Characterization of coating mortars from the warehouse of the former rheingantz factory in the Rio Grande, southern Brazil

Caracterização de argamassas de revestimento do armazém da antiga fábrica da rheingantz no Rio Grande, sul do Brasil

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ABSTRACT
The Rheingantz complex, dating from the 19th century, is composed of several elements, such as the factory, daycare center, and workers' house, and is located in the Rio Grande in Rio Grande do Sul, Southern Brazil. Currently, part of the complex is in the process of restoration. From this point of view, the great importance of the buildings for the conservation of the memory and cultural identity of the city and state suggests the study, of the historical mortars, in a pavilion, a former warehouse of the complex, lent to the Federal University of Rio Grande-FURG. The present paper aims to characterize the historical mortars of the pavilion's external coating. To identify the primary constituent materials, the mortars were characterized using tests suggested in the bibliography, such as X-ray diffraction (XRD), mechanical compressive strength, and water absorption. The characterization of the mortar samples showed that they are mainly composed of calcite and quartz, in a 1:5 ratio (binder: aggregate), and also have a significant presence of dolomite, which is indicative of a mortar substantially formed by dolomitic lime and sand. The results provided subsidies for the formulation of mortar suitable for restoration with characteristics similar to the original, providing mechanisms to reduce future pathological manifestations.

Keywords: historic mortars, physicochemical characterization, rheingantz complex.
RESUMO
O complexo de Rheingantz, datado do século XIX, é composto por vários elementos, como a fábrica, creche e casa dos trabalhadores, e está localizado no Rio Grande do Sul, Sul do Brasil. Atualmente, parte do complexo está em processo de restauração. Desse ponto de vista, a grande importância das edificações para a conservação da memória e identidade cultural da cidade e do estado sugere o estudo, dos morteiros históricos, num pavilhão, antigo galpão do complexo, cedido à Universidade Federal do Rio Grande-FURG. O presente artigo tem como objetivo caracterizar as argamassas históricas do revestimento externo do pavilhão. Para identificar os materiais constituintes primários, os morteiros foram caracterizados utilizando testes sugeridos na bibliografia, como difração de raios X (DRX), resistência mecânica à compressão e absorção de água. A caracterização das amostras de argamassa mostrou que elas são compostas principalmente de calcita e quartzo, em uma proporção de 1:5 (aglutinante: agregado), e também têm uma presença significativa de dolomita, o que indica uma argamassa substancialmente formada por cal dolomítica e areia. Os resultados forneceram subsídios para a formulação de argamassa adequada para restauração com características semelhantes às originais, proporcionando mecanismos para reduzir futuras manifestações patológicas.

Palavras-chave: morteiros históricos, caracterização físico-química, complexo de rheingantz.

1 INTRODUCTION
Wall coverings are commonly used to join, coat, and protect the structure. In old buildings, due to long periods without maintenance, deteriorating factors related to humidity, saline efflorescence, anthropic actions, and aging end up promoting degradation damaging the aesthetics and functionality of the coating [1].

New mortars must provide properties compatible with the type of substrate and mortars already existing on site. Therefore, it is necessary to consider that today’s materials are not always the same as those used in the past, even if they have the same name [2].

From this point of view, the characterization of the original composition of the mortars is necessary for adequately rehabilitating historic buildings and the knowledge and permanence of memory and cultural identity. Applying the characterization methodology enables the formulation of new mortar mixtures suitable for building interventions.
The old Rheingantz Factory stood out as a pioneer in the textile sector in the south of Brazil and was one of the bases on which the city's development was articulated acting today as a symbolic landmark. Given this, the development of this work is justified by the need for studies that provide appropriate restoration interventions in the old factory warehouse. In other words, knowledge about its constituent materials and their properties will be sought through the reconstitution of the old mortar's trace. Furthermore, the study aims to benefit other Rheingantz Complex buildings with similar characteristics.

Thus, in a Factory pavilion lent to the Federal University of Rio Grande (FURG), the characterization of historic mortars taken from 5 points of the external coating was initially performed.

2 THEORETICAL REVIEW

2.1 RHEINGANTZ COMPLEX

The Rheingantz complex, dating from the 19th century, is composed of several elements, built with about 155,000 m² of surface area and 45,000 m² of the covered area [3]. The complex is in the Rio Grande in the Rio Grande do Sul, Southern Brazil.

The factory had different names over the years due to changes in the company that originated it; its last name was from 1891 as Companhia União Fabril [4].

Notably, the complex gained excellent visibility in the regional and national economy by producing textiles for domestic and foreign markets. Regarding labor, it was often necessary to request skilled workers from Europe to compose the workers of the Rheingantz complex [5].

The factory project was based on the founder's experiences and trips to Germany and England. Thus, Rio Grande was chosen to install the manufacturing union mainly because it had a port facilitating importing of equipment by commercial vessels [3].

In 2001 the factory had its activities terminated and closed to the outside world. From this moment, the buildings’ degradation processes increased, in addition to the emergence of actions of vandalism and theft [3].

In 2009 there was a public hearing that aimed to recover and prevent the disappearance of the traces of the past; this act was a milestone in the process of heritage
awareness and involved several social actors [3]. Part of the Rheingantz complex was listed in July 2012 by the State Institute of Historical Heritage of Brazil (IPHAE). The building where the present study was developed is not included in the protected area.

2.2 HISTORIC MORTARS

The historical mortars have a set of characteristics that, according to the time developed, can differ significantly from the mortars produced today due to the materials used and production techniques. It is of paramount importance to propose appropriate interventions to collect information about the building acted [6]. In addition, a good characterization of the original materials is fundamental for restoring monuments [1].

Due to natural phenomena, such as erosion and atmospheric pollution, the characteristics of mortars undergo transformation, and it is impossible to achieve the same physical, chemical, and mechanical parameters in a new mortar [7]. However, the characteristics must be compatible to provide the long-term durability of masonry [8]. Verdum et al. (2021) reinforce the idea that several degradation agents can cause damage to the facades of buildings. Still, they have different characteristics derived from the region where they were produced, for example, the use of shells in a coastal area or organic additives in the country's interior.

Sea shells have been widely used to obtain lime since the beginning of the colonization of Brazil [10]. For Mattos (2018), the construction techniques and materials employed in Brazilian constructions had significant Portuguese influence due to their similarity in features and compositions.

Thus, although it is possible to determine the composition of a historical mortar analytically, it should be taken into account that the current materials and labor do not correspond to the originals [7].

The recovery mortars will not repeat, necessarily, the original composition of the old mortar, but they must be formulated aiming its compatibility with the structure, being essential for the identification of the binder type, aggregate characteristics, organic additives (vegetal and animal fibers), as well as the proportion of binder and aggregate [10].
According to Schiller and Rocha (2019), ancient mortars can be composed of various types of aggregates since the reuse of elements to make mortars happened, are some examples of aggregates used: silica sand (SiO$_2$), brick, tile, or ancient crushed coatings, limestone aggregates, seashells, and shell fragments.

The labor employed in historic buildings was empirical, and it was customary to exploit the maximum potential of materials to solve problems related to construction economically and ecologically [13]. Magalhães (2013) points out that the ancients understood the importance of the granulometry of the aggregates and of adjusting the proportion of lime to be made according to the quality of the sand. Thus, the volumetric ratios used in coating mortars sought the amount of lime to fill the aggregate's voids; although empirically defined, the traces sought to achieve maximum compactness [14].

2.3 HISTORIC MORTARS FROM RIO GRANDE’S CITY – PREVIOUS STUDIES

Before the study developed in this paper, some research regarding the city's historical mortars was conducted. In some of them, samples from other buildings installed in the Rheingantz complex were studied.

In studies done in a pavilion of the Rheingantz factory, the presence of seashells in the external coating and the laying mortar was reported. The authors of the study assume that the shells may have come from the incomplete firing of lime or were used as aggregate. The researcher also says that in the rest of the studied buildings in the city, no traces of seashells were visible to the naked eye [15–17].

In an analysis of the capillarity of the coatings, performed through Karsten tubes, for the measurement of water absorption under low pressure, on the facade of one of the Factory's pavilions, values on the order of 2.11 kg/m² were found, except for one application point where a result much higher than the others was found, justified by the authors of the research as a result of the poor adherence of the mortar with the substrate [18].

The mineralogical constituents of the historic mortars of the Rheingantz factory (daycare center, central office, pavilion, and water tank), Cassino Railway Station, and Rio Grande Railway Station pavilion have similar compositions, mainly composed of
sand and lime. Lime presents itself in the form of calcite (CaCO₃) and dolomite (CaMg(CO₃)₂), and sand as quartz (SiO₂) [11, 17, 19].

The fine aggregates from the buildings of the Rheingantz complex, studied by Falcão et al. (2019), showed a uniform distribution of grains and medium to coarse grain sizes. In the Rio Grande Railway Station pavilion, aggregates with a rough sand classification and high uniformity of the grains were verified [20].

The study of Falcão and Mattos (2020) arranged the characteristics found in the mortars of coatings of buildings in the city of Rio Grande (Table 1); in addition, the authors point out that, from the results, the lime used in the mortars is indicative of dolomitic.

<table>
<thead>
<tr>
<th>Building</th>
<th>Mineralogical composition</th>
<th>Trace (Mass)</th>
<th>Aggregate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Calcite</td>
<td>Dolomite</td>
<td>Quartz</td>
</tr>
<tr>
<td>Town Center</td>
<td>x</td>
<td>x</td>
<td>xxx</td>
</tr>
<tr>
<td>Rheingantz- Daycare center</td>
<td>x</td>
<td>xxx</td>
<td>xx</td>
</tr>
<tr>
<td>Rheingantz- Water tank</td>
<td>xx</td>
<td>x</td>
<td>xxx</td>
</tr>
<tr>
<td>Rheingantz- Center office</td>
<td>x</td>
<td>xxx</td>
<td>xx</td>
</tr>
<tr>
<td>Rheingantz- Pavillon: main facade</td>
<td>x</td>
<td>xxx</td>
<td>xx</td>
</tr>
<tr>
<td>Rheingantz- Pavillon: Secondary Facade</td>
<td>x</td>
<td>xx</td>
<td>xxx</td>
</tr>
<tr>
<td>Federal Railroad Network S.A</td>
<td>x</td>
<td>xx</td>
<td>xxx</td>
</tr>
<tr>
<td>Cassino Railway Station</td>
<td>x</td>
<td>xxx</td>
<td>xx</td>
</tr>
</tbody>
</table>

- x- little present xx- present xxx- very present

Source: (FALCÃO; MATTOS, 2020)

3 MATERIALS AND METHODS

3.1 FORMER RHEINGANTZ FACTORY WAREHOUSE

The study was conducted in an isolated pavilion, the former warehouse of the factory; the building has a "shed" type roof. Fig. 1 shows the area and the study pavilion.
3.2 METHODS ADOPTED FOR CHARACTERIZATION OF HISTORIC MORTARS

Representative samples were taken from the external cladding of the studied pavilion. The process was carried out to extract the necessary amount for characterization tests and not damage the surrounding cladding.

During the removal, it was found that the coverings were visually intact in terms of attachment to the substrate. However, when the collection process started, it was noticed that they disintegrated, making sampling difficult.

The samples A1 - E and A2 - E referred to the external mortar of the lateral facade, and samples A3 - FE, A4 – FE, and A5 – FE referred to the exterior mortar of the main façade (Fig. 2). The samples were taken from different heights and in places with less degradation. To maintain their integrity, they were bagged, adequately identified, and carefully sent to the Materials and Civil Construction laboratory of FURG.
Fig. 2 Location of the sampling points A secondary and B the main facade

Source: The authors

Table 2 shows the specimens collected. It is possible to notice that, although they were all taken from the same building and have the same function, they have different visual characteristics.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Side view</th>
<th>Upper view</th>
<th>Average thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1 – E</td>
<td><img src="image1" alt="A1 – E Side View" /></td>
<td><img src="image2" alt="A1 – E Upper View" /></td>
<td>1.2 cm</td>
</tr>
<tr>
<td>A2 – E</td>
<td><img src="image3" alt="A2 – E Side View" /></td>
<td><img src="image4" alt="A2 – E Upper View" /></td>
<td>1.7 cm</td>
</tr>
<tr>
<td>A3 – FE</td>
<td><img src="image5" alt="A3 – FE Side View" /></td>
<td><img src="image6" alt="A3 – FE Upper View" /></td>
<td>2.2 cm</td>
</tr>
</tbody>
</table>
The mortars presented light coloration and thicknesses varying from 1.2 cm to 2.2 cm. The difference in thicknesses may be related to irregularities in the substrate, resulting in the need for greater coating thicknesses for leveling. Notably, the coating has only one layer (monolayer) laid directly on the substrate. White granules were found scattered in the mortar, and the samples were very friable.

3.2.1 Sample Preparation

In the laboratory, the samples were cleaned, removing all the paint with the help of small steel brushes, which is essential so that the presence of paint and surface dirt does not influence the test results. All the procedures were carried out with the help of gloves so that contamination was minimal. Then they were placed in an oven (T=100±5°C) to extract the humidity.

The samples were macerated with the help of a porcelain mortar and a rubber-tipped pistil to maintain the integrity of the aggregates and thus prevent the results from being masked. Part of the material from the maceration was used for the XRD test (after sieving in a 0.075mm mesh), and the rest was used for the acid dissolution test.
3.2.2 Characterization Tests

3.2.2.1 X-ray Diffraction (XRD)

The fine portion from the 0.075 mm sieve was stored in small clean and dry containers and sent for mineralogical analysis at the South Zone Electronic Microscopy Center (CEME-SUL) at FURG with Bruker X-ray diffraction (XRD) equipment, model D8 Advance, with the following parameters: voltage of 40 kV, current of 40 mA, copper tube (Cu) with wavelength (λ): 1.5418A.

Samples A1 - E, A3 – FE, and A5 - FE were used for the test. The diffractograms were recorded between 3° and 90° (2θ). For the interpretation of the results, the ICSD (Inorganic Crystal Structure Database) diffractometer standards and the X’pert High Score software were used as a basis.

The technique allows a qualitative analysis of samples’ crystalline compounds [2]. For Coelho (2010), the method is one of the main possibilities for microstructural characterization of crystalline materials since it is accurate and efficient. According to Magalhães (2013), with the information obtained from the XRD technique, it is possible to make correlations between compressive strength and water absorption perform a better interpretation of the state of conservation of the coating.

3.2.2.2 Scanning Electron Microscopy (SEM)

The test was performed at CEME-SUL with a scanning electron microscope, in high and low vacuum mode, model JSM - 6610LV with EDS microprobe. Three samples were selected for the assay: A1 - E, A3 – FE, and A5 - FE. With this, a small piece of each sample was coated with a gold film, allowing the production of images with different magnifications, as well as the identification of minerals from the EDS microprobe.

By comparing existing standard diffraction spectra with angular position data, it is possible to identify the compounds present in the sample and perform a semiquantitative analysis through the intensity of the diffraction lines. The technique is widely used for historical mortars to determine the type of binder and sands used [13].
3.2.2.3 Acid Attack

Quantitative chemical analysis was performed to separate the aggregate fraction from the binder fraction, making it possible to characterize the aggregate and estimate the binder: aggregate ratio. This process was done by dissolving the calcium or magnesium carbonates in a solution of hydrochloric acid (HCl 15%) and distilled water.

Thus, the crushed samples, approximately 50 grams, were placed in beakers where they were attacked with the acid solution (150 ml) until the dissolution of the binder, which occurred with effervescence due to the release of carbon dioxide (CO$_2$). Subsequently, the samples were filtered with distilled water until the water was clean when it came out of the filter.

The binder was discarded in dissolved form, and the aggregate, material retained on the filter, was oven dried (T=100±5°C). The mass proportion of the aggregate was calculated by a ratio of the mass of the sample after the acid attack and subtracting the mass before and after the test.

3.2.2.4 Particle Size Analysis

The granulometric analysis was performed by adapting the process described in NBR 248 (ABNT, 2003) since the amount of sample is reduced. Thus, the distribution of aggregates in different fractions on the sieve openings was performed with the aid of a mechanical sieving machine.

Fig. 3 shows enlarged images of the aggregates present in the samples.
From a visual analysis of the aggregates, one can see the possible presence of hyaline, white quartz, and feldspar minerals. In addition, a black mineral was identified in all samples, present in a larger size in A5 - E, which may be a fragment of the mineral hercinite. There is also the presence of pieces of rock that did not undergo the disaggregation process. The visual analysis will be better shown through the XRD technique.

3.2.2.5 Water Absorption by Capillarity

The test followed the general guidelines proposed by Veiga and Santos (2016). However, the test time was performed until 100 minutes, the time that the samples were saturated, having no more variation in mass.

Firstly, the contour of the samples was made on letter paper to obtain the contact area with the help of AutoCAD software. In addition, the thickness of the samples was measured with a pachymeter. Then, the samples were placed on a grid with the saturated geotextile in constant contact with water, and mass measurements were taken at pre-established times. The samples were then dried in an oven (T=100±5°C) and weighed at different times.

The samples were weighed every 5 minutes during the first 40 minutes and then at 60, 90, and 100 minutes. Fig. 4 demonstrates the absorption process that the samples went through.
3.2.2.6 Compressive Strength

The compressive strength test was performed as described by Veiga and Santos (2016). Thus, for the confining mortar, the proportion of one part of the binder, Portland cement CPIV 32 - RS, to three pieces of fine aggregate (1:3) was used, and the mixing process was performed according to the guidelines of NBR 13276 (ABNT, 2016).

Small Styrofoam molds were assembled for molding the confining mortars with an approximate size of 4 cm x 4 cm. Thus, firstly, on the PVC film a Styrofoam form was positioned and filled with mortar; after, the old mortar sample was carefully arranged on top of the form, finally, above the sample, another form was filled with confining mortar (Fig. 5).

After 15 days of curing, the samples were submitted to the compressive strength test. It is important to note that due to the dimensions of the old mortar samples, some could not be imposed on the test. Thus, two samples of A3 - FE mortar and two samples of A4 - FE were tested.
4 RESULTS AND DISCUSSION

4.1 X-RAY DIFFRACTION

The analysis of the diffractograms as a result of the mineralogical characterization test (Fig. 6) showed samples with similar compositions, fundamentally formed by quartz (Q) and calcite (C), in the forms of calcium carbonate (CaCO₃) and quartz (SiO₂), being mortars mainly composed of sand and lime.

The diffractograms also indicated the presence of calcium and magnesium carbonate (CaMg (CO₃)₂) and hercinite (Al₂FeO₄), a black mineral rich in iron and aluminum oxide. Also present is the feldspar family mineral, microcline (AlK₀₈Si₃), the iron oxide based crystalline mineral, corundum (Al₂O₃), and the mineral composed of calcium sulfate, anhydrite (CaSO₄). The minerals found and their respective intensities are presented in Table 3.
Table 3 Mineralogical composition of the samples

<table>
<thead>
<tr>
<th></th>
<th>A1 - E</th>
<th>A3 - FE</th>
<th>A5 - FE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calcite</td>
<td>xxx</td>
<td>xxx</td>
<td>xx</td>
</tr>
<tr>
<td>Quartz</td>
<td>xx</td>
<td>xx</td>
<td>xxx</td>
</tr>
<tr>
<td>Dolomite</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Microcline</td>
<td>x</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Corundum</td>
<td>-</td>
<td>x</td>
<td>-</td>
</tr>
<tr>
<td>Hercynite</td>
<td>-</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>Anhydrite</td>
<td>-</td>
<td>x</td>
<td>-</td>
</tr>
</tbody>
</table>

(*** very abundant (xx) abundant (x) not very abundant (-) not found

Source: The authors

The presence of calcium and magnesium carbonate (dolomite) is noted in all samples. Thus, it is possible to verify that the lime used was of the dolomitic type.

4.2 SCANNING ELECTRON MICROSCOPY

The analyses performed with the scanning electron microscope allowed the identification of constituents present in the historical mortar samples studied through images of different magnifications. Furthermore, semiquantitative analysis of the elements present was possible with the EDS microprobe. Fig. 7 shows the images of the samples.

Fig. 7 Micrographs of the mortar samples (a) A1 - E, (b) A3 – FE and (c) A5 - FE

Source: The authors
In Table 4, the constituents found are presented as a semiquantitative analysis. From the results, one can see that the binder is composed mainly of calcium (C), with high levels of silicon and magnesium and low levels of iron (Fe) and aluminum (Al). As in the mineralogical analysis, magnesium suggests that the lime used was a dolomitic type of lime.

The silicon (Si) detected in all samples comes from the quartz sand present in the mortar, as also evidenced by Table 2 in the mineralogical composition by DRX. In sample A3 – FE, the presence of sulfur (S) was found, possibly derived from the anhydrite mineral composed of calcium sulfate, corroborated by XRD analysis. Although in small amounts, aluminum (Al) is present in most of the minerals verified by XRD, namely, hercinite, microcline, and corundum.

Table 4 Constituents found in the samples (%)

<table>
<thead>
<tr>
<th></th>
<th>C</th>
<th>O</th>
<th>Na</th>
<th>Mg</th>
<th>Al</th>
<th>Si</th>
<th>Cl</th>
<th>Ca</th>
<th>Fe</th>
<th>S</th>
<th>K</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1 - E</td>
<td>1</td>
<td>4.15</td>
<td>37.46</td>
<td>0.2</td>
<td>3</td>
<td>0.75</td>
<td>11.6</td>
<td>0.37</td>
<td>17.8</td>
<td>0.5</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>1.79</td>
<td>21.88</td>
<td>1.11</td>
<td>0.54</td>
<td>27.0</td>
<td>6</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>5.44</td>
<td>44.16</td>
<td>0.2</td>
<td>3.53</td>
<td>0.76</td>
<td>5.6</td>
<td>0.26</td>
<td>18.9</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>A3 - FE</td>
<td>1</td>
<td>3.87</td>
<td>65.59</td>
<td>0.3</td>
<td>1</td>
<td>0.22</td>
<td>1.12</td>
<td></td>
<td>18.7</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>5.06</td>
<td>52.81</td>
<td>0.7</td>
<td>4.17</td>
<td>0.63</td>
<td>2.16</td>
<td>0.54</td>
<td>17.2</td>
<td>5</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>5.81</td>
<td>46.88</td>
<td>1.0</td>
<td>5.88</td>
<td>1.38</td>
<td>3.85</td>
<td>0.91</td>
<td>21.1</td>
<td>8</td>
<td>0.22</td>
</tr>
<tr>
<td>A5 - FE</td>
<td>1</td>
<td>6.74</td>
<td>44.76</td>
<td>3.97</td>
<td>1.08</td>
<td>9.01</td>
<td></td>
<td>12.0</td>
<td>9</td>
<td>0.09</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>7.46</td>
<td>29.32</td>
<td>3.22</td>
<td>1.62</td>
<td>3.96</td>
<td>3.96</td>
<td>23.3</td>
<td></td>
<td>0.62</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>5.4</td>
<td>45.83</td>
<td>1.89</td>
<td>0.49</td>
<td>20.7</td>
<td>1</td>
<td>4.58</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Source: The authors

Also, small amounts of potassium (K) were found in samples A3 - FE and A5 - FE. In samples A1 - E and A3 – FE, there were traces of sodium and chlorine (Cl). Oxygen (O) stands out as the main element in the samples and the considerable presence of carbon (C).
4.3 ACID ATTACK

From the acid dissolution test, we obtained the proportions of the soluble and insoluble fractions of the samples studied, as shown in Table 5.

<table>
<thead>
<tr>
<th>Samples</th>
<th>Mass</th>
<th>Dissolved</th>
<th>Binder</th>
<th>Aggregate</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Before (g)</td>
<td>After (g)</td>
<td>(g)</td>
<td>(%)</td>
</tr>
<tr>
<td>A1 - E</td>
<td>50,05</td>
<td>41,64</td>
<td>8,41</td>
<td>16,80</td>
</tr>
<tr>
<td>A2 - E</td>
<td>50,06</td>
<td>42,25</td>
<td>7,81</td>
<td>15,60</td>
</tr>
<tr>
<td>A3 - FE</td>
<td>50,05</td>
<td>40,91</td>
<td>9,14</td>
<td>18,26</td>
</tr>
<tr>
<td>A4 - FE</td>
<td>50,08</td>
<td>41,98</td>
<td>8,1</td>
<td>16,17</td>
</tr>
<tr>
<td>A5 - FE</td>
<td>50,03</td>
<td>41,33</td>
<td>8,7</td>
<td>17,39</td>
</tr>
</tbody>
</table>

Source: The authors

The samples showed very similar results, with a binder: aggregate ratio of 1:5, except sample A3 - FE, which showed a smaller amount of aggregate with a balance of 1:4. Thus, it is noted that the results corroborate with those found in other buildings of the Rheingantz complex [17].

4.4 PARTICLE SIZE ANALYSIS

Fig. 8 shows that the aggregates of all samples present a larger quantity in the 0.15 mm to 1.18 mm sieve range; thus, from the average fineness module (Table 6) of 2.75 (coefficient of variation 4%), the fine aggregate can be classified as medium sand, Selmo (1986, apud Dujav, 2000).

The particle size distribution curves, except sample A3 - FE, show a slight increase in the accumulated retained weight between the 0.6 mm and 0.3 mm sieve, presenting a discontinuity in the particle size distribution curves, i.e., the aggregates present in the 0.3 mm sieve have a considerable amount less about the others.
Fig. 8 Particle size distribution curves of the samples

Table 6 presents the analyzed samples' fineness modulus, maximum characteristic dimension, and uniformity coefficient.

<table>
<thead>
<tr>
<th>Samples</th>
<th>Fineness module</th>
<th>Characteristic maximum dimension</th>
<th>Uniformity coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1 - E</td>
<td>2.72</td>
<td>4.76</td>
<td>5.26</td>
</tr>
<tr>
<td>A2 - E</td>
<td>2.67</td>
<td>4.76</td>
<td>5.44</td>
</tr>
<tr>
<td>A3 -FE</td>
<td>2.93</td>
<td>4.76</td>
<td>4.76</td>
</tr>
<tr>
<td>A4 -FE</td>
<td>2.76</td>
<td>4.76</td>
<td>5.21</td>
</tr>
<tr>
<td>A5 -FE</td>
<td>2.70</td>
<td>4.76</td>
<td>4.74</td>
</tr>
</tbody>
</table>

Source: The authors

The maximum characteristic size of 4.76 is the same for all samples, indicating remarkable similarity between the diameters of the aggregate grains. The uniformity coefficient indicates that samples A1 - E, A2 - E, and A4 - E have a medium uniformity, and the others, A3 - FE and A5 - FE, are characterized as very uniform. Thus, the average coefficient among the samples was 5.08, with a coefficient of variation of 6%, which describes it as a moderately uniform particle size distribution, according to Bauer (2005).
4.5 WATER ABSORPTION BY CAPILLARITY

The test adapted for friable and irregular samples performed by contact estimated the water absorption by capillarity. Fig. 9 summarizes the results obtained from the absorption and drying of water in the samples analyzed.

![Fig. 9 Absorption and drying of water in the samples](chart.png)

All samples showed a high absorption in the first 10 minutes of testing, the sample A4 - FE with the highest content of absorbed water. Then, the samples continued to slowly increase the amount of water absorbed until 100 minutes, when they were all saturated, with no further increase in weight.

In the drying process, samples A1-E and A2-E showed a fast drying, with most of the water evaporated in the first 60 minutes. In samples A3 - FE and A4 – FE, a slower drying process was observed due to the higher percentage absorbed.

The samples with the most significant similarities belong to the same sampling wall: A1 - E and A2 - E of the secondary facade, without the presence of windows and doors. The samples A3 - FE and A4 - FE belonged to the main facade and were taken from the mortar located on the sides of the door with more excellent proximity to the ground than the rest. Thus, the absorption of a more significant amount of water in the samples taken from the main facade may be related to degradations in the mortar due to the capillary rise of the floor and phenomena such as lime washing.

Table 7 presents a summary of the results found for the samples.
<table>
<thead>
<tr>
<th>Sample</th>
<th>Capillarity coefficient (kg/m².min¹/²)</th>
<th>Total absorption (kg/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ccc(5min)</td>
<td>Ccc(90-10min)</td>
</tr>
<tr>
<td>A1 – E</td>
<td>16,077</td>
<td>0,006</td>
</tr>
<tr>
<td>A2 – E</td>
<td>4,718</td>
<td>0,145</td>
</tr>
<tr>
<td>A3 – FE</td>
<td>61,492</td>
<td>0,011</td>
</tr>
<tr>
<td>A4 – FE</td>
<td>26,520</td>
<td>0,337</td>
</tr>
</tbody>
</table>

Source: The authors

In general, the samples presented variable contact capillarity coefficient values, with a coefficient of variation of the total absorption of 40%. Mostly, the samples show a high capillarity coefficient in the first 5 minutes, except for sample A2 – E, which showed a coefficient lower than 5 kg/m².min¹/².

### 4.6 COMPRESSIVE STRENGTH

The compressive strength was performed using confining mortars as a press adaptation. The results are shown in Fig. 10. It is noteworthy that due to the size of the samples, only A3 - FE and A4 - FE could be submitted to the test, and two samples of each were used.

![Fig. 10 Compressive strength of the samples studied](image)

It is noted that, on average, samples A3 - FE had higher compressive strength, and this result may be linked to the mortar mix presented in the acid dissolution (1:4), which is richer in a binder than the others. Also, in general, the thickness of the samples had no
connection with the strength obtained, except for the second sample, A4 – FE, that in conjunction with a lower thickness, showed a lower resistance. Thus, through the test, the value of 3.23 MPa was obtained as an average among all samples, with a coefficient of variation of 5%.

It should be noted that the test for friable and irregular samples is an adaptation that uses confining mortars to obtain the values of compressive strength. Thus, it is necessary to consider this when performing the comparative analysis with the new mortars.

5 CONCLUSIONS

Through the techniques applied, it was possible to identify their main characteristics, such as granular distribution, size, the color of aggregates, nature of crystalline minerals, lime origin, and binder: aggregate ratio.

From the results obtained, it is observed the importance of characterization in different points of a building, since it can present different properties and evidence possible different construction times and deteriorations.

The application of the methods for the determination of water absorption by capillarity and compressive strength, not usually used by the bibliography, is shown to be simple and important for correlations with the state of conservation and analysis of compatibility with the new mortar.

For the samples analyzed, the compressive strength did not present a significant relationship with their respective thicknesses except for samples A4 - FE. Moreover, the sample that showed the highest results (A3 - FE) is the same one that presented a mix richer in a binder.

The study generated subsidies for developing new mortars that may present similar characteristics to the original ones, not only in the proportion of traits but also with great proximity to several parameters analyzed in the samples of the old mortar.
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