10th Canadian Masonry Symposium, Banff, Alberta, June 8 – 12, 2005

EXPERIMENTAL STUDY ON FOLLOWING PERFORMANCES OF REPAIRED FINISH COATS TO CLAY BRICK MASONRY ASSEMBLAGES

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ABSTRACT

This study deals with an evaluation of the deformational performance of repair finishing coats, as applied to clay brick masonry assemblages for long time preservation of historical brick masonry structures, in response to differential movement (we will refer to this as the ‘following performance’ of a material).

These clay brick masonry assemblages have wet finishing coats repaired with several kinds of repair materials. For finishing, a lime cement mortar finishing coat and a plaster finishing coat were selected. These are general wet finishing methods used to repair historical brick masonry buildings in Japan. For repair materials, 10 kinds of injection and penetration materials were selected in order to analyze the performance of the repair materials currently used in cultural assets preservation. Furthermore, the construction efficiency of these repair materials and the aesthetic effect after construction were reviewed.

This examination revealed that almost all repair materials improved the adhesiveness and following performance of finishing coats compared with specimens that received no repair. In several repair materials, the following phenomena were observed. 1) The adhesion layer absorbed the deformational energy of masonry prisms and didn’t transmit uniaxial strain to the surface of finishing coat. 2) Some of repair materials failed to produce better adhesiveness because of poor construction. 3) Some of repair materials spoiled the aesthetics of the specimen because of leaked repair material.

KEYWORDS: cultural assets, finishing coat, following performance, injection, penetration

INTRODUCTION

Recently, problems have arisen in Japan concerning finishing coats that separate and fall off buildings. This is a serious problem found not only in general reinforced concrete buildings but also in historical brick masonry structures designated as cultural assets. Several historical masonry buildings are being maintained in their present condition by a method where separated finish fragments are jointed with repair materials. However, the correct method for selecting repair materials has not been established. For repairing a historical building, the best choice would be a material that can improve not only seismic resistance but also durability. However, in the past, the selection of repair materials has been largely based on short-term requirements. Moreover, many expedient repairs spoil the fine visual properties of the building.

This research undertook experiments on “following performance” to improve the selection of materials for repairing finishes separated from brick walls.

An evaluation of following performance was accomplished using a uniaxial compression test on masonry assemblages (later renamed ‘prisms’) with repaired wet finishes. The experiments employed lime and cement mortar finishing coats and plaster finishing coats. These finishing coats had been adopted in Japanese brick building in the Meiji and Taisho eras generally. This study is intended to evaluate repair methods used for historical Japanese brick masonry structures.

OUTLINE OF EXPERIMENTS

Specimen

The shape of the basic specimen (prism) is shown in Figure 1. This prism is composed of 3 bricks and 2 joints, about 100 mm length, 100 mm width, and 200 mm height. Table 1 shows the specification of the bricks and joints in this prism. The joint material is a cement lime mortar, of 1:3:12 proportions (cement: lime: sand). This mix has been adopted in actual Japanese historical brick buildings [1]. The mechanical properties of the bricks, joint mortar, and prisms are listed in Table 1. Materials used in prisms and in finishing coats are shown in Table 2. Using this basic prism assemblage, two series of specimens were prepared.

Series A: A lime and cement mortar finishing coat, repaired by injection materials:

The shape of specimens in series A is shown in Figure 1. These specimens have a cement lime mortar finish on two sides of the prism.

Within the A series, specimen A-1 received no repairing finish coat. Specimens A-2 and A-3 received a repair finish consisting of two types of Epoxy resin. Specimens A-4 and A-5 received a repair finish consisting of two types of cement slurry. Specimen A-6 received a repair finish of Polysiloxane. These injection materials have been used to repair historical brick buildings and modern concrete buildings. Repairing by injecting materials is assumed to rebond the finishing coat which has peeled off from the brick wall. The cement mortar finish is composed of three layers (first coat, second coat, finishing coat). The thickness of the respective layer is 1mm, 6 mm, and 8 mm. The mix proportions of the respective layers are as follows: first coat--1:3:4 (cement: lime: sand); second coat--1:3:12; and finishing coat--1:1 (cement: sand). This is a reproduction of the proportions used for the lime cement mortar finish currently used to repair existing historical Japanese brick buildings.

Series B: Plaster finishing coat repaired with penetration and injection materials

The shape of specimens in series B is shown in Figure 1. These specimens have a plaster finish on two sides of the prism.

Within the B series, specimen B-1 received no repairing finish coat. Specimen B-2 received a repair finish consisting of silicic acid sodium. Specimen B-3 received a repair finish consisting of porous water glass. Specimen B-4 received a repair finish consisting of acrylic resin. Specimen B-5 received a repaire finish consisting of silicic acid lithium. Specimen B-6 received a repair finish consisting of water glass based on a mixture used by an experienced plasterer in Japan). Specimen B-7 received a repair finish consisting of polysiloxane. These penetration materials have been used to preserve buried cultural properties and traditional mud walls. Repairing with penetration materials is assumed to reinforce the deteriorated finishing coat.
In this series, two kinds of specimens repaired with injection materials were prepared as with series A. Specimen B-8 received a repair finish consisting of cement slurry, the same material as A-4). Specimen B-9 received a repair finish consisting of polysiloxane. These two specimens had plaster finish boards bonded to their surfaces using the specified repair finish. The plaster finish was composed of three layers (first coat, dubbing out coat, second coat). Ordinary mortar finish is composed of four layers included a finishing coat. The thickness of coating of the respective layers was 2 mm, 6 mm, and 3 mm. The mix proportion of the all layers conformed to the mixture recommended in JASS (Japanese Architectural Standard Specification).

Construction of repair material
The kinds and specifications of the injection and penetration materials are shown in Table 3. The amounts of repairing materials (injection & penetration) are shown in Table 4.

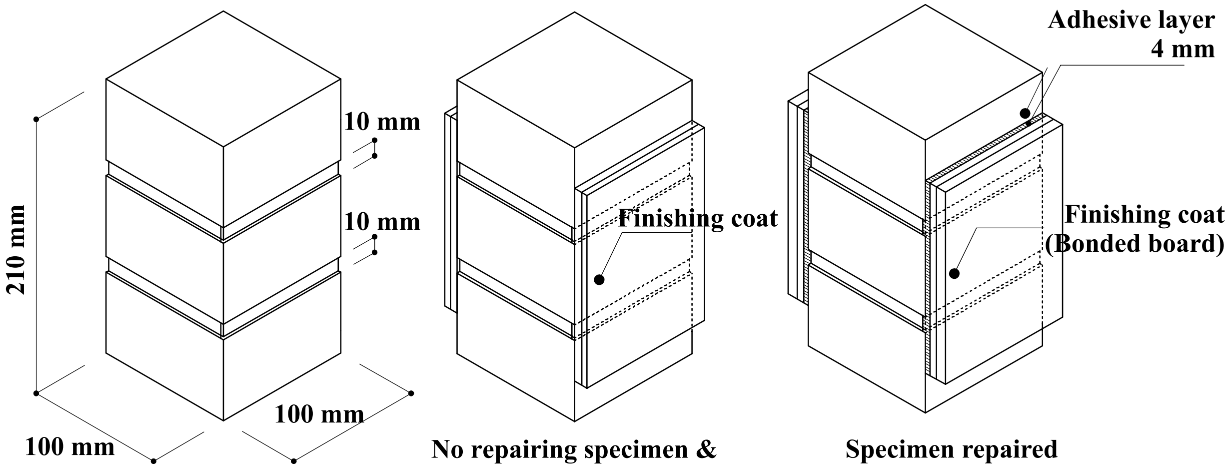
Lime and cement mortar finish boards were set up on both sides of the prism, separated by a little space, and injection materials were poured in from the top. Three sides were sealed (both sides and the lower side) to prevent the liquid from leaking. When the cement slurry was injected, a small amount of water was injected into the space between the brick and the finishing coat board material to prevent drying. The penetration materials were spread five times with a brush on the surface of the plaster finish.

Table 1 – Mechanical properties of joint material in prism

	Compressive strength [Mpa]	Young’s modulus [Gpa]	Poisson’s rato
Brick	30.95	6.24	0.09
Joint mortar	3.17	1.09	0.38
Prism	17.84	5.94	0.20

Table 2 – Kinds of material in specimen

Kinds of materials	Remark
Brick	Present commercial, extrusion moulding (orange color),
Cement	Normal Portland cement
Lime	Produced by Japanese traditional method (called Shioyaki)
Sand	Toyoura silica sand in Yamaguchi, Japan
Paste (for plaster)	Ginnanso, Hidaka (Japanese Tsunomata)



Basic specimen (prism)

No repairing specimen & specimen repaired by penetration materials

Specimen repaired by injection materials

Figure 1 – Shape of Specimen

After spreading porous water glass, the surface of the finishing coat was covered with a transparent film to reduce volatility. Polysiloxane was used in the same mix proportion for penetration and injection.

Experimental method

In generally, the evaluation of following performance was carried out by determining the deformation of the finishing coat in response to the uniaxial movements of the concrete base. In this test, the uniaxial loading is given only to the concrete base.

Between the surface strain of the finishing coat and that of the non-bonded part of the base, the point where the surface strain of the finishing coat decreases rapidly is the separating point of finishing coat. This method is applied to construction of items where the concrete base material is uniform. However, this evaluation involved application to construction composed of different materials such as the bricks and the joint mortar in the prisms. In this experiment, the evaluation of following performance was carried out by comparing uniaxial strain on the whole prism with surface strain on the finishing coat. Details of this evaluation method are explained in the next section.

Table 3 – Repairing materials

Repairing materials	Remarks
Epoxy resin A	Low viscosity epoxy resin (K corporation products)
Epoxy resin B	Low viscosity epoxy resin (T corporation products)
Cement slurry A	Polymer cement slurry
Cement slurry B	Cement slurry for crack repairing
Polysiloxane	Organic silicon polymer
Sodium silicate	Twice solution
Porous water glass	Volatility liquid
Acrylic resin	Toluene: resin = 1: 1
Lithium silicate	Source of alkaline
Water glass	Mixture used by experienced plasterer in Japan

Table 4 – Amount of repairing materials (injection & penetration)

Series	Method of repairing	Repairing materials	Amount of injection (g)
A-2	Injection	Epoxy resin A	143.8
A-3		Epoxy resin B	164.5
A-4		Cement slurry A	219.5
A-5		Cement slurry B	251.5
A-6		Polysiloxane	167.1
B-2	Penetration	Sodium silicate	7.9
B-3		Porous water glass	7.3
B-4		Acrylic resin	9.3
B-5		Lithium silicate	11.2
B-6		Water glass	18.8
B-7		Polysiloxane (penetration)	7.6
B-8	Injection	Cement slurry A	271.2
B-9		Polysiloxane (injection)	215

The attachment position of strain gauges is shown in Figure 2. To measure uniaxial strain of the finishing coat and the prism, 10 mm long strain gauges were fixed to the surface of the finishing coat, while 150 mm displacement transducers were put on the centre of the top and bottom layer bricks. A test apparatus with a capacity of 100 tons was used for the uniaxial compression test. The loading surface of the specimens was capped with gypsum.

Evaluation method of the following performance of finishing coat in this experiment

The relation between the uniaxial strain on the ground and the surface strain on the finishing coat is shown in Figure 3. The initiation point shows the limit point at which the surface strain of the finishing coat is in proportion to the uniaxial strain of prism. At this initiation point the finishing coat begins to separate partially. The critical point shows the limit point at which the finishing coat is able to follow the deformation of the base by progressive separation of the finishing coat from the base. As separation progresses, strain is no longer observed on the surface of the finishing coat because the finishing coat separates completely from the base. It is thought that following performance is better when the uniaxial strain on the critical point increases, and that bonding performance to the base is better when the surface strain on the finishing coat increases. At this time, it appears that the bonding area decreases rapidly as θ gets bigger. In other words, the bonding face of the finishing coat separated rapidly when θ was 90°. Oppositely, it appeared that the finishing coat separated gradually when θ was small.

EXPERIMENTAL RESULTS AND CONSIDERATION

Results of compression tests

Series A

The relation between the uniaxial strain on the prism (εm) and the surface strain on the finishing coat (εf) is shown in Figure 4. The distance from the top edge of the finishing coat expresses the relation between εm and εf. Here the compression strain is positive, and the top in the finishing coat is zero. Almost all specimens experienced cracking and separation in the second layer of the finishing coat. In all specimens, εf was small near the edge of the finishing coat and large near the centre of the finishing coat. It was observed that εf at the edge of the finishing coat tended to increase with tension in the early stage of compression loading in this series.

The εm values at the critical point (εm_{cr}) of each specimen are shown in Table 5. The value in parentheses besides the εm_{cr} value represents the compressive stress (MPa) when the uniaxial strain reaches to εm_{cr}.

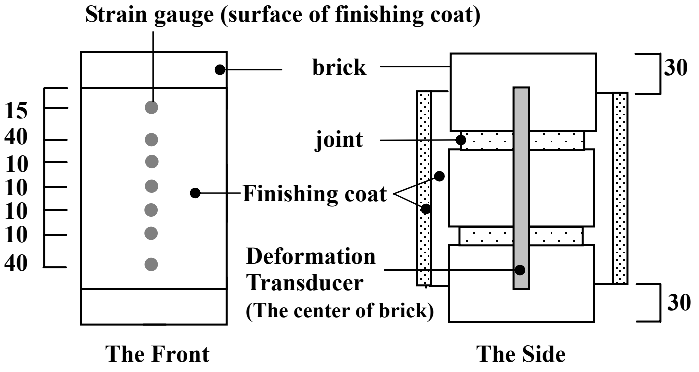


Figure 2 – The position of strain gauges and deformation transducers (mm)

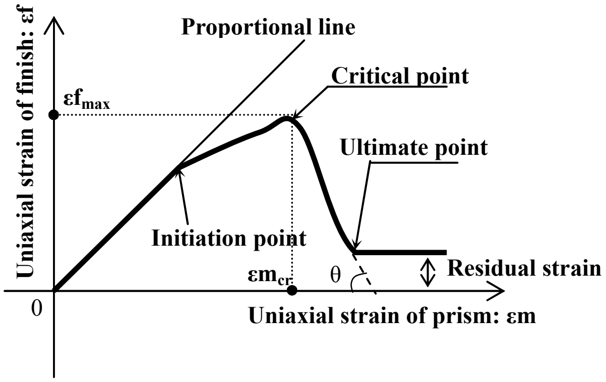


Figure 3 – Evaluation method of the following performance of the finish material

When the cement mortar finish is applied to the concrete base at a thickness of 16mm, εm at the critical point is 570 (microstrain) (compressive stress 5.5 (MPa) [2]. Compared with this result, it is clear that there are not so many differences in εm at the critical point between the concrete and brick masonry bases. The maximum values of εf in each specimen are shown in Table 5. Specimens A-3 and A-4 had larger values than A-1, whereas the values of specimens A-2, A-5, and A-6 were smaller than A-1. Especially, the value of specimen A-6 was smallest of all.

It was determined that repairing by injection of cement slurry A and epoxy resin B was effective to improve the adhesive performance to the base and the following performance of the finishing coat. However, in most of the specimens of this series, εf decreased rapidly after the critical point is reached. This phenomenon shows that the finishing coat caused a brittle separation. Therefore, it may be that the repair using polysiloxane was effective in relaxing the strain on the surface of finishing coat with elasticity, thus preventing rapid separation.

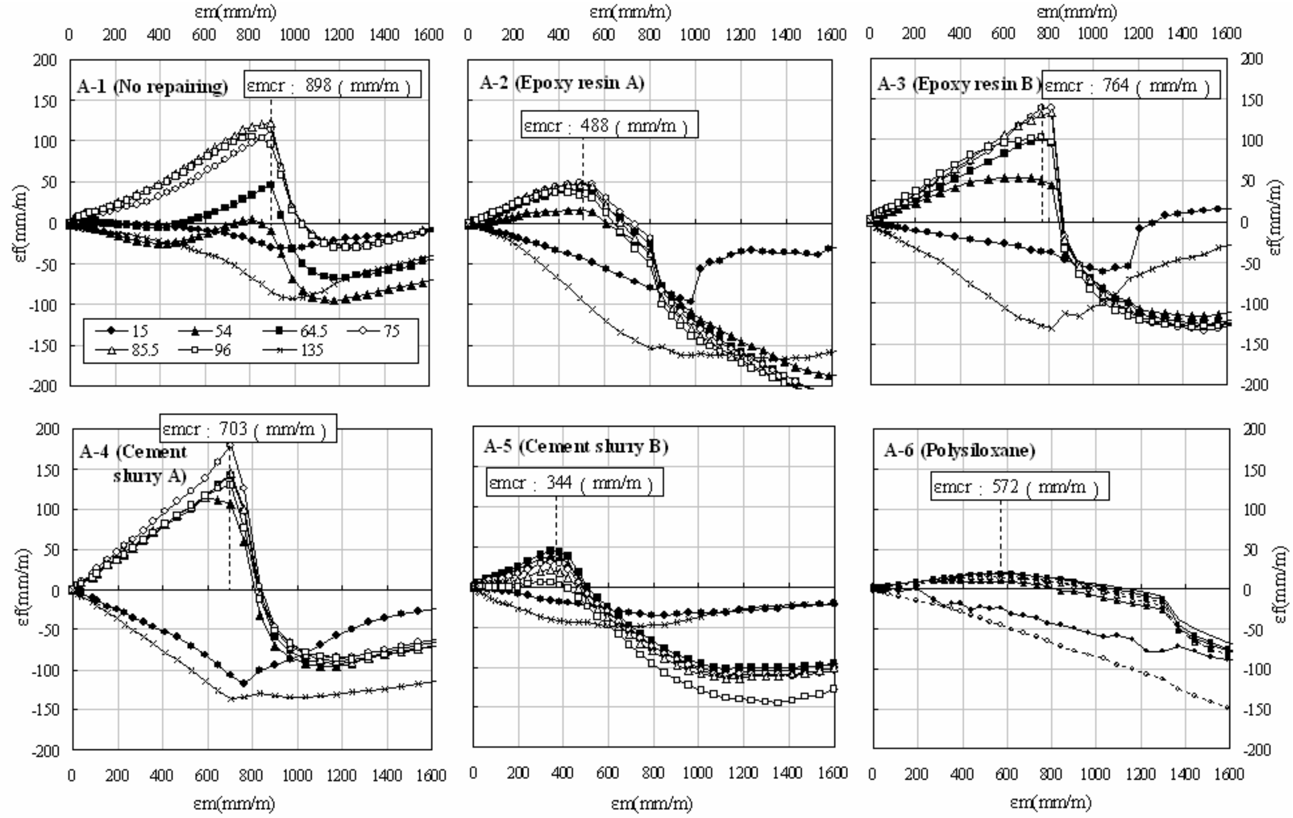


Figure 4 – The relation between the uniaxial strain on the prism (em) and the surface strain on the finishing coat (ef) in Series A

Table 5 –em in critical point (em_{cr}) and the maximum value of ef (ef_{max}) in Series A

Specimen	εm_{cr} (mm/m)	εf_{max} (mm/m)
A-1	898 (5.7)	122
A-2	488 (3.3)	49
A-3	764 (5.1)	140
A-4	703 (4.5)	179
A-5	344 (3.2)	45
A-6	572 (4.4)	20

Series B

The relation between the uniaxial strain on the prism (εm) and the surface strain on the finishing coat (εf) is shown in Figure 5. In specimens B-1, B-2, B-4, B-6, the finishing coat separated in all adhesive examples. In other specimens, separation was observed at the edge of finishing coat.

As in Series A, εf was small near the edge of the finishing coat, and large near the centre of the finishing coat. In B-4, εf was not measured at the edge of finishing coat. Therefore, it appears that the edge of the finishing coat had separated before the compression test began.

The εm values at the critical point (εm_{cr}) of each specimen are shown in Table 6. Specimens that had a larger value than B-1 were B-7 and B-8, and B-9, while specimens B-2, B-3, B-4, and B-6 had the same value as B-1. On the other hand, the value for B-5 was smaller than B-1. When the cement mortar finish with a thickness of 8mm was applied to the concrete base, the εm at the critical point is 1400(mm/m) (compressive stress 12.0(MPa) [2]. Compared with this result, it is clear that the plaster finish on a brick masonry base exhibits a high degree of following performance.

The maximum values of εf (εf_{max}) in each specimen are shown in Table 6. Specimens B-7 and B-8 had a larger value than B-1. Specimens B-2, B-3, B-6, and B-9 had the same value as B-1. On the other hand, the values for specimens B-4, B-5 were smaller than B-1.

It was found that the repair using penetration with Polysiloxane and injection with cement slurry A was effective in improving the adhesive performance to the base and the following performance of finishing coat. However, in repairs accomplished by injection of cement slurry, it was observed that εf decreased rapidly after the critical point.

As in series A, repair by injection of polysiloxane was effective to improve performance of deformation to differential movement. On the other hand, this material tended not to transmit strain on the base to the surface of the finishing coat. As a result, it is observed that polysiloxane demonstrate different effect depending on how to use. In other penetration materials, little improvement was observed in repairs using sodium silicate, or water glass (based on a mixture used by an experienced plasterer in Japan). However, it appears that acrylic resin and lithium silicate caused little separation at the edge of finishing coat within the experimental curing time.

Through the two series, it was observed that specimens using plaster finishing coats had a large deformation compared with those using lime and cement mortar finishing coats, and the process of destruction was gradual.

Table 6 – εm at the critical point (εm_{cr}) and the maximum value of εf (εf_{max}) in Series B

Specimen	Method of repairing	εm_{cr} (mm/m)	εf_{max} (mm/m)
B-1	Penetration	2123 (13.3)	1285
B-2		2453 (13.1)	1907
B-3		2156 (9.8)	1727
B-4		2054 (8.0)	870
B-5		1731 (9.5)	1078
B-6		2469 (12.9)	1663
B-7		3467 (14.9)	3190
B-8	Injection	3526 (16.2)	3727
B-9		3295 (17.9)	1709

Observation of specimens after the construction of the repair materials

Series A

The viscosity of two kinds of epoxy resins is low because they are used for the crack injection. Especially, because the viscosity of epoxy resin B was lower than A, it caused liquid leakage. A complete seal of the injection part is required in actual construction. Moreover, because the stiffening speed of epoxy resin B was slow, it took time for curing. After they hardened, they became transparent yellow and strongly adhesive. It was impossible to remove what adhered to the surface of the finishing coat by the liquid leakage because of the strong adhesion.

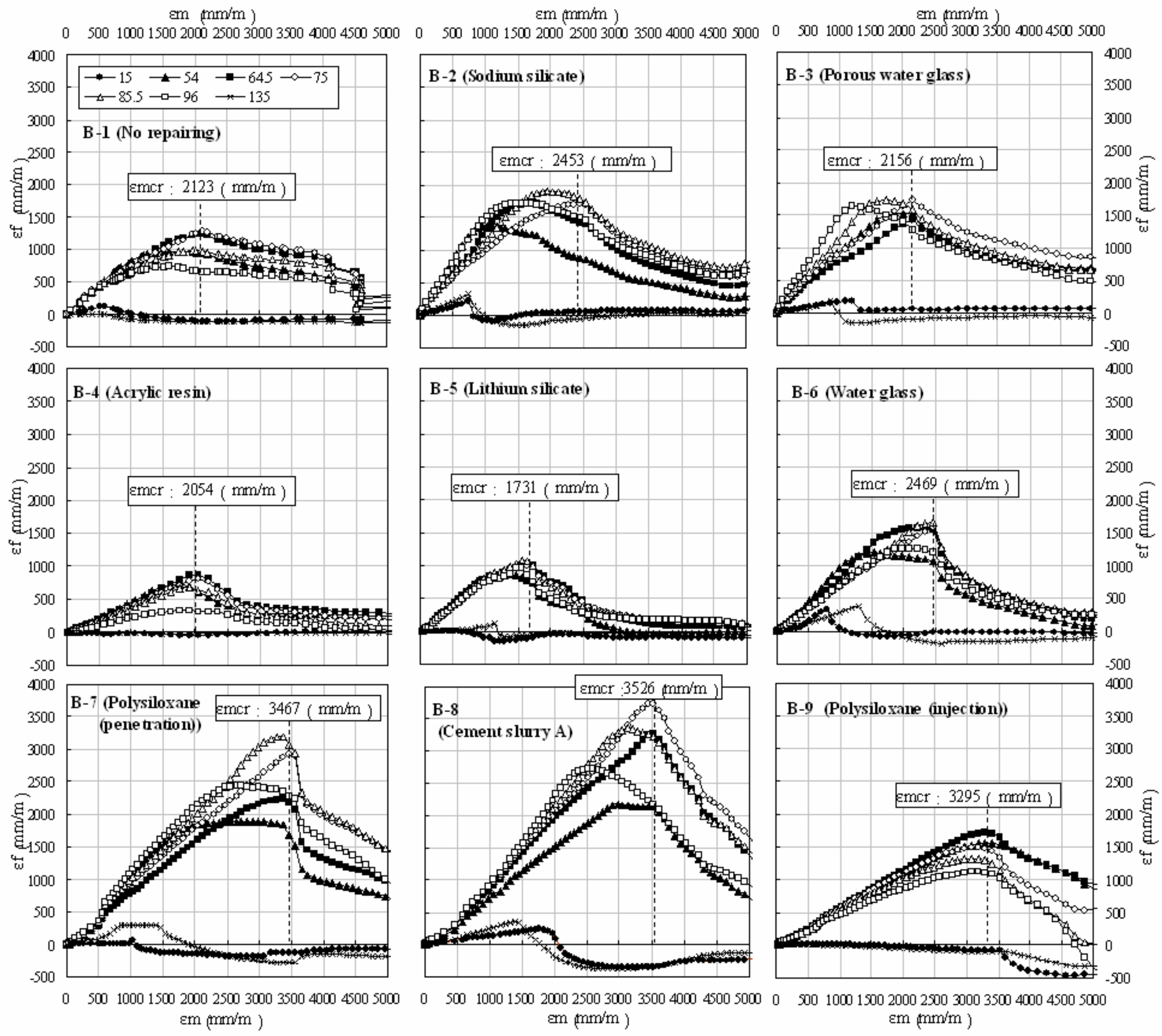


Figure 5 – The relation between the uniaxial strain of prism (em) and the surface strain of finishing coat (ef) in Series B

Cement slurry B tended to dry out and cause defective construction compared with cement slurry A. This phenomenon is thought to be caused by the fact that cement slurry B is intended to be injected into minute spaces like small cracks. Because the polymer is mixed as for cement slurry A, its viscosity was a little higher than cement slurry B. Therefore, the liquidity of cement slurry A was good and construction was excellent. Polysiloxane had a tendency not to be observed in other materials that it penetrated to the base material and finishing coat, and hardened because of the low viscosity as well as epoxy resin. After hardening, lots of bubbles were trapped. The adhesive layer is a semi-transparent white colour and spongy.

Series B

The spreading of the penetration materials is excellent overall. Moreover, they are colourless and there is no negative effect on the aesthetics of the specimen surface material. However, the amount of spreading was different depending on the penetration level and the viscosity. Though polysiloxane had a little stronger lustre after spreading, it arrived at the same state as the other materials after hardening.

The pouring quality for the two kinds of injection materials is excellent. As in Series A, polysiloxane had a tendency to penetrate both the base material and the finishing coat. After hardening, lots of bubbles were trapped. However, the adhesive layer is an opaque white colour and more elastic than those in Series A. Cement slurry A contrasted unpleasantly with the colour of the plaster finish layer although construction with it was excellent.

CONCLUSION AND OUTSTANDING PROBLEMS

Conclusion

1) When a concrete base with a cement mortar finish is compared to a brick masonry base with a lime and cement mortar finish, there were not too many differences in following performance.
2) A brick masonry base with a plaster finish has a higher following performance and adhesive performance than one with a lime and cement mortar finish.
3) With lime and cement mortar finishes, repair by injection of cement slurry (including polymer) and epoxy resin (for crack injection) is effective to improve adhesive performance to the base and the following performance of the finishing coat.
4) With lime and cement mortar finishes, repair by penetration of polysiloxane and injection of cement slurry (including polymer) was effective to improve adhesive performance to the base and the following performance of the finishing coat. However, repair by injection of cement slurry (including polymer) tended to cause rapid separation.
5) A plaster finish repaired by penetration materials showed little improvement in specimens repaired by sodium silicate, and water glass (based on a mixture used by an experienced plasterer in Japan). However, this material caused separation at the edge of the finishing coat at the stage of curing.
6) Repair using an elastic material like polysiloxane is effective to relax base movement, and prevent rapid separation of the finishing coat from the base.
7) Cement slurry has a difference viscosity and hardening speed according to usage. Therefore the one for crack injection tended to dry out and cause defective construction in this experiment. The one mixed polymer was excellent for injection.
8) The construction difficulty with epoxy resin is different according to the difference in the viscosity and hardening speed. In this experiment, lower viscosity epoxy resin was effective to improve adhesive performance to the base and the following performance of the finishing coat.
9) In the penetration materials, there is no difference in the construction. However, the amount of spreading was different depending on the penetration level and the viscosity. It appears that this influences the mechanical properties of the finishing coat.
10) Polysiloxane had a high permeability to the base material and finishing coat. However, there was a difference in the condition of the adhesive layer after the injection according to the material of the finishing coat. It is thought that this difference influences the adhesive performance of the finishing coat.

Outstanding problems

Selected resin materials in this experiment are thought to change mechanical properties of the specimens by aging. Therefore it is necessary to examine durability through periodical experiments. Moreover, because the best material might be different according to the shape of the assumed defect, it is necessary to examine the relationship between the shape of the specimens and the success of the repairing materials.

ACKNOWLEDGEMENTS

Kazuhiro Morita, Hiroshi Kawate, and Shungo Hoko, who belonged to Yamaguchi University as master students 2000.4-2005.3, performed this study as part of their graduate project. The authors would to express great thanks to them for their great cooperation in the execution of this study. Financial support was provided by Grants–in-Aid for Scientific Research (Kakenhi), Japan.

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