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Lime-based Materials and Practices for Surface Refitting of Cultural Heritage

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Abstract: The surface of cultural heritage and façade of historic buildings represent most values. The conservation of such surfaces need special cares, because most of them are non-structural exposed to extreme weather conditions. The refitting and consolidation delaminated surface were carried out using organic resins, like epoxy resins or cement suspension. However the evaluation in the recent years show such kinds of materials are not chemically compatible with historical materials. Based on inspection on cracks of Huashan's Pictographs and other historic buildings in Shanghai and Hangzhou, a new system composed of adhesives and injection grouts based on natural hydraulic lime (NHL) has been developed for refitting and rehabilitation of delaminated surfaces made of natural stones, plaster and bricks. The laboratory researches and trial areas on site have shown the adhesives based on modified NHL have sufficient bonding strength to hold delaminated stone slices and blocks. Furthermore, they show slow setting and carbonation process, almost same heat expansion coefficient as the lime stone and inorganic historical materials. After exposure of 135days on site, the trial areas show neither cracking nor efflorescence. The application of developed adhesives and injection grouts in the restoration work of historic Shanghai plaster gates of Jiuxinli in Hangzhou, Zhejinag Province, has been observed positively. Because of high performance and competitive price against organic resins, they are expected to be an optimal material system in the future for façade restoration of architectural heritage and monuments.

Key words: Cultural heritage, historic surface, refitting, Huashan Pictographs, natural hydraulic lime

Introduction

The surface of stone monuments and façade of historic buildings represent most values of history, art and technology. Because those surfaces are exposed to extreme weather conditions, cracking, delamination are most common defects. However they are mostly non-structural, the refitting needs special cautions.

Unlike most structural deterioration, the most surface defects are caused physically by temperature variation, heat expansion and shrinkage, erosion by water, freezing and thaw. They can also be caused by hygric swelling or shrinking due to water/moisture absorption and drying. Salt crystallization and related hygroscope contributes to extreme extent to decompose cohesion of materials.

From 1920's, materials e. g. epoxy resins, and cement suspension and technology including anchoring, grouting have been used.

However, the observation and laboratory testing proves that both epoxy resins and cements are neither chemically nor physically compatible to historical substances.

The latest approaches are to develop new adhesives based on natural hydraulic limes (NHL). As early as 1996, G. Struebel and Sh. Dai at the Justus Liebig University of Giessen, Germany, has developed injection grout based on NHL 2 and evaluated the performance to fill cracks in masonry from natural stones in Church Lohra, Germany. The further research works have been published by Victoria & Pingarr (2006) at the University of Pennsylvania and Egloffstein, Simon & Oezer (2007) in Germany.

Since 2006 a team from China National Academy for Cultural Heritage in Beijing and Tongji University in Shanghai has evaluated all literature on hydraulic limes for restoration of natural stones and other materials. This paper summarizes the latest research results in terms of performance criteria, material development, trials on various sites of Huashan Pictographes, painted app. 1500-2500 years ago on lime stone.

Surface Delamination of Cultural Heritage – an Example from Huashan Pictographs

Huashan Pictographs are located in Ningming, Guangxi Autonomy, riverside of Ming Jiang, a Chinese National Heritage, one of few heritage of Chuang Nationality in Autonomous Region Guangxi. She is becoming very popular in the world since in the opening ceremony of Olympic Games 2008, a part of the Huashan Pictographs has been displayed to demonstrate the ancient Chinese culture (Fig. 1).

Figure 1: Part of the Huashan Pictographs displayed during the opening ceremony of Olympic Games, Beijing 2008

However the surface of painted limestone is becoming very instable. Falling down of stone pieces is often to be observed and this unique heritage needs to be rescued.

The main defects are cracks along the cliffs: parallel or horizontally. The width of cracks ranges from micrometer up to several centimeters (Fig. 2). Microscopic studies show the hole space behind cracks are filled with dusts, carbonate and clay sedimentation, insect bodies etc. Those contamination can not be thoroughly cleaned. Ants are also found to settle in the cracks. The refitting needs special caution. Very critical is the desolving of painted limstone, by condensation water, the pictographs are fading (Fig. 2).

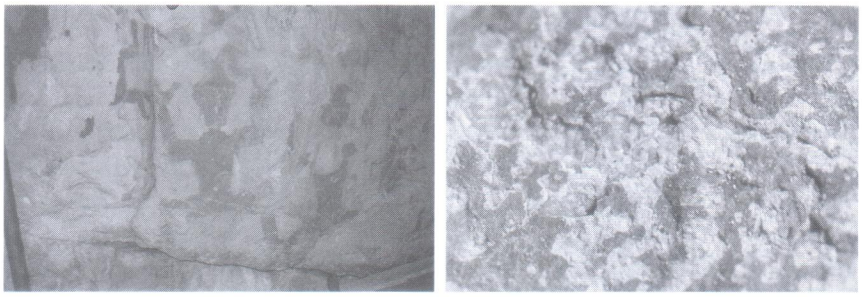

Figure 2: cracks (left) and desolving of painted limestone surface (right)

The preliminary studies show the limestone is very dense with porosity of less than 5%. The cracks are mostly caused by thermal expansion and shrinking. The urgent measurement is to fit cracked surface to make it safe.

Technical Requirements for Surface Refitting of Cultural Heritage

The Huashan Pictographs are located on natural cliffs, similar to all heritage architectural facade. The environment factors, like heat, humidity, can not be changed. Theoretically all refitted cracked will crack again in the future so we need to optimize the material performance to fit the cracks in the current rescuing stage, but leave more options in the future. A second important idea is: new cracking should happen within fitted cracks, i. e. to sacrifice new adhesives to preserve the original materials. Since the condensation contributes to fading of pictographs, the new adhesives shall absorb more condensation to minimize the water load on the painted limestone surface.

Based on site inspection and empiric evaluation, the technical requirements for surface refitting have been defined in order to optimize the formulation and application of on site (Table 1). Two kinds of materials are specified: one as crack filling mortar (CFM) and second is injection grouts (IG) to meet defferent cracks. Both mateirals shall be mechanically and chemically compatible to limestones and sedimentation within cracks.

Table 1: Technical requirements for adhesives to refit the surface of Huashan

	Criteria	*Remarks*
Pull-off strength	≥0.1～0.5Mpa, ≤ 1.0Mpa	High pull-off strength may cause more cracking within stone surface.
Capillary water absorption	≥2kg/m^2·√h	The new refitting materials shall be able to absorb and store condensation of the pictographs
Water vapour permeability	μ≤100	All water either from condensation or from limestone shall diffuse as quick as possible
Heat expansion coefficient	± 50% of limestone	In case of new cracking, the shearing shall occur within the refitting materials, not in limestone
Sustainability	Leave possibility of future preservation work	-
Water soluble salts	As low as possible	-
Deterioration	Same as limestone both physically and chemically	-
Application	Easy application	-
Cost	reasonable	-

Formulation and Laboratory Testing

The recepts both for crack filling mortar and injection grout have been fomulated based on natural hydraulic lime NHL according to EN 459-1: Building Lime. The agregates are fragments of limestone from Huashan or petrographically and chemically same as Huashan. Redespersible acrylic resin is to improve pull-off strength at the ealier setting stage of NHL-adhesives. Other additives, like methyl cellulose (MC) is to improve theworkability of adhesives. After having compared more than 40 different formulations, 2 formulations have been evaluated as qualified CFM for rescue works of Phase I, the evaluation are based on criteria in the Table 1. The performance of CFM-I have been summarized in Table 2.

Table 2: physical performance of the optimized Crack Filling Mortar

Physical properties	*Under Shanghai humid climate*	*High temperature and high humidity simulated Huashan climate*
Compressive strength（15days）	4.9 MPa	4.0 MPa
Flexural/tensile strength（15days）	3.2 MPa	2.35 MPa
Pull-off strength on marble surface（20days）	0.3 MPa	0.5 MPa
Adhesive strength（28days）	0.5-0.6MPa	——
Shear strength (7days)	0.26 MPa (under standard climate and temperature)	
Lineal heat expansion coefficient	4.9-6.5 x10^{-6} 1/k(limestone: 4.6x10^{-6})	

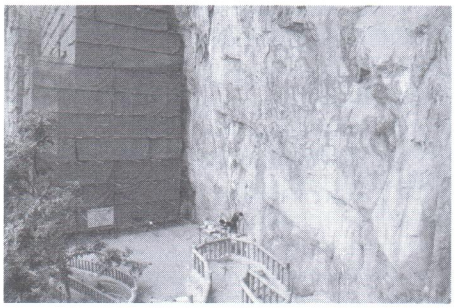

Figure 3: trial area on site, 8. March 2009

Site Testing on the Area without Pictographs

The site testing has been carried out in March 2009 on areas without any pictographs (Fig. 3). The testing included cleaning methods, refitting with CFM-I and it's modification, grouting to different cracks with IG of various fragment sizes.

The tests on site have been evaluated after 135 days exposed to local climate. The adhesives have showed surficient bonding strength to hold delaminated limestone, no by effects have been identified.

Starting of Rescue Work

Because of positive results both in laboratory and on site, the rescue work of phase I has been started in Nov. 2009 to consolidate most severe damaged surface (Fig. 4). The CFM was mixed on site and filled into app. 50% cracks. The pull-off strength was tested also in local laboratory.
Further testing was carried out direct on areas of pictographs. New evaluation will be done in Sept 2010 in order to finalize the recepts, application process and quality control criteria.

Figure 4: Pointing to hold cracked limestone

Conclusion and Discusssion

The developed adhesives and injection grouts have been also applied to many other restoration works. For example, to restore historic Shanghai plaster gates of Jiuxinli in Hangzhou, the development injected grout has been injected with low pressure in 2009. The cracked stone monuments in a temple of Hangzhou, Zhejinag Province have been restored with CFM and IG of Huashan Formulation. Both have been observed positively.

The preliminary laboratory testing and site trials prove a system of adhesives on the basis of natural hydraulic limes can be used to refit the delaminated limestone pictographs, Shanghai plaster etc.

Because of high performance and competitive price against organic resins, the natural hydraulic limes are expected to be an optimal material system in the future for façade restoration of architectural heritage and monuments.

Further research works are focusing in setting process of different hydraulic limes, mechanical and chemical performance of different formulation in long term under different climate. The altering process of organic additives will be also detailed researched.

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