RESEARCHING IN ANCIENT ENGINEERING PHYSICAL AND CHEMICAL ANALYSIS IN HYDRAULIC ROMAN MORTARS

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Abstract

Around ten years ago investigation of technical and material construction in Ancient Roma has advanced in favour to obtain positive results. This process has been directed to obtaining some dates based in chemical composition, also action and reaction of materials against meteorological assaults or post depositional displacements. Plenty of these dates should be interpreted as a result of deterioration and damage in concrete material made in one landscape with some kind of meteorological characteristics. Concrete mixture like calcium and gypsum mortars should be analysed in laboratory test programs, and not only with descriptions based in reference books of Strabo, Pliny the Elder or Vitruvius. Roman manufacture was determined by weather condition, landscape, natural resources and of course, economic situation of the owner. In any case we must research the work in every facts of construction. On the one hand, thanks to chemical techniques like X-ray diffraction and Optical microscopy, we could know the granular disposition of mixture. On the other hand if we develop physical and mechanical techniques like compressive strength, capillary absorption on contact or water behaviour, we could know the reactions in binder and aggregates against weather effects. However we must be capable of interpret these results. Last year many analyses developed in archaeological sites in Spain has contributed to obtain different point of view, so has provide new dates to manage one method to continue the investigation of roman mortars. If we developed chemical and physical analysis in roman mortars at the same time, and we are capable to interpret the construction and the resources used, we achieve to understand the process of construction, the date and also the way of restoration in future.

Proposal of intent

This work is summarized as a review of a methodology today, but selectively depending on the material, type of construction and chronology. Two years ago, after reviewing repertoire of literature on Roman mortars in Europe, we set out from the Madrid School of Architecture one

investigation that already had numerous bibliographical examples. Knowledge about materials and construction techniques is an important part of one area of research, Archaeology of Architecture. For years research on historical mortars has many studies focused on restoration and characterization of mortar mixes. In the other hand studies about roman mortars are less numerous, although there are good examples in Italy, Portugal or France. After reviewing bibliography, a test plan was proposed with which it achieve the objectives: firstly create a statistical map of mortars in Iberian Peninsula, and then build a pattern of materials applicable to restoration. But there are few cases in which they were taken about twenty samples of roman mortars in six archaeological sites. This is our case. Thanks to a series of archaeological digs in Cuenca province, in Spain, we had the chance to take samples of mortar from production and housing areas. The chemicals and physicals assays developed (X-ray diffraction and optical microscopy) are part of a protocol comprehensive testing that tray to develop a pattern of production.

Facts of chemical characterization

Characterization of any construction resource does not give us an absolute chronology, but it gives us a first witness. Among the early case studies we can not forget the baggage of Bessac [1] and Gian Pietro Broggiolo [2]. In this field both developed an extensive and fundamental study of materials and Roman building techniques, not only from the description of the monuments but throughout its evolution and its study based on archaeology. We must also mention the work of Donati, one of the first exceptional studies of ancient material of construction [3].

Combined with archaeological data, they can give us an absolute chronology. This protocol that we defend has been used by some research groups in isolated samples from specific sites in Spain [4], Italy [5] or in Mediterranean Basin [6]. However the development of several tests in a single archaeological area of twenty kilometres around has not been developed before. This research has not only served as example of protocol for other areas been tested in the future. Also it has characterized different mortars located on several settlements in domain area of *Segobriga*. However similar cases are particularly relevant with amazing results, as projects developed by Civil Engineering Laboratory (LNEC) in Lisbon [7] and research project about lime mortar developed by Antonia Moropoulos at University of Athens [8]. We have been inspired by those serious works.

In any case, samples are part of pavements and foundation walls, settling basins, decantation pools and an aqueduct *specus* unknown in the area. We can see other research in similar areas in

archaeological complex as Roman Coliseum. There archaeologist applied several analyses in samples of lime mortar from walls and cistern too [9]. In our case when archaeological intervention finishes the work we proceeded with sequence of samples in an area of about twelve miles. One of the most important successes was that administration requested these series of samples, after a good work of archaeologists in the area. Time before discovery we developed a proposal for intervention based on careful reading of the existing studies. We want to acknowledge the help provided by Jorge Morín de Pablos and AUDEMA S.A. Company, in Spain, responsible of archaeological intervention. Once in work area we developed a sampling based on existing studies. Many of these works analyzed the materials from the point of view of buildings restoration [10]. Others however, focused on the characterization of the mass itself, without interpolating the results to archaeological context.

First we start surveying the place, and then we analyze each and every one of the structures that make it up. Finally we took samples in strict accordance with international standards. As Bisconti researching in Venetian historical mortars we manage a statistical table which is comparable with chronological dates [11]. We extracted samples from several building elements (walls, floors and foundations) whoso a relative chronology was collected thanks to archaeological found before. Sampling was developed using extraction tools. Foundations were drilled below to extract the mortar block. Thank to this protocol we made sure not to modify physical characteristics of binder and aggregates of sample.

Laboratory work has been developed at the Faculty of Geological Sciences, in Complutense University of Madrid. Performance of thin sections allowed the identification of components in different optical magnification. In this phase of research we could see certain expertise to make some mortars related to older chronology. Microscopy observation allows distinguishing visually blending components. This could be a first step in the characterization of mortar. As well as knowing if the mortar is hydraulic or not, we can distinguish partial grain size of aggregates. The particle size distribution, called granulometry too, is developed through sieves, and in certain times can determinate grain qualify. In our case we could observe a regular distribution of clay grains and binder well-mix. We have a full collection of works with thin films with excellent results in terms of optical microscopy. In opinion of Maartens Broekmans, around petrography method in two cases of deterioration: ñ(é) *both cases illustrate that petrography is an indispensable tool in the forensic assessment of concrete* (é)ò [12]. Petrography method and optical microscopy should be required in initial stages of any analysis of building materials. References are as wide as complete, so we highlight the work of Luxán, Dorrego and Laborde in mortars gypsum of Spain [13], sampling and analyses in Roman

Gaul baths developed by François Rassineux staff [14] and research work led by Domenico Miriello about several kind of materials of construction [15].

Second part in laboratory was developing an X-Ray diffraction in Faculty of Geological Sciences too. Graphics comparison between archaeological sites is essential to understand the different occupational phases. Every samples of lime mortar has common features, such as presence of calcite and quartz in high percentages. Have also been detected by X-ray diffraction some percentages of dolomite, andalusite, illite and microcline [16]. Results were as expected, except some high-dolomite percentages present as a residual in the geological resources of the area. It has also allowed specifying the timing of different rooms. One of the most important results has been that these resources are present in the area. For example now we are capable to understand the energy cost of transporting materials to the processing site (Tab. 1).

Moreover we have the possibility of improving the lime and gypsum mortars intended for archaeological restoration. If we have a good knowledge about physicochemical characteristics of this kind of material, also we will be able to create models which optimized to enhance long-time and comply with requirements and criteria museological restoration. In this sense it has been sizable to the existence of poor performances right through ignorance the compositions of the materials to restore. This should be our main purpose in future.

These tests were destructive with sampler, but they must been completed with a rigorous visual analysis process through binocular lenses, as they are being developed in several archaeological sites [17]. Also we are currently developing a model of physical and chemical tests for these kinds of samples. As they are hydraulic mortars we pretend to know what are the physical characteristics and how is the reaction mass against water condensation. In this way physical test should be directed to determinate, in general terms, water reaction, gradual degradation by weather effects, loss of dry aggregates, loss of binder through precipitation, reaction and ruptures the surface by temperature changesé Many are restored mortar outdoors, and have not been designed to withstand the weather [18].

Conclusions

Now we can compare the manufacture of a Roman mortar whose chronology we know, with another mortar in other place whose chronology is unknown. In this way we can cross the information obtained and establishes a chronological pattern between archaeological settlements. In the study areas in Spain it has been possible thanks to sampling in several archaeological sites with different chronologies and typologies. Results were used to establish a

system of hydraulic mortars study in areas of industrial production. At first not only allowed us to know the mineralogical components of the samples, but rather compared to the natural resources of the region.

Secondly, we have achieved to date partially different settlements depending on mortar chemical characteristics. Obviously this system should be reviewed and compared always with results of archaeological excavation. And of course comparison of results obtained in roman settlement provide us an archaeological interpretation of the area (Tab. 2)

The work we are developing from the Polytechnic University of Madrid is based on studies carried out by research groups of high prestige from Greece, Turkey or Italy. Our intention is only to establish some basic parameters and a protocol for the analysis of Roman mortars. We know the path of researchers working in Pompeii ground, in Merida landscape (Spain) or in Rhine Valley. All of them are developed testing and analysis with results that enriching the standpoint of characterization of historical mortars.

Finally we defend the use of test based on electromagnetic technology, as Raman Characterization [19], Synchrotron Radiation or Conventional Spectroscopy [20]. Consequently with this theory we defend an analytical system and testing protocol based on combining laboratory techniques and archaeological interpretation. Thanks to this we have obtained results about setting mineralogical of lime mortars, extract in clear places from settlements and dated at the same chronological line.

If we could develop the same testing system in areas like Guadalquivir valley, in archaeological complex of Sussex in England, or in roman fortifications on Danube between Leskovac and Belgrade, we would have the opportunity to learn about making models of Roman concretions. And of course would improve the results in restorations works in future.

At last we emphasise the partnership between geologists, archaeologists and architects. Likewise, researchers should insist governments to include this kind of analytical works. Roman architecture can hardly be known only using Greco-Roman sources.

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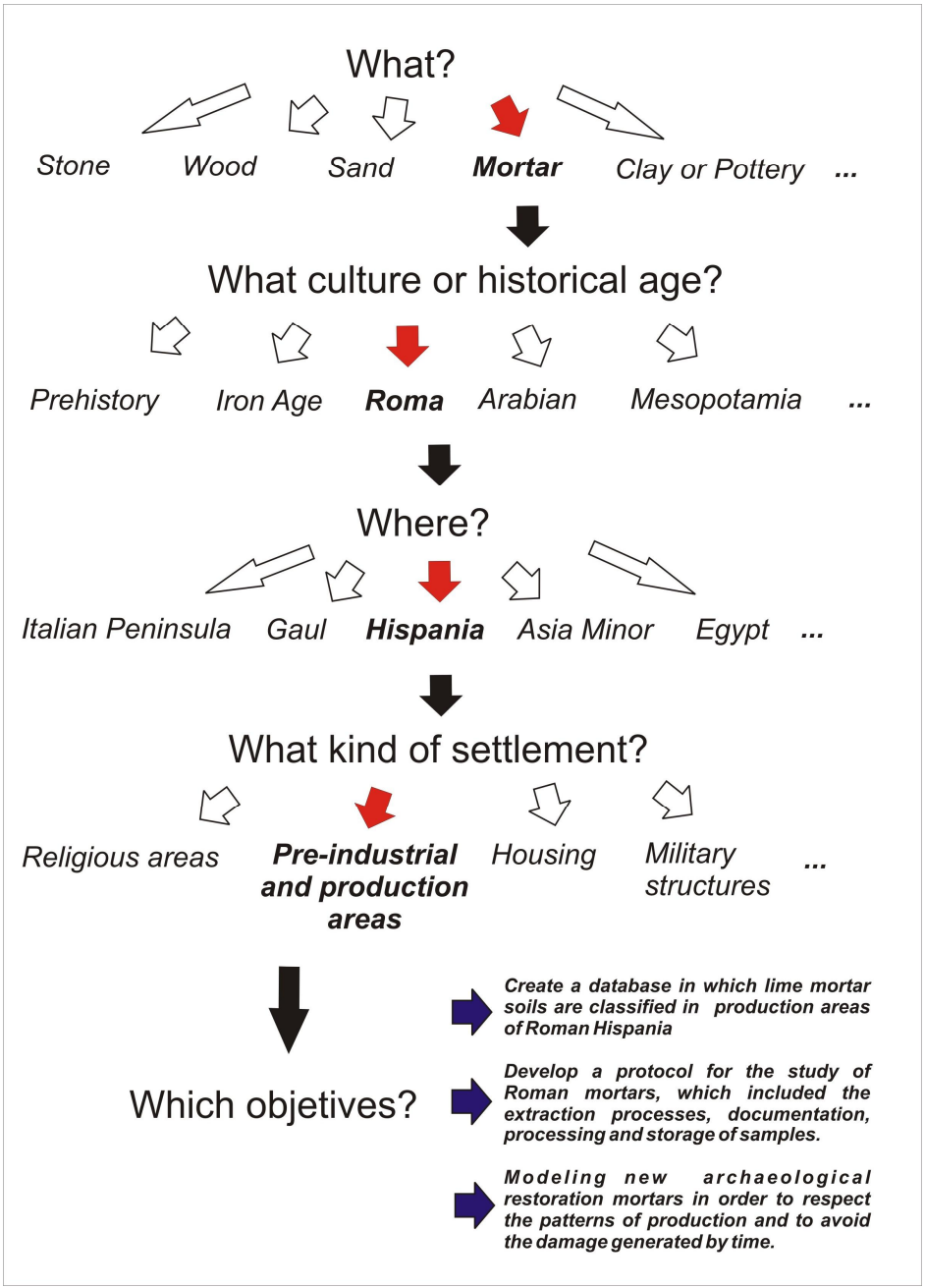
TABLES AND GRAPHS

Settlement Sampled	Roman villae Mining areas Pre-industrial areas	Extraction Procedure	Mechanical with appropiate tools Stored in location of each sample
Areas Sampled	Production and habitable zones	Macroscopic Testing	Stereoscopic check (Binocular lenses) Taking photographs
Structures Sampled	Decantation pools and trays Rooms floors Soil pressing Buckets and other	Microscopic Testing	Optical microscopy X-Ray Diffraction

Tab. 1. Procedure carried out during analyzes of Roman lime mortars in Polytechnic University of Madrid, ETSAM.



Tab. 2. Proposed initial approach in the study of any historic building material, and specifically for Roman mortars investigated in Spain.