CHARACTERIZATION OF EARTH, LIME, AND GYPSUM MORTARS IN THE CONSTRUCTIONS OF THE 16TH, 17TH, AND 18TH CENTURIES

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The historical mortars of three ecclesiastical assets of the Colonial Quito were analyzed, which by 1978 was declared as heritage by UNESCO. The emblematic works of Jesuits, Dominicans, and Franciscans, built between the 16th to 18th centuries have multiple constructive stages and interventions of which there is no technical record because of the historical and present space of worship, living and religious museum of Quito. The objective of the lining mortars characterization is to provide the clear information of the composition of the analyzed samples for better understand the constructive chronology of the churches and to determine which earth, lime, gypsum, etc. mortar was used frequently according to the epoch and religious order. A total of 48 samples of lining mortars of the interior and exterior of the temples were examined, with the protocols and norms on non-destructive essays suggested by the research team. The analysis comprising stereomicroscopy studies that were complemented with mineral characterization and quantitative analysis by X-ray diffraction, as well as polarized light optical microscopy and scanning electron microscopy with microanalysis of the samples, among others. The results in the laboratory allowed us to demonstrate the existence of earth mortars, lime and gypsum bastards, and gypsum mortars with carbonate aggregate, those elements have volcanic and metamorphic volcanic mineralogical composition, this allowed us to date into the constructive stages registered in the church.

Keywords: Lime mortars, Mortars with volcanic aggregate, Mineralogy of historic mortars, Quito Cultural Heritage, Church of the Company of Jesus, Church of Santo Domingo, Church of San Francisco.

1 INTRODUCTION

In this work we show the results of the analysis carried out in the framework of the doctoral research entitled “Characterization of the lining mortars of the Colonial Quito in the 16th, 17th, and 18th centuries”, which seeks to identify the types of mortars used in this period, to recognize their composition, artistic quality and mode of preparation as a part of the valuation of the historic buildings (Lara Calderón et al. 2020, Lara et al. 2023).

Heritage constructions, due to their value and historical importance, make it necessary to study the use and application of old and new lining mortars for the consolidation of the masonry, hence the study and characterization of the historical mortars is the main premise of this research, with the sole objective of determining their composition, dosage, their chemical, physical, and
mechanical characteristics; and, thus, to be able to evaluate future proposals in those constructive elements, since there is an enormous amount of inadequate interventions in historical buildings, using systematic resources for modern solutions, forcing to the progressive disappearance of the finishes (Veiga et al. 2001).

Figure 1. Location and context of the study area, and the drawing by Dario Donoso Samaniego, included in Church of the Company of Jesus page. 5; Church of Santo Domingo page. 139 and Church of San Francisco page. 92 (Donoso Samaniego 1983).

The study area is the heritage buildings of the Historic Center of Quito, named centuries ago by Simón Bolívar and enhanced by Alfonso Ortiz as the "Great Convent" delimited by 375.25 hectares with more than 4674 properties built, of which 130 are monumental properties and by the sixteenth century, 15 religious buildings stood out in this colonized urban center where only 4000 people lived in an estimated area of 70.43 hectares (del Pino Martínez 2009, Ortiz Crespo 1990, UNESCO 2021).

In the research published by R. Boada – I. del Pino (del Pino Martínez and Yepes 1990), M. Aleman – A. Kennedy (Alemán and Van Balen 1994), S. Webster (Webster 2009, Webster 2012), the progressive use of mortars is described as a primary empirical response of the constructive element, however up to now there is no table of compositional elements of mortars except even a dosage sheet, only the experimental applicability “trial and error of mixture dosages” waiting for the consolidation of the new mortar on the already built surface, which must be compatible with the pre-existing materials in contact, mechanically, chemically, physically, and aesthetically (Válek et al. 2000).

The best exponent of this hierophanic interpretation of oppression and domination of power after the conquest, is evident in the religious temples, case study, such as the Church of the Company of Jesus (1605 – 1765), the Church of Santo Domingo (1541 – 1688) and the Church of San Francisco (1537 – 1705) see Figure 01; of which a rigorous and systematic scientific-technic study of the lining mortars is necessary, capable of providing objective and precise data on the materials that constitute them, their construction technique, and their composition.
2 MATERIALS AND METHODS

In this work, 48 lining mortar samples or plaster extracted from the three temples were analyzed, of the study cases such as the Church of the Company of Jesus (14 analyzed samples), Church of Santo Domingo (13 analyzed samples), Church of San Francisco of Quito (21 analyzed samples), the methodology maintained a regulatory process that covered fundamental aspects, such as firstly, to carry out a historical analysis of the property in order to know and understand the history of the heritage property, its construction process, and the existent chronology of the same (del Pino Martínez and Lara 2021).

It should be noted that in the 1980s the FONSAL Rescue Fund of the Municipality of Quito accompanied by other entities such as the INPC, AECID, Junta de Andalucía, among others, carried out maintenance, reinforcement and enhancement of some of the emblematic temples of the historic area which the investigation took into account and knew how to extract samples from those less altered and registered areas that had no intervention.

The next step is to perform a general visual inspection of the masonry, pointing out those sectors where the extraction of the mortar will be performed, identifying the mortar layers, color, imprints, impurities, etc. (López Martínez et al. 2021). Subsequently, the samples were extracted to be subjected to mechanical, physical, and chemical-mineralogical studies where the results of the analytical study of the laboratory were compared with the existing historical values to catalog them and propose a historical-scientific chronology of the sample.

![Figure 2. Location of the extraction points of the (a) Church of the Company of Jesus; (b) Church of Santo Domingo; and (c) Church of San Francisco.](image)

The identification and mineralogical characterization of the samples was carried out at the Research Assistance Center (CAI) of the Complutense University of Madrid (Spain); it was analyzed by X-ray diffraction (XRD) in a Bruker D8 ADVANCE diffractometer with Cu radiation. The diffraction diagrams of disoriented powder were obtained in an angular range from 2 to 65°, a step size of 0.02°, and a time per step of 1s. The identification and the determination of the relative proportions of each mineralogical phase was carried out following Chung’s method (Chung 1975), and using Bruker’s EVA software.

For the morphological and textural study, the most significant samples of each one of the temples were selected, that is, from the Church of the Company of Jesus (6), Church of Santo Domingo (5), Church of San Francisco of Quito (6), differentiating in each church the constructive stage and comparing with the precedent historical part. The study by means of optical microscopy (POM) was carried out in thin film, but since the samples were not very consolidated, it was necessary to carry out a previous consolidation with resin. For the morphological and chemical
study by means of scanning electron microscopy (SEM-EDAX), the samples were studied in fracture. The equipment used was a ZEISS Primotech transmitted and reflected light microscope equipped with 5X, 10X, and 20X objectives and a JEOL JSM-820 scanning electron microscope with secondary and backscattered electron detector and microanalysis. The software used by the equipment for the acquisition, treatment, and evaluation of the analysis is the EDX Oxford ISIS-Link.

3 RESULTS

In the samples of the Church of the Company of Jesus, some types of mortars have been identified, among them: lime and gypsum lining mortars used in places where there are works with greater detail in the compositional technique of the mural painting such as the apse, main altar, and transept dome. Lime and gypsum mortar with carbonate aggregates associated with surfaces of regular use where mural painting, moldings, and iconographic and narratives typical of the religious order were impregnated, this type prevails in the sectors of the central nave and the lateral surfaces of the church. Lime mortars with volcanic aggregates which is a very common surface on the areas behind the altarpieces of the church and in low areas of the foundation. And, mortars with volcanic aggregates with a rustic granulometric composition often used on non-visible surfaces (Lara et al. 2021).

In the samples of the Church of Santo Domingo, another reality is reflected by the type of volcanic material used, here some types of mortar have been identified, among them: lime mortar with carbonate aggregates associated with the surfaces of regular use where mural painting, images, and narratives of the order were impregnated, the places of use are the apse of the main church, as well as relevant areas of side chapels. Lime mortar with volcanic aggregates, of not very regular use but evident in some areas of the central nave. And, the mortars with volcanic aggregates of characteristic a thick granulometric composition, tuffs, rough with frequency of common use on the zones of the central nave, sector of the altarpieces of the temple, and in low zones of the foundation, the characteristic of these mortars is attributed to the volcanic origin of the mines that the Dominican order possessed (Beltrán et al. 1994, Lara et al. 2022).

In the samples from the Church of San Francisco, the temporality and the origin of the material applied according to the construction stage is reflected more strongly, some types of mortar have been identified among them: the most commonly used is the lime mortar with carbonate aggregates applied to the surfaces of common use where mural painting was impregnated such as the apse, transept and coatings of the central nave as well as the lateral ones, surfaces where mural painting, narratives and imaginary of the religious order are applied (Lara Calderón et al. 2023, Moropoulou et al. 2003). The mortars with volcanic aggregates of a thick granulometric composition, often commonly used on the areas of the central nave, sector the altarpieces of the temple and in low areas of the foundation. And, earth mortars with vegetal fiber, located on the high walls of the central nave and lateral walls on the roof section (Lara and Bustamante 2022).

4 DISCUSSION

The constructive processes described historically by chroniclers and historians were validated and compared through sample analysis, thus identifying their compositional elements, the results of X-ray diffraction (XRD), and scanning electron microscopy with microanalysis (SEM-EDAX), this determined the volcanic origin (Andesites, Dacites) of the used materials in the construction of the coatings of the churches, it is evident that each of the religious orders that are part of the study, Jesuits, Dominicans, and Franciscans, had quarries with different geological nature where the common factor of the three is evident in volcanic origin of vitreous texture, typical of the Basaltic Andesite historically described by Ortiz (Moreno Egas 2008), as the stone used in the construction
of the historic center of Quito; as well as common patterns in the components, including Rhyolite, Dacite, Pumice, Tuffs, Andesite, Pyroxene, Calcite, Plagioclase, Amphibole, Quartz, and Gypsum.

![Figure 3. EDX analysis at three different churches, (a) Church the Company of Jesus; (b) Church of Santo Domingo; and (c) Church of San Francisco.](image)

Figure 3 allows us to visualize some of the results obtained, section (a) is a sample of the Church of the Company of Jesus, a secondary electron image of gypsum and lime with 500 magnification is observed, the EDX analysis allows us to show three different points with the main chemical elements: Spectrum 1 with Ca, C, O; Spectrum 2 with Ca, S, O; and Spectrum 3 with Ca, S, O, C. Section (b) corresponds to a sample from the Church of Santo Domingo and shows an electronic secondary image of lime joint mortar with volcanic aggregates with 500 magnification, the EDX analysis at three different points with the main chemical elements: Spectrum 1 with Si, C, K, Ca; Spectrum 2 with Ca, Si, K; and Spectrum 3 with Ca, Sil, K. While Figure 3 (c) is one of the San Francisco samples where we visualize an electronic secondary image of lime joint mortar with volcanic aggregates with 1500 magnification, the EDX analysis at three different points with the main chemical elements: Spectrum 1 with Si, C, K, O; Spectrum 2 with Ca, Si, K; and Spectrum 4 with Si, AL, C, O together with natural fiber.

5 CONCLUSIONS

As conclusions we could comment that we obtained a clear idea of the conformation and compositional characteristics of the mortars of the Church of the Company of Jesus, Church of Santo Domingo, and Church of San Francisco, that the religious orders respected typologies and adapted to the particular reality of the materiality they possessed; today we can have a starting point, that is, the genesis of the constructive elements for the new interventions in this preferential heritage area.

The temples in Colonial Quito were built by indigenous, mestizos, black and European builders, who applied and merged European techniques with local ones, this is evidenced by the use of mortars ranging from earth-based to those of lime and gypsum; the same with a considerable volcanic mineralogical composition, as it was part of its geolocation, they gave creative solutions to solve specific problems of the place and thus transmit us this emblematic architectural work.

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