NATURAL CONSOLIDATION OF ANCIENT HISTORIC BUILDINGS MORTARS SUBMITTED TO HUMID AND MARINE ENVIRONMENT: A MICROSCOPIC STUDY

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Abstract

Ancient historical buildings are important features of the history, culture and development of a country and its people.

This study presents the results of chemical, physical and microstructural characterization performed on mortars in order to assess their durability and performance in a marine and humid environment, The mortars are collected in two historical monuments in Lisbon region, the Santa Marta Fortress (SM), and the Defence Wall of Lisbon (M).

1 Introduction

Effect of seawater on ancient mortars deserves special attention due to the simultaneous action of physical and chemical deterioration processes which can turn into an accentuated degradation of renders in historical buildings. In Portugal, a country with a long coast by comparison with its geographical territory, there are several historic buildings located near the sea with air lime renders in very good conservation state (Silva, 2008;Adriano, 2009;Elsen, 2004;Gleize, 2009) . In coastal regions, the atmosphere is enriched with particles that are naturally generated by the action of wind on the water surface (Adriano, 2009; Rizzo, 2008; Jackson, 2010; Oleson, 2010; Costa, 2009; Paiva, 2010; Veiga, 2001; Bakolas, 1998). These particles compose the sea spray, which introduces ionic species into the atmosphere, principally chlorides and sulfates. These sprays can cause accumulative ions deposition on the external surfaces, that can penetrate into the material through ionic diffusion. This kind of environment has proved to be very severe for construction materials as a whole, and in particular also for recent cement mortars and concretes. Nevertheless some air lime mortars survive to it in good conditions.

Physico-chemical and microstructural techniques for materials characterization, e.g. optical and electron microscopy, X-ray diffractometry, thermal analysis and chemical analysis, were used to determine composition, microstructure and main characteristics of the selected mortars. Conclusions were drawn concerning the compounds formed and the reasons for the durability of those mortars.

2 Experimental

The selection of the sampling sites was made according to LNEC methodology for the characterization of mortars in ancient buildings (Silva, 2002; Silva 2004), and taking into account information collected from archaeological and historical researches.

The specific preparation for each analytical technique and the analysis conditions employed are presented in previous works (Silva, 2008;Adriano, 2009). At stereo-zoom microscope all mortars revealed a very heterogeneous aspect with high amounts of calcitic binder. Both SM samples have similar aggregate quantity, but in SM1the aggregates seem to be finer and more rolled than in SM2. The M mortars also present high amounts of binder and very heterogeneous aggregate particles.

XRD showed that the SM mortars were composed by quartz, feldspars, mica, kaolinite, calcite, hematite, magnesite, ettringite, halite and calcium carboaluminate hydrate. XRD analysis of M samples revealed that are mainly composed of quartz, feldspars, mica and calcite.

The TGA-DTA charts for all samples are typical of aerial calcitic lime mortars, showing an intense weight loss in the range 550-900º C that corresponds to the calcite decarbonation. The SM2 mortar present several weight losses in the decarbonation zone (550-900º C), attributed to the presence of different carbonate species, including, besides the carbonated lime, some calcitic aggregates and carbonated pozzolanic compounds.

Chemical analysis showed diversity in soluble salts content that correlates well with their actual environment, and are also consistent with the high neoformation compounds detected by XRD in the SM2 mortar. Excluding the M2 sample, all mortars have a similar siliceous sand content. Highest chlorides and alkalis contents are as expected evidenced in SM2.The grain size distributions revealed that the aggregate on SM and M mortars is mainly between 0,16 and 1,25 mm. However, the M mortars have a larger aggregate size distribution, and a larger proportion of fine particles that could contribute to a more compact and cohesive structure.

Petrographic analysis of SM samples reveals sub-rolled aggregates mainly composed of siliceous grains (quartz and feldspars) and altered metamorphic calcitic rocks. The carbonated lime paste presents several microcracks connecting voids, being visible some features in cavities that seem to be due to recrystallisation processes. The siliceous and calcitic grains present a sub-rolled morphology, suggesting a marine or river origin. Moreover, reaction rims are evident around some aggregates, suggesting the occurrence of pozzolanic reactions between these aggregates and the calcitic lime, that create neoformation products, such as calcium-aluminates, which are normally responsible for the improved mechanical resistance of the ancient mortars. M samples presents aggregates with a less diversified mineralogy than SM samples. The aggregates are mainly composed of polycrystalline quartz and alkaline feldspars. Some basaltic grains and calcitic fossils were also observed. One of the most interesting observations were the occurrence of big lime lumps, and recrystallized products inside the cavities and pores in the mortar paste. These lime lumps could be related to a badly calcination process of the lime, which is also corroborated by the detection of dispersed fragments of coal.The microstructural observation reveals that all mortars have the pores normally fulfilled with reaction products, ettringite in the SM mortars and calcium carbonate and phosphate in M mortars. Moreover, reaction rims are evident around some aggregates, suggesting the occurrence of pozzolanic reactions between aggregates and the calcitic binder that creates neoformation products, such as calcium-silico-aluminates, which seems be, besides the pores filling, the responsible for the resistance and cohesion of these ancient mortars submitted to aggressive humid environments.

SEM/EDS analysis shows that all mortars exhibit a compact calcitic matrix, typical of old lime mortars, with aggregates well mixed with the binder. The binder is, as expected, strongly carbonated, with a large number of pores, with irregular size and shape, generally with recrystallized calcium carbonate crystals.

3 Conclusions

The results obtained in this study points out the importance of the raw materials used in the lime mortars manufacture. No hydraulic binders were found in the mortars from the two monuments studied, the Santa Marta Fortress (SM) and the Defence Wall of Lisbon (M). In particular, no hydraulic lime or natural cement was detected, confirming the idea that old Portuguese mortars were mainly based on air lime, both calcitic or dolomitic. In some mortars the presence of ettringite was detected, which seems to be formed by the reaction between the sulphates from the exterior environment and the calcium-aluminates from the pozzolanic reactions of the sand with the calcitic lime binder. Despite the expansive behavior of the ettringite, in these cases its formation seems to be *diluted* in the porous structure of the lime mortars, avoiding the destructive usual effect. Probably this fact is related to the slow kinetics of its crystallization, and could contribute to the mortar strength increase. Some of the lime paste microporosity has also been covered by secondary calcite, which may have been formed by the water action by slow dissolution/re-precipitation processes.

In both case studies, the pores observed were often filled with neoformation products and in the majority of cases not connected. In author's opinion, the ingress of salts with the corresponding compounds formed, in conjunction with the water ingress, have contributed to the durability of these lime mortars. The studied cases could be referred as natural consolidation of historical ancient mortars.

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