RILEM Bookseries

Rafael Aguilar · Daniel Torrealva
Susana Moreira · Miguel A. Pando
Luis F. Ramos *Editors*

Structural Analysis of Historical Constructions

An Interdisciplinary Approach

Springer

Conservation and Restoration on Cement-Based Renders of Built Heritage in Shanghai, PR China

Xiaomin Zhu[1(✉)], Yuee Zhou[2], and Shibing Dai[1]

[1] College of Architecture and Urban Planning, Tongji University, Shanghai, China
14l0096@tongji.edu.cn, ds_build@163.com
[2] Shanghai Baowen Architecture Consulting Company, Shanghai, China
562709487@qq.com

Abstract. Lime-based mortars were mainly used in buildings until the second half of the 19th century, when they started being increasingly replaced by a new binder: Portland cement. And then at the first of 20th century, the cement had become the key role as the binder of renders at Shanghai Modern historic architecture. Those finishing coats show different style: plaster (stucco), fair faced brick, stone coat, etc. The prevalent finish coats were applied with cement-based render as a result of economic way to imitate the stone texture, which includes the water brush stone (It is called Shanghai plaster as well later), pebble dash, artificial stone with chopping (called Zhanjiashi in Chinese), wet dash, Terrozzo, Mane brush drag Sgraffito (called Lamao in Chinese including different statement) at the first half of last century. Some former restoration on renders was discovered to replace the original materials and change the original texture or even the color since the research and analysis on the binder and aggregate was neglected, which is too far from authenticity principle. This paper aims to discuss the restoration method on cement-based renders by analyzing data of lab experiment with petrography and wet-chemical method. Instead of just simply repeating the principle quoted from established standards, the paper tends to provide realistic goals and information to get a more rational and sustainable restoration method in order to avoid the damage coming from unqualified restoration as well as get the authentic texture and color as original facade showed.

Keywords: Restoration · Conservation · Cement-based renders
Built heritage · Experimental analysis

1 Introduction

Cement-based renders as decorative and protective coats are most vulnerable constituents of built heritage due to being exposed to climatic actions, mechanical forces and polluted environmental impact. They tend to be depredated with aging and weathering. Unreasonable maintenance and insufficient knowledge about conservation technologies can result in severer deterioration. Render solutions for restoration are

R. Aguilar et al. (Eds.): *Structural Analysis of Historical Constructions*,
RILEM Bookseries 18, pp. 241–249, 2019.
https://doi.org/10.1007/978-3-319-99441-3_25

sometimes incompatible with pre-existent materials which will produce new pathologies. The choice of adequate materials and statement becomes the crucial factor on renders conservation. Experimental analyses are presented before restoration at the case study of this paper. And their main characteristics such as color of aggregates, grade and ratio are analyzed and compared. Strategies to choose preservation, not to displace, are always the best option when it is possible to handle the degradation like small repairs, fulfillment of lacunae, cracks repair, consolidation. However, if there are large areas of detachments or defects, it could be necessary to substitute old materials. In this case study, new mortars are compatible with the pre-existent wall materials by simulating the same components of the original coat, but less strength and higher permeability. This is essential to keep the original appearance and to maintain integrity and authenticity. In addition, standards of workmanship and statement applications are vital to the durability.

2 Cement-Based Renders in Shanghai

2.1 History of Cement in Shanghai in Brief

As early as the Neolithic age of YangShao culture period, Chinese ancestors had used white lime to plaster interior wall of the mountain caves and then built exterior walls with yellow clay. Until 7th century, the material: 'lime mixed sand and earth' was applied to buildings in the period of the Northern and Southern Dynasties [1]. In 1824, Joseph developed Portland cement which is the striking mark in the cement industry [2]. Cement as the import product to China called Yanghui (means cement coming abroad literally) for a long time at the end of 19th century. The first cement plant is Qing Zhou cement plant in Macau [3], set up by British and local Cantonese in 1886. Three years later, the Ximiantu (translated from the word 'cement' according to pronunciation) plant of Tangshan was founded in 1889, supervised by the Germany technician. This plant was the predecessor of the subsequent dominant cement plant: Chee Hsin which had monopolized the Chinese cement market later, covering most historic buildings before 1920. In 1923, Hua Shang Cement as one of the three important plants (Chee Hsin, HuaShang and ZhongGuo) occupied the dominant market in Shanghai.

2.2 Main Types of Cement-Based Renders in Shanghai

Before introducing of cement to Shanghai, coats of historic buildings were plastered with lime-based mortar mixed with other materials such as vegetable fibers (straw, tow etc.) and sands. However, the import of the cement and progressive construction technology contributed to the new statements of coats. The workability of cement-based plaster allows a variety of shapes and textures. Cement-based finish coats provide better water resistant and anti-frozen performance than lime-based plaster. But the scratch and brown coat often includes cement and lime at the same time. And only the rational ration of cement to lime can provide better performance. The general category of renders can be divided into three aspects: common render, decorative render and aggregate exposed render as Table 1 shows.

Table 1. Main types of cement-based renders before 1949 in Shanghai

Types	Sub-Types	Common aggregates and statement	Case	
1.Common flat render	Render mixed with lime, bits of cement and straw	the ratio of lime to cement> 5:1	No 1761. Si Chuan North Road.	
	Cement-based Render (sometime mixed with sands)	the ratio of cement to sands: 1:2 ~ 1:3	Russian Orthodox Mission Church	
2.Decorative render	Mane brush drag Sgraffito（Called Lamao in Chinese including different statement）	The appropriate ratio of cement: gypsum: sands=1:0.5:0.5 Required amount of water is necessary. More water can lead to the fluid of mortar and less water can lead to the difficulty of statement. More gypsum, deeper shadow	BD apartment. No.700 Hengshan Road	
		Iron float is used to flatten the wall partly after trowel sweep	Ke Ling Apartment	
	Trowel sweep or Trowel Skip or Spanish texture	Using mortar with coarse aggregates, trowel on in fan-shaped or curve line. Lap each stroke to form high ridges off the toe of the trowel. Many variations of this type of texture are possible.	No.831 Huashan Road	
	Sand surface(Spray mortar)	The ratio of cement to sand is 1:2~1:3. Dipping a small amount of cement mortar with brush and throw it to the wall before the wall finally becomes hard.	Rong Desheng former residence	
	Ornamental plaster(stucco)	Casting, moulding or free hand modeling	No.205 Kang Ping Road.(Fig2)	
	Artificial stone with chopping (Zhan Jiashi in Chinese)	Chopping with an axe after setting of the cement-based mortar.	Jianye Lane. No.442 Jianguoxi Road	
3.Aggregate exposed plaster with stone gravel or pebble stone (to imitate the stone vision)	Shanghai plaster (Water brush stone)	The common ratio of aggregates to cement is 2:1 The main aggregates are marble or granite gravel, fine sands etc. After plastered, using water to wash the cement binder in order to expose the aggregates.	Black stone apartment(No.1331 Fuxingzhong Road)	
	Pebble dash	Making the pebble stone wet; A variation on roughcast is pebble-dash or dry dash; Cleaning aggregates are thrown onto a preparatory coat of soft, adhesive mortar.	No.849 Huashan Road	
	Terrazzo	It consists of chips of marble, quartz, granite, glass, or other suitable material, poured with a cementitious binder. Finally polishing the surface.	Amyron apartment No.14 Gaoan Road	

The common render generally refers the flat surface without special decoration. For example, Shanghai Russian Orthodox Mission Church, its facade was plastered with cement and yellow sands. The decorative renders with different statement provide different texture and visual effect such as Shanghai exhibition center. Cement-based plaster may be applied to flat, curved, or rusticated beds made from concrete or lime binder mixed other materials. Decorative renders can be applied by hands and pumps directly or sprayed onto a wall, which provide numerous shapes and textures. Lamao render was originated from Mediterranean district, which was developed in Shanghai since Spanish style was prevalent and the costs was comparatively lower.

The application of Trowel sweep includes big stroke Trowel sweep, small stroke trowel sweep and press trowel sweep to form various textures. It can also shape rich textures by sweeping wet plasters with different tools like a reed row or a bristle brush. For aggregate exposed coats, personal statement technique and selection on aggregates are key factors to form the wanted appearance. Deeper textures may require adding coarser sands to minimize cracking. Therefore, the restoration of these types of renders should be prudent to get the significantly improved performance.

3 Conservation and Restoration

3.1 Guidelines and Codes of Practices

'Principles for conservation of heritage sites in china' issued by ICOMOS China mentions the methodology to original materials in article 36. *Modern and contemporary sites and architecture: the conservation of modern and contemporary building and structures, industrial heritage and scientific and technological heritage should focus on the basic attributes of the original materials, design and function.* Any intervention measures can not alter these attributes as much as possible. New materials should be recognizable and reversible as much as possible. The original materials are emphasized at the article; hence, it is necessary to provide useful information on its primary ingredients and proportion to ensure that new materials will be compatible with the old in strength, physical and chemical performance, color and texture. However, it may not be worthwhile to attempt to duplicate all of ingredients, particularly some of the additives [4].

3.2 Defects

The finish coat with cement binder is inhibiting the evaporation of moisture drawn up from the ground, creating a damp area at the base of the wall. Cracking may occur since cement renders are too inflexible to accommodate thermal movements. The hairline cracks are universal in the exterior wall with long time exposed to the climate. Standards for cement-based stucco are commanded at Shanghai such as using chopped fibers, which has been independently tested to reduce shrinkage cracks in stucco. Environmental causes of deterioration such as acid rain, leaching, frost damage and biological causes like microorganisms are the vital factors to damage cement-based renders. The imprudent restoration such as poor workmanship or even covering original coats with cement will lead to the inappropriate intervention which is deviation of authenticity principle.

3.3 Specific Techniques for Restoration

According to conservation principles, the exterior wall with crack, hollowing void is prior to be repaired in situ by consolidation. Stricter requirements based on long term research, controllable laboratory experimentation and literature reading can be imposed. The prequalification of plaster materials, tools and equipment requirements, mixture proportions, application procedures, and the most important, original statement should be analyzed in the conservation scheme. Additives to control time of set, reduce shrinkage cracking was popular like straws so that finding the original additives is necessary as well. New renders should not lead to further damage, not transmit high stress to the pre-existent materials, not retain water within inside materials, and not have a high salt content. The restoration plaster should be the sacrificial material to pre-existing materials. To assure mechanic compatibility, the replaced mortars should have similar elastic properties and lower flexural and compressive strength to avoid changing original stress distribution. New render should not block the passage of water vapor circulation due to the gradient of water vapor pressure between the interior and the exterior of building. Chemical compatibility implies slow content of soluble salts. Substitution mortars should fulfill several requirements concerning mechanical and chemical behavior, especially aesthetic requirements [5].

When parts of exterior wall system have to be replaced, the three layers (scratch, binder, finish) would be treated carefully. Properties of first and second coats can affect the finish coat appearance. Generally accepted procedures for repairing include the following: 1. Survey and detect the extent of damage. 2. Remove loose, unattached or damaged material. 3. Each succeeding coat is cut back further, the basecoat being the smallest area and the up coat being largest area. After the finish coat has set, washing the area with adaptive materials to remove plaster residue. Sample panels should be completed before any jobsite plastering starts. To ensure that the intended color and texture is correct, sample panels should be made on the jobsite by plasterers who will be doing the actual work. The sample should be large enough to incorporate every component in the wall assembly including joints and other aspects of the desired appearance. The sample should remain on the jobsite until the project is completed and accepted [6].

4 Case Study

Wukang road is regarded as the celebrity road, located in Xujiahui district. The case, Wukang Residence is a building group, including 4 units. The former restoration is unreasonable because it changed the whole south elevation and part of north elevation from pebbledash render to common yellow flat painting (Fig. 1).

The original pebble dash wall covered by painting will be exposed by cleaning on the new restoration scheme. Some severe damaged parts were replaced due to the hollowing voids and cracks in large areas. In order to get the appropriate sample for replacement and infer the possible application process, the two samples were selected, one(D2) from the east elevation which is the most valuable due to facing Wukang road directly (Fig. 2a) and the other sample(D1) from the north elevation since some

uncovered pebble dash parts provide the initial naked eye's observation and taking the sample from the damaged part of exterior north wall is non-destructive (Fig. 2b).

(a) (b)

Fig. 1. (a) The south elevation (covered with flat plaster), (b) the north elevation (original render is kept partly)

(a) (b)

Fig. 2. (a) Dash pebble uncovered with coating (D1), (b) dash pebble covered with later coating (D2)

The sample D2 was cleaned at the laboratory (Fig. 3b). Compared with D1, dark pebbles of D2 were less. Initially, D1 was regarded as original dash pebble. The composition of D1 was analyzed at Fig. 3a and Table 2.

(a) (b)

Fig. 3. (a) Pebble distribution diagram (D1), (b) dash pebble cleaned coat (D2)

Table 2. Pebble distribution analysis of decorative finish coat (D1)

Line name	Black pebble		Grey white pebble		Yellow pebble		Brown pebble	
	Number	Size (mm)	Number	Size (mm)	Number	Size (mm)	Number	Size (mm)
Y1	4	17,28,12,15	2	25,13	2	18,12	–	–
Y2	2	11,27	4	20,19,6,9	2	18,16	–	–
X1	3	28,27,12	2	20,15	2	21,16	–	–
X2	2	12,17	3	13,21,18	1	16	1	26

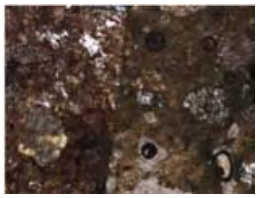
From the above, the pebbles composition, to be concluded, is black pebble 40%, grey white pebble 30%, yellow pebble 25% and brown pebble 5% (the volume ratio). The different size distribution of black pebbles: 25 mm occupying 27%, 15–25 mm occupying 27%, 10–15 mm occupying 36%. Grey white pebbles size distribution: above 25 mm occupying 36%, 10–20 mm occupying 45%, the rest below 10 mm occupying 19%. Yellow pebbles size scope is from 12 mm to 21 mm and the brown pebble size is 26 mm.

Fig. 4. (a) Section of sample D2, (b) section of sample D1

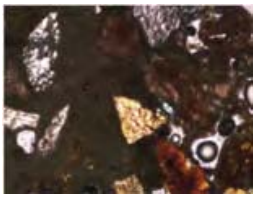
From Fig. 4a, the white lime layer is mottled, which is speculated, because the cleaning of surface with water resulted in the lime layer's uneven distribution after pebbles dashing to the exterior wall. Some lime was cleaned out and other lime stayed around the pebble. It is also possible that the lime was applied between the pebbles during later restoration. On the top of the sample surface, the thin cement could be observed under the white lime which means the last lime coat was used to get the original white color appearance. Then, the cement was for the strong binder to pebbles and getting the good water resistant performance of the exterior wall. The tight sticking can be inferred between the cement paste and lime paste, therefore, it is concluded that before pebble dashing, grey cement paste was applied on the straw lime brown coat, then the white lime painted on cement paste, the pebbles wrapped the cement dashed to the wall and finally the surface was cleaned by water to get the current pebble dash wall.

Fig. 5. (a) Aggregate grading of D1, (b) aggregate grading of D2

The binder ingredients of D1 and D2 were tested by laboratory with the wet chemical method (Fig. 5). The conclusion is as follows: the binder of Sample D1 is lime-based mortar mixed with sands, less cement and less straw and tow. The ration of lime to sand is 1:1. The main aggregate is the fine sands with 0.25–1.0 mm (Fig. 5a). In addition, the original hydraulic composition occupies 10% or so. The binder of Sample D2 is lime mortar with a high quantity of straw. The original ratio of lime to sands is 3:2.



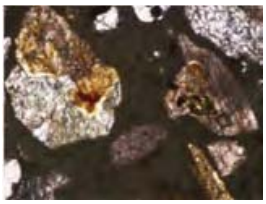
(a)



(b)

Fig. 6. (a) Interface between pebble and mortar (lime-based) of D1, (b) interface between brown and scratch coat of D1

Before the final decision of replacement composition, the analysis was carried out by transmitted-light microscope through petrography. Figure 6a shows that the pebbles (left) and the lime-based binder (right) has a tight cohesion. However, Fig. 7b shows the crack in the middle of the brown scratch between the lime mortar and course aggregate. The possible reason is that the lime hadn't got enough time to set and the lower original hydraulic composition is another illustration for this phenomenon.



(a)

(b)

Fig. 7. (a) Lime-based (mixed less cement) brown coat of D1, (b) interface between sand and mortar (lime-based) of D1

Because of no cement in scratch and brown coat of sample D2, D2 tends to be considered the original materials. Further, the east elevation provides vital vision to the city so that the east render was decided to be preserved by injecting to consolidate. Considering that the pure lime mortar as brown and scratch coats has a weak performance to the moisture and rain etc., D1 was selected to basis of experimental sample. At the same time the replaced pebbles according to D1 (different from the original D2) provides the readability of restoration. But at the specific ratio and thickness, the sample components have a slight changing to get the better durability and avoid the crack like Fig. 7b due to excess lime causing short set. The final decision made to

repair the exterior wall with the binder (the brown and finish coat) is: lime 40%, fine sands 40%, grey cement 10%, straw 10%. From the case study, the scratch coat includes cement and sands. The brown coat is mixed with cement and lime since the mixed mortar with lime has a good performance in shrinkage resistance. And the finish plaster includes the lime layer and cement layer, considering that cement provide the high bonding strength and the white lime provide the aesthetic visual effect by high contrast to main dark color of pebbles.

5 Conclusions

Since cement was imported to shanghai in next half of 19th century, cement gradually replaced lime partly. Lime has some advantages different from cement so that lime and cement were coexisting in the first half of 20th century. The finish coat is mainly cement plaster which endures aggressive climatic and environmental conditions because of the good moisture resistant and high strength. However the problems of cracking, shrinkage and excessive strength are being observed in cement mortars as well. Combining lime and cement provided one solution to these problems. Lime and cement mortars have a possible application field for strong old masonry and brick wall in no capillary rising, although there are always some risks of introducing soluble salts into masonry and brick. Compatibility with pre-existent elements and durability of the mortar must always guide the choice. The cement mortar added lime as the brown coat mitigate the shrinkage and increase moisture permeability, which is beneficial and compatible to the brick wall base. It must be emphasized that the quality of crafts-manship is also crucial for the artistic renders like Lamao, pebble dash etc. It influences strongly the compatibility, the fitness for use, and durability of the renders as well.

Acknowledgments. ‘Conservation Masonry Patina’ sponsored by Natural Science Foundation of China.

Architectural Conservation Laboratory of CAUP, Tongji University.

References

1. Yanmou W (2004) History of Chinese cement. China Building Materials Industry Press. TU.466
2. Lesley RW (1924) History of the Portland cement industry in the United States. International Trade Press Inc.
3. Zuitian Z (2011) History of China cement (I). Cement Technol. 1001–6171. 01-0020-06
4. The Lyons Press (2004) The preservation of historic architecture
5. do Rosário Veiga M, Fragata A, Velosa AL, Magalhães AC, Margalha G (2010) Lime-based mortars: viability for use as substitution renders in historical buildings. Int J Archit Heritage 4 (2):177–195. https://doi.org/10.1080/15583050902914678
6. Flynn RT (1964) Guide to Portland cement plastering reported by ACI Committee 524. ACI 524R-93