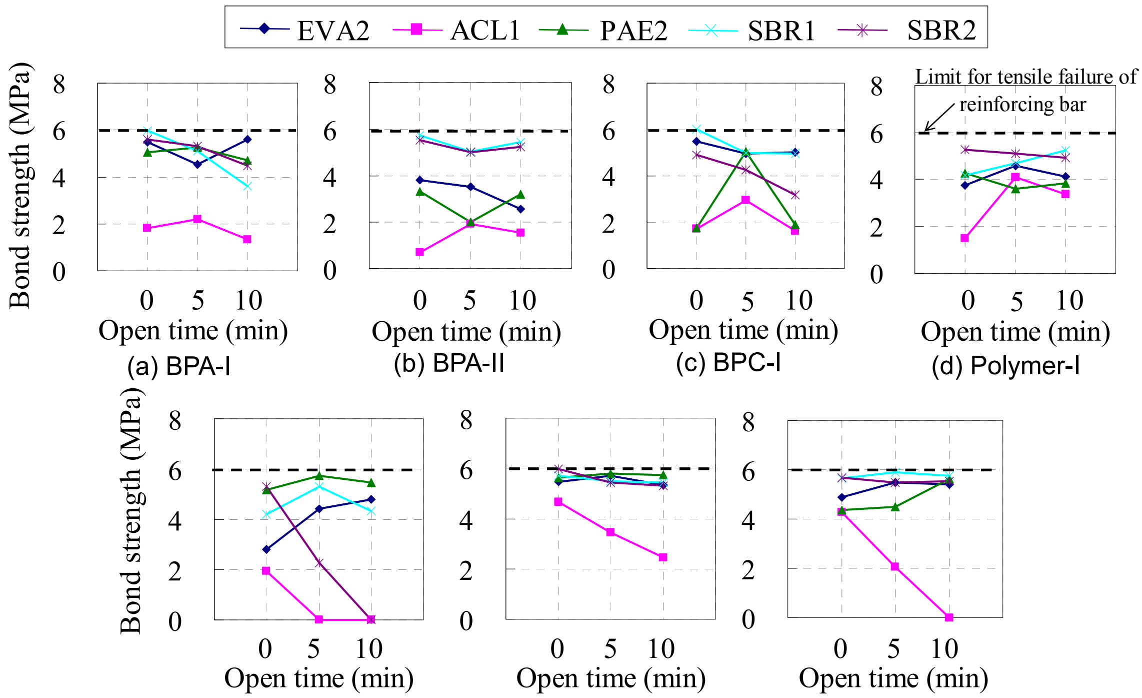
Workability tests showed clearly that pretreatment plays an important role in keeping the PCP workable for longer duration of time. Use of impregnants -- BPA-I, BPA-II and BPC-I, all significantly increased the workability of all the PCPs used. Test on the use of polymer itself as a water penetration barrier system showed significant differences with Polymer-I working better as a water penetration barrier system as compared to Polymer-II. In fact, Polymer-II adversely affected the workability of the PCPs due to the formation of a thick layer of polymer film by drying, with its response inferior even compared to the untreated specimens.

3.2 Bond strength tests

Direct pull-out test results on steel bars of the specimens are shown in Figs. 5 and 6. Fig. 5 shows the failure patterns observed for pull-out test results. Three different types of failure patterns were observed during the pull-out tests -- bond slip along PCP joint interface, tensile failure of reinforcing bar and brick failure as shown in Fig. 5. For impregnant pretreated specimens, dominant failure mechanism observed varied with the type of PCP used. For EVA2, ACL1, PAE2 PCPs, majority of pull-out tests showed bond slip along PCP joint for all the impregnant pretreated specimens. However, for SBR1 and SBR2 PCPs injected specimens

(a) Bond slip along PCP (b) Tensile failure of reinforcing bar (c) Brick Failure

Fig. 5 Failure patterns observed during bond strength tests



(a) BPA-I (b) BPA-II (c) BPC-I (d) Polymer-I

(e) Polymer-II (f) Water treated (g) Untreated

Fig. 6 Average bond strength from pull-out tests on specimen for different impregnants, polymers, water treated and untreated

Table 2 Results for pull-out tests

Impregnant \ PCP	OT (min)	EVA2 τ_b (MPa)	EVA2 σ (MPa)	EVA2 γ (%)	ACL1 τ_b (MPa)	ACL1 σ (MPa)	ACL1 γ (%)	PAE2 τ_b (MPa)	PAE2 σ (MPa)	PAE2 γ (%)	SBR1 τ_b (MPa)	SBR1 σ (MPa)	SBR1 γ (%)	SBR2 τ_b (MPa)	SBR2 σ (MPa)	SBR2 γ (%)
BPA-I	0	5.48			1.81			5.06			5.98			5.60		
	5	4.54	0.48	9.15	2.21	0.36	20.45	5.25	0.23	4.50	5.10	0.97	19.85	5.31	0.48	9.35
	10	5.60			1.32			4.71			3.62			4.47		
BPA-II	0	3.82			0.69			3.31			5.72			5.52		
	5	3.52	0.54	16.48	1.93	0.52	37.42	2.00	0.59	20.95	5.04	0.28	5.18	5.00	0.21	4.03
	10	2.55			1.55			3.19			5.44			5.24		
BPC-I	0	5.50			1.72			1.74			6.02			4.91		
	5	4.97	0.24	4.61	2.94	0.59	28.29	5.04	1.52	52.32	4.99	0.49	9.18	4.25	0.71	17.20
	10	5.02			1.65			1.91			4.97			3.19		
Water	0	5.48			5.60			5.63			5.71			5.97		
	5	5.72	0.16	2.91	4.82	0.81	17.36	5.78	0.06	1.07	5.51	0.11	2.01	5.44	0.29	5.14
	10	5.33			3.62			5.73			5.45			5.31		
Untreated	0	4.86			5.67			5.51			5.64			5.68		
	5	5.47	0.27	5.20	N/A	N/A	N/A	4.49	0.51	9.74	5.89	0.10	1.73	5.47	0.09	1.55
	10	5.40			N/A			5.61			5.74			5.53		

OT-Open Time, τ_b – Average bond strength, σ – Standard deviation, γ – Coefficient of Variation
N/A – Not available (unable to insert reinforcing bar)

pretreated with impregnants, slightly higher bond strengths were observed with higher number of tests resulting in tensile failure of reinforcing bars. This showed the superiority of SBR1 and SBR2 over other PCPs.

Fig. 6 shows pull-out test results for specimens with three impregnants -- BPA-I, BPA-II and BPC-I, polymer treated, water treated and untreated for the comparison purpose. There is an obvious variation in bond strengths of different PCPs used with ACL1 and PAE2 having the least of bond strength among the used PCPs. EVA2, SBR1 and SBR2 showed comparatively better bond strengths.

Also bond strength of each PCP was largely affected by other two factors -- pretreatment agent used and open time set. With the increment in open time, average bond strength of PCP was seen to be decreasing in most of the cases. Better PCP would be the one which shows better bond strength even at larger open time, or the one which shows lesser variation of bond strength at variable open time sets. Table 2 shows the consistency of results in terms of bond strength and its coefficient of variation at different open times for combinations of PCPs and impregnants. The best combination of PCP and pretreatment agent showing strong bond with minimum strength variation at different open times was attained for SBR1 and SBR2 PCPs with BPA-II as pretreatment agent as shown in Fig. 6(b) and Table 2.

Untreated and water treated specimens also showed good workability as illustrated in Fig. 4 for EVA2, SBR1 and SBR2 injected specimens and majority of pull-out tests resulted in tensile failure of reinforcing bar which meant better bond strength as shown in Table 2. However, it should be noted that the experimental tests were performed in an idealistic condition with well-cut bricks which is particularly different to that in actual practice with old brick masonry and porous mortar joints. This possibly makes untreated and water treated specimens show contradictory behavior to the one observed in this study when performed in real practice. Additionally, when water is used as a pretreatment agent, it is very difficult to pour water in to the hole uniformly resulting in non-uniform distribution of dry and wet surfaces. Therefore, there exists strong evidence of variability for untreated and water treated specimens in actual practice making their use less appealing. A better control of loss of water by PCP, when used in old brick masonry with mortar joints, can be done with the selection of proper water penetration barrier reagents which results in an improved workability without affecting the actual strength of PCP. SBR1 or SBR2 PCP with BPA-II impregnant is the best combination of PCP and pretreatment agent found in this study.

4. CONCLUSIONS

Experimental works have been done to compare the workability and bond strength of different polymer-cement pastes (PCPs) -- EVA2, ACL1, PAE2, SBR1 and SBR2, in brick masonry. Workability was checked with the measurement of reinforcing bar insertion load at 0 minute, 5 minutes and 10 minutes open times with various pre-treatment techniques studied in the process as water penetration barrier system for masonry. Afterwards, bond strength of these specimens was measured performing pull-out tests of the inserted reinforcing bar. Based on these tests, the following conclusions can be drawn:

(1) Results of workability tests showed PCPs are highly workable even at adverse working conditions, specifically for untreated specimens of SBR1 and SBR2 PCPs workable even at the open time of 10 minutes. The workability test also showed the importance of pre-treatment agents or impregnants, as water penetration barrier system, to increase the workability of PCP, effectively avoiding the loss of water from PCP. The untreated and polymer treated specimens showed poor performance whereas use of BPA-I, BPA-II and BPC-I as impregnants resulted in substantial increment of workability. Additionally, use of impregnants did not influence the strength of PCPs used.

(2) From the pull-out test results, ACL1 and PAE2 have least bond strength as compared to EVA2, SBR1 and SBR2 PCPs. Observed bond strengths of EVA2, SBR1 and SBR2 PCPs were in the range of 5 MPa or more, which represents extremely superior bond strength.

(3) The best combination of PCP and pretreatment agent showing strong bond with minimum strength variation at different open times was attained for SBR1 and SBR2 PCPs with BPA-II impregnant as pretreatment agent.

ACKNOWLEDGEMENT

The authors acknowledge the supports provided by Grant-in-Aid for Scientific Research (B) No. 20360253 and by the Global COE Program, provided by the Japan Society for the Promotion of Science (JSPS). The authors would also like to acknowledge the technical assistance of Mr. Shinnousuke Kaneuchi and Mr. Hiroki Sekine of Nihon University in undertaking the experimental works.

REFERENCES

[1] Abrams, D. et al., “Effectiveness of Rehabilitation on Seismic Behavior of Masonry Piers,” Journal of Structural Engineering, ASCE, Vol.133, No.1, 2007, pp. 32-43.

[2] Willis, C. R., Seracino, R. and Griffith, M. C., “Out-of-Plane Strength of Brick Masonry Retrofitted with Horizontal NSM CFRP Strips,” Engineering Structures, Vol.32, No.2, 2010, pp. 547-555.

[3] Takiyama, N. et al., “Cyclic Out-of-Plane Flexural Behavior of Masonry Walls Rehabilitated by Inserting Steel Pins,” Proceedings of the 14th WCEE, Beijing, 2008.

[4] Shrestha, K. C., Nagae, T. and Araki, Y., “Finite Element Modeling of Cyclic Out-of-Plane Response of Masonry Walls Retrofitted by Inserting Inclined Stainless Steel Bars,” Journal of Disaster Research, Vol.6, No.1, 2011, pp. 36-43.

[5] Pareek, S., “Evaluation of Polymer-Cement Pastes as Bonding Agents for Flexural Strengthening of RC Beams by Continuous Fiber Sheets,” Proceedings of the International Symposium on Latest Achievement of Technology and Research on Retrofitting Concrete Structures, Japan Concrete Institute, 2003, pp. 107-112.

[6] Ohama, Y., “Polymer-Based Admixtures,” Cement and Concrete Composites, Vol.20, 1998, pp. 189-212.

[7] Ohama, Y., “Handbook of Polymer-Modified Concrete and Mortar, Properties and Process Technology,” Noyes Publications, 1995.

[8] Fowler, D. W., “Polymers in Concrete: A Vision for the 21st Century,” Cement and Concrete Composites, Vol.21, 1999, pp. 449-452.

[9] Kikuchi, K. et al., “Seismic Retrofit of Unreinforced Clay Brick Masonry Wall Using Polymer-Cement Mortar,” Proceedings Of the 14WCEE, Beijing, 2008.

[10] Anagnostopoulos, C. A. and Anagnostopoulos, A. C., “Polymer-Cement Mortars for Repairing Ancient Masonries Mechanical Properties,” Construction and Building Materials, Vol.16, 2002, pp. 379-384.