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Repair Mortars Studied for the Conservation of Temple G1 in Mỹ Sơn, Vietnam

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Abstract Since 2001 the authors have been involved with the archaeologists of the Fondazioni Lerici, Politecnico di Milano, in the preservation of some Hindu temples in Mỹ Sơn, Vietnam. The characterisation of the brick-masonry materials was carried out at the Politecnico di Milano. Especially interesting was the successful study of the natural resin used to bond externally the bricks in the masonry; this allowed the formulation of a new compatible resin to be used for the conservation project. In the masonry internal leaf, the joint material, based on clay, was substituted by a new hydrated lime and powdered bricks mortar. The results of the research presented here allowed the direct application of the new materials in the conservation project of G1, G3, and G5 of group G.

1 Introduction

When the contemporary principles and theories of conservation that have been developed mainly in the Western world are applied to Asian monuments, it is a difficult task to compromise with the position of the experts in that part of the world. Furthermore, when the monuments are at the state of ruin in archaeological sites it becomes more difficult to apply these principles. Conservation in countries that have suffered wars and consequent poverty is even more difficult, also due to lack of advanced techniques and materials.

The authors have been working since 2001 on the conservation of a group of buildings in Mỹ Sơn, Vietnam (called group G by H. Parmentier). The groups of temples in Mỹ Sơn were called by alphabetic letters from A to N by Parmentier, who discovered them in the jungle near DaNang at the end of the 19\textsuperscript{th} cent. Conservation works on group G began in 2004, followed by the Politecnico di Milano, within the framework of a tripartite contract between Politecnico, Institute for Conservation in Hanoi, and UNESCO, supported by the Italian Ministry of Foreign Affairs. The group G was built, as all the others, in brick masonry with some peculiarities.
Principles were applied to the preservation of the buildings, especially for the use of new materials, mortars, resins, and bricks. The choice of the new materials was made according to some important criteria: (i) the possibility of finding local materials and production techniques, (ii) control of the parameters defining the quality and compatibility of the new materials, and (iii) execution of the works on site by non-specialized workers.

The climate in Mỹ Sơn, typical of the tropical areas, has deeply influenced the choice of the mortar to be used to consolidate the internal part of the wall, which was two- or three-leaf masonry; the original material between the pieces of bricks constituting the internal leaf was simply clay and brick powder. In the meantime, the external joints were found to be made with a resin coming from a local tree. Therefore, when the works on the G group started, an investigation was carried out in the Northern and Central part of Vietnam in order to find a hydraulic binder. On the basis of the experimental research based on chemical, physical, petrographical, and mechanical tests, different compositions - from hydrated to hydraulic lime-based mortars - were examined. Unfortunately no suitable hydraulic lime was found in Vietnam, so the only possibility was to prepare a mortar based on hydrated lime and brick powder, which testing indicated was the best fit due to the proven pozzolanicity of the brick powder.

The paper will describe the results of the experimental tests in laboratory and on-site, where some specimens were prepared following the special conditions of temperature and humidity of the site. The difficulties of preparing the brick powder following the imposed grain size distribution and of realizing on-site the mortar composition and the quality control with available rough tools will also be described.

The chosen mortar composition gave acceptable properties in the short- and long-term, and some samples from the site examined in thin section and at SEM after two years gave evidence that very good pozzolanic reactions had taken place. Even at visual inspection, the top joints exposed to humid and rainy climate is still showing compactness.

2 Description of the Mỹ Sơn Hindu temples

The archaeological area of Mỹ Sơn is situated in Central Vietnam, 30 km southwest from Da Nang; it is located in a valley surrounded by low mountains dominated by the Rang Meo mountain, and it is crossed by the Thu- Bôn river. The Mỹ Sơn area (Figs. 1, 2) is 15 ha wide and composed of several groups of buildings made with brick masonry, each organized around a main temple (Kalan). Mỹ Sơn is the most important holy place of the Champa kingdom. The Cham people built over seventy buildings here, from the 6th to the 14th cent AD, but now only thirty with at least 1 m in elevation are still recognizable. The site was rediscovered after centuries of abandonment in 1898 and studied at the beginning of the 20th cent. by French architect H. Parmentier, from the École Française d’Extrême Orient (EFEO) [1]. A Vietnamese-Polish expedition (lead
from 1982 until 1986 by K. Kwiatkowski and K. Hoang Dao) carried out restoration works on some group of buildings damaged during the war at the end of the sixties [2].

The buildings in Mỹ Sơn are made of fired bricks thinly joined by natural resin. The wall section is made of two leaves with small connections or three leaves, with brick rubble in the middle and faced externally with bricks (Fig. 3). The most peculiar characteristic of the brick masonry was the special construction technique which created a bond between bricks so tight they practically did not show real joints (Fig. 4). The special building technique protects the walls from the attack of the vegetation; where the thin joint is not damaged, there are only very low biological attacks [3].

In order to realize a more tight physical bond, the technique of rub-joining was used during wall construction before applying the resin. Scratches can be seen on the horizontal and vertical surfaces of the bricks in contact with other bricks. The scratch can be clearly observed by a magnifier and even by naked eye (Fig. 5) [4].

Following some hypotheses that organic natural materials could have been used as binder between the bricks as in historic buildings in other parts of Vietnam and Southeast Asia, a careful study was carried out on materials sampled from the Mỹ Sơn masonry walls. Furthermore, it was decided for the safety and durability of the masonry in the future to use a new mortar based on hydrated lime and brick powder in the locally reconstructed parts and, when possible, to connect the three or two leaves.
3 Characterisation of the existing materials

In order to carry out laboratory research on the masonry materials, samples were taken during several visits to the site, starting from 2000. The samples were collected from the groups A, D, E, and G, which was a group of interest for the Italian pilot project. At DIS, Politecnico di Milano, the authors carried out several tests on the sampled materials in order to detect the properties of: bricks, brick assemblages, and joint material.

3.1 Material sampling

Due to the difficulty of sampling without damaging the walls, the number of samples was rather small to be statistically representative of the materials used. Nevertheless the experimental research gave rather good results, as will be shown below. All the brick samples were taken from the material available on the ground (buildings A1, A13, B9, D4, and G1) or in the ruins (E4, E5, and E7) in order to avoid spoiling the standing parts of the buildings. In 2001, a special glue of vegetal origin, used for caulking of boats, was bought at the local market in Hoi An (RES1); in 2004 another resin coming from local trees (called Daù Rai) and sold as glue was bought close to the Mỹ Sơn site (RES2).

3.2 Chemical, physical, and mechanical tests on bricks, joints, and rubble filling

The analyses concerned the bricks and the binder in the external joints and in the inner leaf of the walls. Chemical analyses according to [5] were carried out on the sampled materials [6].

The results showed that the composition of all the sampled brick is the same, despite apparent visual differences, and that the composition of the bricks and of the so-called joint is the same, but also contains an organic resin. The presence of a very low CaO content in the joint (from 2.33 to 4.48%) showed that no lime was used in the external joints. Chemical analyses were also carried out on the material sampled from the internal leaf of the walls. They show that the composition of this material does not differ from that of the bricks [7].

Physical tests were performed on four to six small brick cubes (40 mm side) cut from the bricks; the tests were carried out according to the European standard (UNI EN 2001). The results show a certain in-homogeneity; nevertheless, some orientation values can be given as an average: (i) bulk density = 1,630 kg/m³, (ii) I.R.S from 0.41 to 1.92 kg/m²/min, (iii) water absorption coefficient = 160.09 g/cm²×s⁰.⁵, and (iv) water absorption by total immersion between 18.18 and 23.99%. Some XRD tests carried out on a specimen from A1 show that the bricks were fired at a temperature below 900°C, [7].

Compression tests were carried out on cubes (40 mm x 40 mm x 40 mm). Once
again, all of the values were very much scattered, between 8 and 14 N/mm². The modulus of elasticity E and the Poisson coefficient were also calculated, and the values are typical of a rather soft material [7].

4 The natural resin used for the external joints

The “Giulio Natta” Department of Chemistry, Materials and Industrial Chemistry of the Politecnico di Milano (G. Zerbi), and the Institute of Biology of the Faculty of Science of the University of Milan (F. Tomé) have performed the chemical characterization of the resin found in the joint [8]. The identification of the main components of the organic materials was carried out mostly by means of infrared spectroscopy with FT-interferometers. To help in the analysis, a few procedures of separation of the components have been followed, such as evaporation in vacuo and extraction with suitable solvents.

The idea behind these analyses was that the materials used in the building of the Mỹ Sơn temples should be fully related to what nature offers in the area and what people can manufacture locally from the resins of the trees that grow in the surrounding area. These trees belong to the species of the dispterocarpaceae.

The results of the analyses are as follows:

- 1) Identification of the chemical nature of sample of resin found in the area of Mỹ Sơn, RES1 (a special resin, liquid at room temperature, used for caulking boats) and RES2 (extracted as viscous fluid from a local tree called “Đaû Rai”). The infrared spectrum of RES1 shows that Dammarenediol seems to have the highest relative concentration with respect to many other possible substances in much lower concentration. Difference spectroscopy provides the infrared spectrum of the volatile component of RES 1, which can be identified as alloaromadendrene. The two materials RES1 and RES2 are practically identical, thus indicating that the local people obtained the glue from local trees.

- 2) Analysis of the material scratched away from the joint (JRES1). Fig. 6 shows the great similarity of the organic component extracted from JRES1 with the solid residue of RES1. The spectrum shows, however, that some chemical modifications have occurred from RES1 to JRES1. It is likely that the resin taken from the brick originally could have been just the resin from the trees; self-oxidation processes that possibly occurred over the many years could justify the spectral changes observed.

In conclusion, the new resins have a similar composition to the old ones and can be used for joint repair.
Fig. 6 Comparison of the FT-IR spectra of the material extracted with carbon tetrachloride from the brick (red) and the FT-IR spectrum of the solid residue of RES1

5 The repair mortar composition

It was decided to use a lime based mortar for the repair or reconstruction of the internal leaf of the walls; the resin could not be used because the internal joints between rubble bricks were rather thick and the original joints were simply filled by clay. This mortar should be a hydraulic one, but as said above, it was practically impossible to find a hydraulic lime in the Mỹ Sơn area. Therefore, it was decided to choose a mortar made with hydrated lime and brick powder and/or pebbles if it could be detected that the Mỹ Sơn bricks were pozzolanic. Tests were carried out on powdered bricks from the site. The bricks were ground very fine and the powder showed a positive behaviour at the pozzolanicity test carried out at the Politecnico di Milano (Fig. 7). The pozzolanicity test was performed according to the European Standard [9] used for cement, adapted to the special case. The bricks showed pozzolanicity after 30 days.
In the meantime, the research of the lime was started in the area around Mỹ Sơn in order to minimize the price of transportation. Since it was impossible to find a lime from stones, as the existing quarries had been closed in order to avoid the continuous spoiling, only natural lime coming from the sea shells could be found. Lime samples from the nearby village of Lang Co, from the village of Kiern Lam, and from Hoi An were collected along with a putty lime from Ha Noi. The third lime from Hoi An was finally chosen after comparison by chemical and physical tests was carried out in Milan at DIS, Politecnico [10]. It was the best mortar available in the Mỹ Sơn area, and therefore it was chosen.

It was then decided to produce two types of mortars: (a) with fine aggregates for thin joints and (b) with coarser aggregates for thicker joints. The maximum diameter size varies according to the thickness of the joint from 2 to 16 mm (Figs. 8 and 9).

During the intervention, specimens were prepared on-site, cured at the site environment, and sent to Milan for testing (Fig. 9). Flexural and compressive tests were carried out in Milan according to the European Standard [11]. The results are given in Tab. 1, where $\sigma_f$ is the flexural strength and $\sigma_c$ is the compressive strength. As seen in Tab. 1, the mortars were tested at different ages of curing, but the number of days did not follow the same increase as is normally done in laboratory. This was due to the fact that some mortars were prepared on-site and tested in Milan whenever possible. Nevertheless both the scattering in the data and the values of the tensile strength were rather acceptable for a low strength hydraulic mortar.

The chosen mortar was first used for the repair of the two remains of the buildings G3 and G5, which only emerged from the ground from 50 to 100 cm, in order to check the compatibility of the new materials used in external and internal
joints. The works ended in 2005, and up to now they have shown a very good behaviour. In 2009 the works started on the most important building of group G, the Kalan G1.

![Fig. 8](image1.png)  **Fig. 8** Grain size distribution of aggregate for new mortars

![Fig. 9](image2.png)  **Fig. 9** Specimens realized on site

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Age of curing</th>
<th>$\sigma_f$ [N/mm²]</th>
<th>$\sigma_c$ [N/mm²]</th>
<th>Age of curing</th>
<th>$\sigma_f$ [N/mm²]</th>
<th>$\sigma_c$ [N/mm²]</th>
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<td>0.67</td>
<td>1.40</td>
</tr>
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The results found by the observation of new mortars in thin section and with the SEM-EDS were very interesting. Three specimens were observed, two sampled on-site from G3 (MS.05.1 and MS.05.2) and one in the laboratory at DIS-Politecnico (MS.06.1). The results of analysis of the thin sections of MS.05.1 on a polarised microscope are shown in Figs. 10 a and b. It can be easily seen that in all the sections, reaction borders between binder and brick pebbles are present, also showing a pozzolanic reaction which is still ongoing in MS.05.1. The SEM-EDS observations of MS.05.1 (Figs. 11 a, b, and c) show the presence of reaction borders composed of calcium and aluminium, calcium and silica, silica, and calcium and aluminium.

### 6 Conclusions

After the application of the new materials on G3 and G5 ended in 2005, the
observation of their durability and the optical tests on the sampled mortars some conclusions can be made: (i) the resin and mortar used in Mỹ Sơn show a good durability after five years, (ii) the optical observations of the new mortar made after two years show good pozzolanic reaction of the brick powder with the lime, and (iii) the new materials can be adopted in the conservation of the main kalan G1.

Fig. 10 Specimen MS.05.1: a) photomicrograph in transmitted light (3.5×); b) photomicrograph in transmitted light (10×)

Fig. 11 Reaction borders composed: a) calcium and aluminium; b) calcium and silica; c) silica, calcium and aluminium
7 References

9. UNI EN 196-5