XII DBMC
International Conference on Durability of Building Materials and Components
PORTO - PORTUGAL, April 12th-15th, 2011

Repair Mortars for Rammed Earth Constructions

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ABSTRACT

Rammed earth buildings, with resistant and monolithic walls, often have constructive pathology. A survey on more than thirty rammed earth buildings, mainly in Alentejo region (South Portugal), was conducted. As a result, it was found that surface deterioration of the walls seemed to be an usual problem.

Many rammed earth buildings are deteriorating due to lack of maintenance and rehabilitation, but also due to incorrect repairs. Several of them were repaired by applying cement-based mortars in the attempt to overcome the general decay, of the walls that could or not be deep.

This paper presents the most common pathology: problems due to water ingress and low drying capacity; salt transport and contamination; construction technology like voids left from the formworks; biological attack; different mechanical behaviour between the walls and the repair mortars - mechanical incompatibility.

An intervention methodology for repair the degradation of exterior surface, including anomalies diagnosis and application of these repair mortars, is proposed. The support samples preparation - laboratorial rammed earth blocks with surface deterioration - is also described. Finally, an experimental campaign foreseen for the development and application of earth-based mortars for repair rammed earth walls is presented.

KEYWORDS

Rammed earth walls, pathology, causes, laboratory wall samples, repair mortars.

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1 INTRODUCTION

Earth buildings are nowadays redrawing the attention of professional and scientific communities due to peculiar characteristics of earth materials. They are environmentally friendly, recyclable, low cost, accessible, incombustible, provide good acoustic and thermal insulation and thermal inertia. Rammed earth - earth compacted between formworks - is among the oldest and most widespread building techniques in the world. In recent years, this technique has seen a revival and new developments. In Portugal, it has been used in new constructions and also in old rammed earth buildings rehabilitation.

For build with earth it is necessary to understand the main construction methods, the characteristics of the materials used and their mechanisms of degradation. This knowledge is also needed in order to hold proper rehabilitation and/or conservation interventions. When those factors are not taken into account it may lead to errors and premature anomalies appearance in buildings. The development of suitable repair methods for rammed earth is therefore necessary. Indeed, many old buildings are still deteriorating due to lack of maintenance or rehabilitations works, what leads to the need of deep interventions. Because the knowledge on rammed earth building techniques is still far from being consolidated, new buildings often present problems. This is related with the fact that this type of construction was not used for a long period of time and the investigation about it ceased with the appearance of new building materials, such as steel and concrete.

The anomalies are usually caused not only by one but by a combination of different agents. However, water is probably the main decay agent - moisture reduces the internal cohesion and mechanical strength of the material, increments the destructive action of soluble salts and favours biological development. The result is often the walls surface degradation. One of the major difficulties in rehabilitation works regards the correct use of repair mortars. Sometimes the repairs are inadequate due to the use of incompatible materials. The use of mortars based on hydraulic binders, as cement, is a bad example of an attempt to overcome degradation.

2 PATHOLOGY AND CAUSES OF DEGRADATION

Old earth buildings are considered vernacular architecture but, in the last decades, many new earth constructions have been built in Portugal and in other countries. In some of these countries the industrialization and regulation of this kind of buildings is becoming a reality, like the German reference, Lehmbau Regeln [2009]; however, the Code and Standard support is still not enough developed in Europe, unlike countries like New Zealand, Australia, New Mexico and USA. The preservation and conservation of these buildings, carried out by the owners, is often very weak or inexistent.

Most rehabilitation interventions, or even new constructions, do not take into account the specific characteristics of the raw material or the specificity of the construction system, leading to errors and premature appearance of anomalies in buildings. According to several authors [Guettala *et al.* 2006, Atzeni *et al.* 2008, Hall & Allinson 2009] it is important not only to understand the materials and techniques of these constructions, but also their behavior when exposed to natural agents. Surface coatings, renders and plasters have a very important function in protecting the wall against such actions as climatic - mainly water, moisture and wind -, mechanical actions or environmental contamination. They also contribute to improve thermal and acoustic comfort, namely indoors, to hide wall imperfections and to change building aesthetics. Because exterior surface coatings - paint layers and renders - are exposed to many potentially destructive actions, these elements are more prone to degradation in constructions.

Analyzing the most frequent anomalies in earth constructions, several deterioration agents can be identified, namely water which is the main degradation agent that causes the most important and frequent anomalies. When combined with other agents, water can cause serious damage to the materials. After analysing, *in situ*, over than thirty rammed earth buildings - old and new ones -

recurrent anomalies were detected in the exterior surface of the walls in a significant number of buildings.

2.1 Exterior surface pathology and causes of degradation

The pathology can range from a simple alteration to severe degradation. The main anomalies found in the exterior surface of walls are: surface deterioration - loss of cohesion, cracking, appearance of salt deposition, detachment, patch repair poorly made, dust and dirt. The main causes are: structural strain, lack of ductility, continued acess of water, salt contamination, low drying capacity, lack of adhesion to substrate and lack of rendering. They can be due to: inappropriate conception, inappropriate construction technique, the use of inappropriate materials, sloppy application, aging of materials and lack of maintenance. In many cases the exterior surface of the wall was never rendered and was not protected, the coating no longer exists or is already detached, endangering wall integrity (Fig. 1).

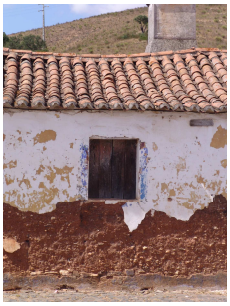

Figure 1. Rammed earth house in Bemposta, Odemira. Detachment of the coatings due to capillary rising and problably hygroscopic salts, with degradation of the wall.

In rammed earth walls is usual to detect anomalies due to the application of incompatible renders. The renders should be made of mortars with similar physical, mechanical and chemical properties with the walls where they are supposed to be applied, but often this does not happen. The main problem with renders is ensuring the long-term integrity of bond between the render and the earth substrate; this characteristic is very important but also difficult to achieve.

There are many anomalies with respect to exterior surface of walls but in this paper only the most frequent will be discussed. It is usual to observe coatings detachments, with different depths, causing wall degradation. This kind of pathology is due to different anomalies which may be, or not, associated with each other. It is usual to find very brittle coatings, with very low cohesion, that easily begin to disintegrate. This defect leads to the appearance of recesses and degradation with different depths that may even reach the support. It is mainly caused by the loss of the binder from the mortar, washed by water. On unrendered or unmaintained walls it can happens on the surface of the support. These anomalies occur mainly in more exposed areas of the wall surface like corners [Houben and Guillaud 1994].

Render cracking is another common anomalie in wall coatings, that often accelerates its rate of failure and increase the risk of water penetration. Cracks may be few but wide open or very numerous with small aperture. Microcracks may evolve into larger cracks over time. If the mortars of the new render are too stiff and cannot support the wall movements because of the incompatibility between materials - mortar and substrate -, the adherence between them can be very weak and the render may crack; the stiff and strong render can also induce the wall to break within its superficial thickness.

After the application of a mortar it will tend to shrink due to evaporation of the water contained; this shrinkage is restrained by the adhesion to the substrate and it will lead to the development of tensile stresses in the coating which may tend to crack. This shrinkage will also develop shear stresses in the plane of contact between the coating and the support, which may leads to their detachment.

Crazing is a network of fine cracks on the surface of a material; they are in infinite number very thin and linked. If the mortar is less rich in binder and applied in a thin layer, cracks are usually less deep, less spaced and the stress levels are smaller. By contrast, in a mortar with very rich binder, for example containing a high clay fraction and which is quite active, the cracks tend to be fairly wide, separated from each other but quite deep.

Salt crystallization commonly occurs near the interface between the support and the render, and it may accelerate the coatings decay and detachment. That crystallization usually produces crystalline or amorphous deposits of alkali or alkaline salts: carbonates, chlorides, sulphates and nitrates, causing usually small white or gray colourful halos in the walls surface. According to Faria Rodrigues [2005] and many other studies, the movement of salts is due to the moisture flow inside the wall that tends to carry them in its dissolved state to the surface - depending on the drying capacity of the different layers -, where they accumulate. It often occurs with problems of water penetration - as it can be the case due to capillary rising (Fig. 1). Sucessive cycles of drying/hydration of the salts produce tensions which induces loss of cohesion in the material close to the salt deposit [Gonçalves *et al.* 2007].

It is important to repair these anomalies in order to prevent the continuous deterioration of the wall and to restore its protection. For a proper intervention a right combination of the repair mortar and the substrate is needed. It may be necessary to do a quite deep repair, which may lead to multiple mortar layers. For this type of intervention compatible repair mortars need to be developed and the effect of shrinkage of the new mortars on the rammed earth walls is very important and should be taken into special account.

3 DIAGNOSIS

To achieve a reliable diagnosis for the rehabilitation of a rammed earth building it is necessary to know it beyond what is in sight. It is essential to understand: the materials used and their conservation condition, the building's structural typology, the building's current uses and the surrounding environment. The building and its surroundings are in an equilibrium that may be disturbed by the implementation of any construction works. According to Guillaud [2008], there is a "golden rule" that should be applied whenever conservation and rehabilitation interventions are needed. This rule defines the following course of action:

- observe and document the baseline condition of the building;
- minimize the intervention, with compatible materials and techniques;
- assure the reversibility of interventions;
- document the interventions;
- make a regular inspection and maintenance.

Before any intervention it will be necessary to determine which degradation processes occur and if the circumstances which led to the deterioration are complex or combined. In most cases the "domino effect" is rather drastic: one problem creates another problem, which in turn generates another and so on. The diagnosis should be sought to address the causes and origins of the anomalies found in the building. No intervention should be held while the causes and origins of the anomalies are not yet properly addressed and resolved.

4 INTERVENTION METHODOLOGIES

Mortars need to be formulated and tested in order to be applied in repair interventions. There is a premise in all mortars application, especially for those with common binders: the first layer applied should not be stronger than the substrate and the binder content should not increase along the coating thickness from the inside to the outside, avoiding the creation of tensions that could lead to craking or peeling of the upper layer. As said before, also the materials used for repairs must be compatible with the original material. These characteristics are similar between any repair mortars, being them earth-based mortars or not. Whenever possible, materials for earth-based mortars should be collected from

the same place as those originally used. It is necessary to check if the materials are suitable for the objective set and how the mortars can be further improved.

Repair mortars for total or partial replacement of renders and thickness reconstitution of the walls shall contribute to the protection of those walls being durable and without contributing to their degradation. Compressive and flexural strength and elasticity modulus should be compatible to the original support materials. The resistance to the pullout should not be higher than the tensile strength of the support. The capillary absorption should not be high but particularly the drying capacity of the new mortars can not be lower than those of the support and interior layers.

Taking into account all the characteristics mentioned, an intervention methodology based on the use of earth-based mortars is proposed, supported by an experimental campaign for the development and application of repair mortars for rammed earth walls. A variety of repair mortars will be characterized for the most critical properties - dimensional stability, mechanical resistance, adherence, water absorption and drying, durability to ambiance factors - and tested on different rammed earth laboratory blocks - samples that intend to reproduce different rammed earth walls with common anomalies.

It is necessary to choose the most promising mortars. According to Moropoulou & Bakolas [1998] the selection process of a mortar composition should be an iterative process, idea that is accepted by other authors [Válek *et al.* 2000, Veiga *et al.* 2001, Papayianni 2008]. This process should contain the following steps:

1. determination of the approximate constitution and the physical and mechanical characteristics of the original mortar;
2. preparation of a mortar similar in terms of constitution and appearance, with similar aggregates, preferably local;
3. testing to verify minimum requirements and the similarity of the main features;
4. corrections to the formulation tested in order to approximate the characteristics;
5. repetition of steps 2 through 4 until reaching a reasonable likeness of the fundamental characteristics and therefore expected proper behavior;
6. realization of experimental panels at work site;
7. again, if necessary, carry out adjustments in the formulation tested.

4.1 Rammed earth blocks

Before the execution of experimental panels at work site, and in order to develop and evaluate different repair mortars, some rammed earth blocks were manufactured. The material used was obtained from non deteriorated walls of rammed earth buildings. Ten rammed earth blocks were produced with three different compositions of soil. Each material composition represents a material gathered in a diferent building. They were particularly chosen in an attempt to represent different soils usually used for rammed earth technique in Portugal - with different grain size distribution, type of clay and colour. In order to obtain similar dry mass to the existing building wall, it was conducted a test based on LNEC Specification E205 by measuring the weight and volume of undisturbed samples, that were collected directly from the building wall. Through the values obtained in the test it was extrapolated the value of the mass needed for the volume of the each block, with dimensions 30cm $\times$20cm$\times$28cm.

Two types of anomalies, most currently found in the exterior surfaces of rammed earth walls, were recreated on the sample blocks: superficial irregularity with loss of cohesion and deep voids (Fig. 2). The block samples are being kept in a controlled ambiance - 20ºC and 50% RH. The repair mortars will be applied over the two types of anomalies, in order to verify the compatibility between the substrate and the repair mortars and the applicability and effectiveness of the intervention.

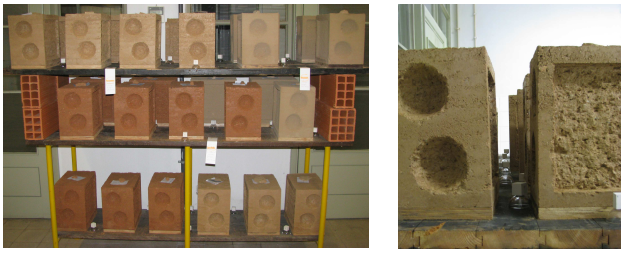

Figure 2. Rammed earth laboratory blocks with different soils and with two types of surface degradation - deep voids and superficial irregularity with loss of cohesion.

4.2 Constituents for repair mortars

Rammed earth has a relatively weak surface and cannot tolerate strong renderings. There are some recomendations in the literature for the composition of mortars for rammed earth walls: Delgado & Guerreiro [2006] recommend the use of earth-lime mortars; Ashurst & Ashurst [1995] recommend a lime/sand composition of 1:2.5/3 prepared with lime putty; Gernot [2006] refers that an earthen render should contain 5-12% of pure clay.

All earth-based mortars have a binding agent that can be only clay or added lime or cement. In the twentieth-century most of the references on conservation of earth construction, in order to improve the waterproofing properties of renders, recommended the addition of Portland cement. However some other studies refer that this component is not recommended for the repairs [Ashurst & Ashurst 1995], which may be a problem and represents a colossal mistake when used in unstabilised earth constructions [HB 195 2001, Guelberth & Chiras 2008]. Cement wicks moisture into the interior of walls causing deterioration. Also Delgado & Guerreiro [2006] do not agree with the use of cement-rich renders to cover unstabilised walls. Figure 3 shows an unrendered rammed earth house with a cement mortar in a localized repair; it is possible to see biological agents of degradation underneath the repair.

Figure 3. Rammed earth market house in S. Luís, Odemira. Left, repair with hard cement; and right, agents of degradation namely insects underneath the repair.

These recommendations can be used as a starting point but not as a rigid solution. It is well known that all cases are different (soil change from region to region) and is therefore necessary to assess which features exist in the building and try to get the best solution for a repair mortar.

The repair mortar to be used in earth buildings must have the following features: suitable workability and adherence to the support, ecological sustainability - this should be consistent with the rammed earth walls -, effectiveness as repair and protective systems. The final quality of repair mortars depends on the proportions but also on the quality of each component. It is necessary to understand the main characteristics introduced by each component. Although these recommendations, cement will be used in some compositions in order to show its problems and the results will be evaluated and compared with other ecological mortars that will be optimized, for efficient and protective repair applications.

In this study four types of components will be used for the repair mortars: clay soil, sand, eventually a binder - lime or cement - and hemp fibbers. The amount of water used will be strictly the one needed to make the mortar workable and adhesive. Also a composition for a standard soil to use for repair mortars will be pursuit. Different earth-base mortar compositions will be characterized and the most promising will be tested in the three different types of rammed earth blocks.

5 DISCUSSION

Rammed earth construction is an old traditional method but most of their characteristics and properties still remain poorly investigated. The shortage of training courses and the lack of specific specialists and researches in this area do not allow the updating of knowledge; in this field the know-how lies on elderly people that have experience (in terms of construction practices or even maintenance) but they are disappearing. However, since the last decades, the interest on earthen architecture, both nationally and internationally, raised awareness for the important gains of this construction technique, as well as for the need of its conservation and preservation.

The maintenance of this type of buildings is fundamental. If the exterior drainage of the wall base is assured, if the roof is properly functioning, if the walls are protected and if the interior ventilation of the dwellings is assured, the longevity of the building is guaranteed. In order to assure the superficial protection of the exterior walls, at least when needed, they must be rendered and painted. The paint should be compatible with the render and the render with the wall - mechanically, physically and chemically - and, for the time being, that can easily be assured with traditional and ecological materials: lime paints for finishing layers and lime mortars, earth-lime mortars or earth mortars for renders or for deterioration repair.

Lime paints and lime mortars have been investigated by many researchers all over the world; not many studies have been held for earth-based mortars. The aim of the continuity of this study, in the frame of the first author PhD, intends to contribute for a better knowledge on this type of mortars and for the possibilities of applications in order to repair two very common types of degradation that occurs in the exterior surface of rammed earth walls. As said before it is fundamental that repair mortars for this type of application must fullfill specific requirements and present specific characteristics, including compatibility with existing elements (in order to effectively protect the taipa walls) and durability.

ACKNOWLEDGMENTS

This work was carried out at LNEC, Lisbon. M. I. Gomes was supported by a doctoral grant from the Portuguese Foundation for Science and Technology (FCT). The authors are grateful to the many people from the Materials Department of LNEC, in particular to Eng. Teresa Diaz Gonçalves for her valuable collaboration in this study; also thankful to the technicians that collaborated on the experimental work, João Júnior, José Costa and João Ribeiro.

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