ABSTRACT

The Phaselis Hadrian Gate locating Kemer (Antalya, Turkey) has become the subject matter of the archaeometrical examinations conducted within the scope of the restoration & conservation project. The archaeometrical methods of physical, chemical and petrographical were applied to the samples from the monument that were examined to get their raw material characteristics (basic physical properties, binder/aggregate ratio, particle size distribution in aggregate, total soluble salt and types of salt), mineralogical and chemical compositions, and microstructural properties (Optical Microscopy and XRF). The physical conditions of the building stone samples were determined by means of basic physical tests. Limestone samples were physically very weak in condition and also affected by past forest fires. Conductometric analyses were conducted to find out about the soluble salt content of the stones and their pH values. The total soluble salt contents of stones in weak basic condition had very high rate caused by environmental impacts. Aggregate/binder in mortar and the grain size distribution of aggregate were found by means of aggregate granulometric analysis. The total binder and sand sized aggregate compositions of the mortar samples were quite similar and 1:4 and 2:3 in ratio. The petrographical characteristics of the stone and mortar samples were determined by thin section optical microscope analysis. Ancient gate were limestone of the main rock group of local formation. The binder type of the mortars were lime and classified into three main groups petrographically. Micro-XRF analysis was carried out to determine the chemical composition of two ancient metal clamp pieces as iron and lead. The element analysis for stone, mortar as well as the soil sample was undertaken applying the PED-XRF analysis in order to characterize and determine the raw material origin of limestones and mortars. The types of the lime mortar, which makes up the binding structure of mortar samples, were assessed in terms of their hydraulic properties by the Cementation Index data.

KEYWORDS: Phaselis, Hadrian Gate, Stones, Limestone, Mortars, Archaeometrical Analyses, XRF, Thin Section Analysis
INTRODUCTION

The ancient city of Phaselis, today located in Tekirova of the Kemer district at a 35 km distance from Antalya, was an important port that was situated between the Lycia and Pamphylia of the ancient period. The city was founded by Rhodian Colonists at the beginning of 6th century BC. It has three ports: in the north, in the northeast and in the southwest. The structures, which can still be seen in the archaeological site, get denser in the narrower pass of the peninsula between the northeastern and southwestern ports. The very-well-laid street/road connects these two ports. The ancient street starts from around the southwest port and at the start of the street, a gate/arch was built in memory of the Emperor Hadrian's visit to the city. The Phaselis Hadrian Gate dates back to the 2nd Century AD and it is very important for Lycia. Actually, it is the main entrance gate from the port and the most important monument of the city (Akurgal, 1986).

The first scientific excavation in Phaselis was carried out through a World Bank funded project between 1981 and 1985 by Prof Dr Cevdet Bayburtluoğlu. The aim was to use the site as a tourist attraction center. In the last 15 years, owing to the excavations made by the Head of Antalya Museum, the site has been visited by tourists. In 2011, Antalya Surveying and Monuments Directorate awarded a contract for the Documentation, Restitution and Restoration Project for Phaselis (implemented by Cumhur Gürel Architecture Ltd.). Thus, the Hadrian Gate has become the subject matter of the archaeometric examinations conducted within the scope of the project.

Stone, jointing and rubble filler mortar samples taken from the stone blocks from the Hadrian Gate – piled on the east of the gate – soil from the vicinity and metal
clamp samples were first evaluated visually and classified. Then, they were photographed and coded (Table 1 and Fig. 1). Within the scope of the archaeometrical investigations, the physical conditions of the building stone samples were determined by means of physical tests (Table 2 and Fig. 2). Conductometric analyses were conducted to find out about the soluble salt content of the stones (anion types and total salt quantity) and their pH values (Table 3 and Fig. 3).

Aggregate/binder in jointing and rubble filler mortar and the grain size distribution of aggregate were found by means of aggregate granulometric analysis (Table 4 and Fig. 4). Furthermore, the petrographical characteristics of the stone and mortar samples were determined by thin section optical microscope analysis (Tables 5, 6 and Fig. 5). To determine the chemical composition of a metal clamp piece

<table>
<thead>
<tr>
<th>Sample Code</th>
<th>Material Group</th>
<th># of Sample</th>
</tr>
</thead>
<tbody>
<tr>
<td>APK-T</td>
<td>Stone Samples</td>
<td>7</td>
</tr>
<tr>
<td>APK-H</td>
<td>Mortar Samples</td>
<td>6</td>
</tr>
<tr>
<td>APK-D</td>
<td>Soil Sample</td>
<td>1</td>
</tr>
<tr>
<td>APK-M</td>
<td>Metal Samples</td>
<td>2</td>
</tr>
</tbody>
</table>

Figure 2. Schmidt hardness test devices (upper left), ultrasonic velocity measurement (upper right and down left) and limestone (sample APK-T7) exposure to fire.
Table 2. Basic physical test for stones; wet & dry unit volume weight (UVW), water absorption capacity (WAC), porosity (P), ultrasonic velocity (SV) and Schmidt hardness (SH).

<table>
<thead>
<tr>
<th>Samples</th>
<th>UVW-w (g/cm³)</th>
<th>UVW-d (g/cm³)</th>
<th>WAC (%)</th>
<th>P (%)</th>
<th>SV (μs)</th>
<th>SH</th>
</tr>
</thead>
<tbody>
<tr>
<td>APK-T1</td>
<td>2.71</td>
<td>2.69</td>
<td>0.26</td>
<td>0.71</td>
<td>57.20</td>
<td>29.7</td>
</tr>
<tr>
<td>APK-T2</td>
<td>2.62</td>
<td>2.52</td>
<td>1.46</td>
<td>3.69</td>
<td>36.80</td>
<td>19.3</td>
</tr>
<tr>
<td>APK-T3</td>
<td>2.68</td>
<td>2.66</td>
<td>0.27</td>
<td>0.72</td>
<td>67.00</td>
<td>34.8</td>
</tr>
<tr>
<td>APK-T4</td>
<td>2.64</td>
<td>2.54</td>
<td>1.55</td>
<td>3.92</td>
<td>34.90</td>
<td>25.6</td>
</tr>
<tr>
<td>APK-T5</td>
<td>2.69</td>
<td>2.67</td>
<td>0.27</td>
<td>0.71</td>
<td>24.90</td>
<td>-</td>
</tr>
<tr>
<td>APK-T6</td>
<td>2.69</td>
<td>2.66</td>
<td>0.35</td>
<td>0.94</td>
<td>24.50</td>
<td>-</td>
</tr>
<tr>
<td>APK-T7</td>
<td>2.56</td>
<td>2.27</td>
<td>5.08</td>
<td>11.51</td>
<td>23.40</td>
<td>-</td>
</tr>
<tr>
<td>Average</td>
<td>2.66</td>
<td>2.57</td>
<td>1.32</td>
<td>3.17</td>
<td>38.39</td>
<td>27.35</td>
</tr>
</tbody>
</table>

Fig 3. Long term official atmospheric and meteorological data for Antalya region; seasonal variations of rain water of (a) pH, (b) sulphate concentration, (c) nitrate concentration and (d) long term (1975-2008) official meteorological data (sampling was in September, 2011) (http://www.meteor.gov.tr).
(obtained by chance from stone block coded T-269), Micro-XRF analysis was carried out (Table 7). The element analysis for stone, jointing and rubble filler mortar as well as the soil sample was undertaken applying the PED-XRF method (Tables 8, 9). The types of the lime mortar, which makes up the binding structure of mortar samples, were assessed by the Cementation Index data (Table 10).

**METHOD AND ANALYSES**

By using various archaeometric methods, the construction materials of the Phaselis Hadrian Gate were identified physically, chemically and petrographically, and the results were documented.

Basic physical properties of construction materials show their current physical characteristics (competent / incompetent) within certain standard limits (RILEM, 1980). To determine the competency of materials, it is necessary to know their physical properties (unit volume weight, water absorption capacity, porosity and hardness). The basic physical properties of the stone samples are provided in Table 2.

The Uniaxial Compressive Strength (UCS) values of rocks are frequently referred to in designing both above and under the ground structures (Başarır, 2004; ASTM, 1984). Tests such as the Schmidt Hammer (SHV) and sonic speed tests are widely used to predict the uniaxial compressive strength values. The Schmidt hammer is used to determine the hardness value of rocks precisely (Fig. 2). The hardness values are used to predict UCS and to classify rocks. Especially in situ historical rock material analysis, the portable digital Schmidt hammer is a practical tool used to determine the uniaxial compressive strengths of rocks indirectly. In this purpose both in situ application and the limestone rocks taken from the Phaselis Hadrian Gate were hit at 5 points and the average hardness values were found over all measurements (Table 2 and Fig. 2). During the measurements, a Proseq digital Schmidt hammer was used.

Ultrasonic techniques are used to determine the dynamic characteristics of

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**Table 3. Water soluble salts/anions (SS), anion types and pH determination tests for stones and soils.**

<table>
<thead>
<tr>
<th>Samples</th>
<th>SO₄²⁻</th>
<th>PO₄³⁻</th>
<th>CO₃²⁻</th>
<th>Cl⁻</th>
<th>SS (%)</th>
<th>pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>APK-T1</td>
<td>20</td>
<td>-</td>
<td>19.2</td>
<td>-</td>
<td>0.25</td>
<td>7.56</td>
</tr>
<tr>
<td>APK-T2</td>
<td>-</td>
<td>0.40</td>
<td>25.6</td>
<td>80</td>
<td>1.43</td>
<td>8.14</td>
</tr>
<tr>
<td>APK-T3</td>
<td>-</td>
<td>0.20</td>
<td>19.2</td>
<td>150</td>
<td>1.92</td>
<td>8.22</td>
</tr>
<tr>
<td>APK-T4</td>
<td>40</td>
<td>0.80</td>
<td>40</td>
<td>80</td>
<td>1.81</td>
<td>8.28</td>
</tr>
<tr>
<td>APK-T5</td>
<td>20</td>
<td>1.20</td>
<td>19.2</td>
<td>60</td>
<td>1.37</td>
<td>8.15</td>
</tr>
<tr>
<td>APK-T6</td>
<td>40</td>
<td>0.80</td>
<td>40</td>
<td>120</td>
<td>1.16</td>
<td>8.19</td>
</tr>
<tr>
<td>APK-T7</td>
<td>20</td>
<td>0.40</td>
<td>19.2</td>
<td>180</td>
<td>1.00</td>
<td>7.95</td>
</tr>
<tr>
<td>APK-D1</td>
<td>40</td>
<td>0.40</td>
<td>59.2</td>
<td>220</td>
<td>0.71</td>
<td>7.93</td>
</tr>
</tbody>
</table>

*Sensitivity Limit of Spot Tests; SO₄²⁻: 20 mg/L, PO₄³⁻: 0,20 mg/L, CO₃²⁻: 4 mg/L, Cl⁻: 3 mg/L.*
Fig 4. Total aggregate/binder distribution (upper) and particle size distribution in aggregate (Aggregate Granulometry) analyses of mortars.

Table 4. Acidic aggregate (TA) and binder (TB) rate and particle size distribution analyses results of the mortars.

<table>
<thead>
<tr>
<th>Samples</th>
<th>TB (%)</th>
<th>TA (%)</th>
<th>Aggregate Particle Size Distribution (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&lt;63</td>
<td>&gt;63</td>
<td>&gt;125</td>
</tr>
<tr>
<td>APK-H1</td>
<td>80.92</td>
<td>19.08</td>
<td>2.06</td>
</tr>
<tr>
<td>APK-H2</td>
<td>77.93</td>
<td>22.07</td>
<td>4.19</td>
</tr>
<tr>
<td>APK-H3</td>
<td>53.63</td>
<td>46.37</td>
<td>2.46</td>
</tr>
<tr>
<td>APK-H4</td>
<td>75.03</td>
<td>24.97</td>
<td>27.40</td>
</tr>
<tr>
<td>APK-H5</td>
<td>74.53</td>
<td>25.47</td>
<td>2.94</td>
</tr>
<tr>
<td>APK-H6</td>
<td>70.63</td>
<td>29.37</td>
<td>3.06</td>
</tr>
<tr>
<td>Average</td>
<td>72.11</td>
<td>27.89</td>
<td>7.02</td>
</tr>
</tbody>
</table>
Fig 5. The thin section microphotographs of stone (upper) and mortar samples (lower).

Table 5. Petrographical thin section optical microscopy analysis of the stones.

<table>
<thead>
<tr>
<th>Stone Sample Groups</th>
<th>Rock Type</th>
<th>Descriptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group 1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>APK-T1</td>
<td>Sparitic Limestone</td>
<td>Carstic matrix (especially for the sample APK-T2), micro cracks filled with recrystallised calcite</td>
</tr>
<tr>
<td>APK-T2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>APK-T3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>APK-T4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>APK-T6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>APK-T7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Group 2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>APK-T3</td>
<td>Breccia Limestone</td>
<td>Volcanic rock fragments (basalt and serpantinite particles) in the matrix, micro cracks filled with recrystallised calcite</td>
</tr>
<tr>
<td>APK-T4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>APK-T5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>APK-T6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>APK-T7</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
rocks. These techniques have been used increasingly as they are easy and non-destructive. The dynamic elasticity coefficients of rocks are determined by analyzing the ultrasound measurement values obtained from cylindrical or cubic test samples prepared (in historical samples, both surfaces have been cleared). By applying vaseline on the lower and upper surfaces and by placing a transmitter in between the seismic analyzer (receiver/transmitter), the instrument is calibrated/adjusted through a seismic velocity measurement dependent on the crossing time of impulses. Then, test samples (limestones in this case) are placed between the ends of both receiver/transmitter, net required crossing times for the P and S wave velocity samples are determined and then recorded (Fig. 2). The values found are used to calculate the wave velocities:

\[ V = \frac{L}{T} \]  

\[ (1) \]

\[ [V : P \text{ and } S \text{ wave velocity (m/s), } L : \text{Sample thickness (m), } T : \text{Crossing time of the wave (s)}] \]

A Matest brand (High Performance Ultrasonic Tester) C372N Model ultrasonic velocimeter has been used in the analysis of limestones from the monument (Table 2 and Fig. 2).

Salts, which are naturally contained in various construction materials or dissolved in water and carried to the surfaces and pores of materials as a result of capillary action, provide information on chemical changes that may occur in material structures of both the material itself and other materials that they contact with (Black et al., 1965; Feigl, 1966; Means, and Parcher, 1963). The total amount of the soluble salt contained in the stone and soil samples from the Hadrian Gate, their average pH values and anion types were determined by using a pH-temperature-conductometer (Neukum Serie 3001 brand) (Table 3). The salt contents of the samples were also evaluated by official meteorological data from the Antalya city center and environments (Fig. 3).

To detect the aggregate and binding parts of the samples from the Hadrian Gate, samples were first weighed. Then, they were treated with dilute acid (5% HCl) to remove the binding carbonate content (CO\(_3^{2-}\)) from the sample. Samples were separated from their lime and all carbonate content by means of filtration, washing and drying, and thus, the aggregate part was obtained. Then, the samples were dried at room temperature. Later, they were weighed again to obtain the weight of the total amount of binder and aggregate (Table 4 and Fig. 4). Systematic sieving was performed on the aggregates obtained from the acidic analysis of samples.
Consequently, aggregate grain distribution ratios were calculated (granulometric analysis) (Table 4 and Fig. 4) (TS 3530 EN 933-1/April 1999).

Thin cross sections of stone and mortar samples were prepared – so that all the layers could be seen from exterior towards interior – and examined under an optical microscope (Tables 5, 6 and Fig. 5). In the examinations, the optical microscope LEICA Research Polarizan Microscope DMLP Model was used. Photographs were taken by the digital camera Leica DFC280, connected to the microscope and assessments were made by using the Leica Qwin Digital Imaging Program (Kerr, 1977; Rapp, 2002).

The element contents of the metal piece, obtained from a clamp cavity on one of stone blocks (Code T-269) from the Phaselis Hadrian Gate, were determined by using the X-Ray Fluorescence Analysis Method (non-destructive point Micro-XRF Analysis) (Table 7). In the analysis, Spectro Midex Model Micro-XRF (M-XRF) spectrometer was used.

Because of the heterogeneous structure of the stones and mortars as distinct from homogeneous structure of metals, the element contents of these samples were identified by means of X-Ray Fluorescence Spectroscopy (XRF) (Pollard and Heron, 1996; Shackley, 2011). In this study, a SPECTRO X-LAB 2000 model PED-XRF (Polarized Energy Dispersive-XRF) spectrometer was used. The analysis used the USGS (United States Geological Survey) standards and referred to GEOL, GBW-7109 and GBW-7309. The precision limit of the device is 0.5 ppm for heavy elements and 10 ppm for light elements. In this study, about 50 elements were identified and the main elements were evaluated (Table 8, 9 and Fig. 6).

RESULTS AND DISCUSSIONS

The samples reflecting the construction characteristics of the Phaselsis Hadrian Gate have been examined by using various archaeometric methods. The archaeometrical methods of physical, chemical and petrographical were applied to the samples from the monument that were examined to get their raw material characteristics (basic physical properties, binder/aggregate ratio, particle size distribution in aggregate, total soluble salt and types of salt), mineralogical and chemical compositions, and microstructural properties (Optical Microscopy and XRF).
Basic tests have been applied on the stone/rock samples from the masonry of the ancient gate in order to determine their physical characteristics as well as unit volume weight, water absorption capacity, porosity, hardness and ultrasonic velocity measurement (Table 2 and Fig. 2). As the amount of the samples was little, the competency properties have been assessed using cementation index instead of direct standard physical tests (Table 10).

The physical properties of the limestone samples from the Phaselis Hadrian Gate range as follows. Wet unit volume weight: 2.56 – 2.71 g/cm³ (average 2.66 g/cm³); dry unit volume weight: 2.27 – 2.69 g/cm³ (average 2.57 g/cm³); total water absorption capacity: 0.26% – 5.08% (average 1.32%); and total porosity: 0.71% – 11.51% (average 3.17%) (Table 2). The examination of the stone samples according to their rock types show that they are samples of limestone with the same rock structure (sparitic and breccia) (Table 5). Stones have different physical properties based on their natural rock structures and environmental properties. Samples with low density and high porosity are more incompetent. Among the stone samples, the one with the lowest competency is APK-T7 (limestone) – which has a low unit volume weight and high porosity; it has burnt so its outer patina has deteriorated. The samples with highest competency are APK-T1, APK-T3, APK-T5 and APK-T6 (limestone) samples (Fig. 2).

Among the seven main stone samples, four allowed for the Schmidt hardness test and all four are from the same rock type (limestone). The hardness value of the sample with code APK-T2 is much lower than others (Table 2).

The ultrasonic velocity measurements yielded the following values (over average values) in an increasing order: APK-T7 < APK-T6 < APK-T5 < APK-T4 < APK-T2 < APK-T1 < APK-T3. Furthermore, it was measured that the samples with codes APK-T6 and APK-T7, which have burnt layers, have lower competency properties than other samples. The APK-T3 sample, on the other hand, has the highest competency.
Some of the limestone must have been directly affected by forest fires that have been happening in time. This is clear from the disintegration that is particularly seen in APK-T6 and APK-T7 samples. With the effect of fire (increasing heat), the stones (CaCO₃) are converted into quicklime (CaO) and easily disintegrated due to humidity.

Efflorescence in construction materials can be due to many reasons such as structural (porous limestone or mortar with cement), periodical/climatic (cyclonic precipitation, temperature changes, freezing and melting processes), and environmental/atmospheric (proximity to

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(Table 2 and Fig. 2). Some of the limestone must have been directly affected by forest fires that have been happening in time. This is clear from the disintegration that is particularly seen in APK-T6 and APK-T7 samples. With the effect of fire (increasing heat), the stones (CaCO₃) are converted into quicklime (CaO) and easily disintegrated due to humidity.

Efflorescence in construction materials can be due to many reasons such as structural (porous limestone or mortar with cement), periodical/climatic (cyclonic precipitation, temperature changes, freezing and melting processes), and environmental/atmospheric (proximity to
sea, industrial regions and waste sites, exhaust gas emissions, effect of air pollution). The salt contents of stone/rock samples taken from the Phaselis Hadrian Gate range between 0.25% -1.92% (average 1.28%). The salt content of the single soil sample analyzed is 0.71% (Table 3). A high rate of salification was identified in all original stone samples. The main reason for efflorescence was determined to be environmental impacts (due to proximity to sea, salts were carried to construction materials by humidity). The soil sample, which reflects the characteristics of the soil reservoir, is an example of the salifereous soil category (>0.15) with a high ratio of water soluble salt (0.71%) (Dursun et al., 2008).

The examination of the stone samples from the Hadrian Gate according to their rock types and physical properties show that they are samples of limestone with the same rock structure (sparitic and breccia). The samples have come under efflorescence depending on structural, functional and location differences. As the samples are of porous/cavity involving nature (~1-12%) depending on the origin of their formation, such stones are more advantageous in terms of efflorescence. Efflorescence in stones may result in occurrences such as disintegration, especially due to weakness happening in its inner structure after a new patina forms on the outer layer (breakings/cracks are formed with the effect of the crystals in pores). This situation may yield constructional results (static). It is notable that the salt content of the APK-T3 sample, which is quite porous, is lower than others’ (Tables 2, 3).

Within the scope of archaeometric studies on the Hadrian Gate, samples were collected in September, 2011. Long-term meteorological data (http://www.meteor.gov.tr) pertaining to this date are as follows (official data for Antalya and environments): (all values are average): temperature: 24.5°C, day time sunlight duration: 9.9 hours, number of rainy days: 1.7 days, and precipitation amount: 12.3 kg/m² (Fig. 3d). Anions which dissolve in such a period – i.e., mild climate, beginning of rainy season and in a hot climate zone – are carried into construction materials and from the first months when precipitation falls (May and June), they can be observed in the form of crystallization. This condition also leads to lichenification under humid conditions as the stone blocks of the monumental structure have direct connection with soil. Moreover, an intense deterioration takes place starting from the surfaces and advancing to the porous inner structure (causing disintegration from loss

Table 10. Lime type determination of the mortar samples by Cementation Index values.

<table>
<thead>
<tr>
<th>Samples</th>
<th>Cl</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>APK-H1</td>
<td>0.56</td>
<td>MHL</td>
</tr>
<tr>
<td>APK-H2</td>
<td>1.20</td>
<td>C/NC</td>
</tr>
<tr>
<td>APK-H3</td>
<td>0.98</td>
<td>EHL</td>
</tr>
<tr>
<td>APK-H4</td>
<td>1.07</td>
<td>EHL</td>
</tr>
<tr>
<td>APK-H5</td>
<td>0.41</td>
<td>WHL</td>
</tr>
<tr>
<td>APK-H6</td>
<td>0.77</td>
<td>EHL</td>
</tr>
<tr>
<td>Average</td>
<td>0.83</td>
<td>EHL</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Cementation Index</th>
<th>Lime Type</th>
<th>Notation</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;0.30</td>
<td>Fat Lime</td>
<td>FL</td>
</tr>
<tr>
<td>0.30 - 0.50</td>
<td>Weakly Hydraulic Lime</td>
<td>WHL</td>
</tr>
<tr>
<td>0.51 - 0.70</td>
<td>Moderately Hydraulic Lime</td>
<td>MHL</td>
</tr>
<tr>
<td>0.71 - 1.10</td>
<td>Eminently Hydraulic Lime</td>
<td>EHL</td>
</tr>
<tr>
<td>1.11-1.70</td>
<td>Cement/Natural Cements</td>
<td>C/NC</td>
</tr>
<tr>
<td>1.70&lt;</td>
<td>Cement</td>
<td>C</td>
</tr>
</tbody>
</table>
of pieces) (Fig. 3d).

Additionally, anions such as sulphates and nitrates carried by seasonal precipitation also increase the destructive effects on materials. The pH, sulphate and nitrate values of rain water of Antalya are known for the fall months (Fig. 3a-3c). The acidic effect of rain water in Antalya (pH<7) results from its salt content (such as sulphates causing acid rains) (Fig. 3b); and in construction materials of limestone type containing carbonates, such as those in the monument, this effect causes destruction (Fig. 3a). In Antalya, meteorological data vary according to months. Compared to other months, the acidic effect increases in September (Fig. 3a). Sulphate and nitrate type of anions are lower in fall months (Fig. 3b,3c).

The anions that dissolve in water and carried to the material are groups such as sulphates, phosphates, nitrates, nitrites, chlorides and carbonates which are salts of sodium, potassium and magnesium. The standard (Merck) spot anion tests (chloride, phosphate, sulphate and carbonate) applied to the stone and soil samples from the Phaselis Hadrian Gate and the pH distributions of the medium are presented in Table 3. The pH values of the examined stone / rock (limestone) samples varied between 7.56 – 8.28, and the pH value of the soil is 7.93. All samples have weak basic quality (pH≥7) (Table 3). All of the stones in a weak basic environment (pH≥7) involve carbonation at varying ratios, as well as salt sulphate at a low ratio, phosphate at an average ratio and chloride at a high ratio.

In stone and soil samples (supporting the meteorological data), sulphate is contained at a low ratio (20 and 40 mg/L). Phosphate is found in all of the stone samples (between 0.200-1.200 mg/L), and in APK-T5 sample, the amount was higher (1.20 mg/L). Salification occurs due to the salts carried from the soil reservoir (APK-D1) in humid environment through vegetation (lichenification). Dissolved carbonate was generally identified in the stone samples at average and high ratios (19.2-59.2 mg/L), and in stone samples with codes APK-T4 and APK-T6, as well as the soil sample with code APK-D1 at a high level (40.0 and 59.2 mg/L). In all of the stone and soil samples, due to proximity to sea, chloride was identified at a quite high ratio (60.0-220.0 mg/L) (Table 3). Regarding water soluble salts, the samples from the Phaselis Hadrian Gate involve anions of the following types: carbonates, low level of sulphates, average levels of phosphate and high levels of chloride. In the samples, the source of salification was found to be the salts carried to the structure from the soil due to environmental impacts (proximity to the sea) (Table 3).

Mortar samples from the Phaselis Hadrian Gate were treated with acid. The aggregates obtained after the analysis were weighed and the total aggregate/binder ratios of the samples were found (TA% / TB %) (Table 4 and Fig. 4). The total aggregate contents of the examined mortar samples vary between 19.08-46.37% (average 27.89%). The jointing mortar samples were examined for non-carbonated aggregate content and it was identified that their aggregate/binder compositions were quite similar and at low levels, except the rubble filler sample APK-H3. The original jointing mortar samples did not comply with the 2:1 (aggregate:binder) ratio seen in traditional/standard applications. The ratio is 1:4 and 2:3 in jointing mortar sample and in rubble filler sample (APK-H3), respectively (Table 4 and Fig. 4).

Systematic sieving was performed on the aggregates obtained from the acidic analysis of mortar samples (sieves between 63-1000 μm were used). Consequently, aggregate grain distribution ratios were calculated (Table 4 and Fig. 4). The ratio of aggregates with very coarse sand-sized grains (1-3 mm grain size) ranges between 9.73-63.01% (average 36.63%), and that of the clay/silt-sized grains (<63 μm) changes
between 2.06-27.40 % (average 7.02%). The remaining are silt/sand-sized grains (63-
1000 μm) (Table 4). Of the six mortar samples examined, the aggregate structure
of three (APK-H1, APK-H3 and APK-H6) is very coarse sand size (>1000 μm); in sample
APK-H2, very coarse silt and average / coarse / very coarse sand sized (125-1000
μm) aggregates together; in sample APK-
H4, average / coarse silt (<63 μm) and very coarse silt sized (>125 μm) aggregates
together; in sample APK-H5, coarse sand sized (500 μm) aggregates form the main
structure (Wentwort, 1922). The mortar
sampled from the jointing of the stone
blocks of the Hadrian Gate and from the
rubble filler taken from the platform (APK-
H3) have different aggregate distributions.
In the APK-H4 sample, clay/silt content is
dense (<63 μm), whereas the aggregate
content of the APK-H1 and APK-H3 samples are composed of quite coarse
aggregates. The aggregate content of the
APK-H2 sample, on the other hand, has a
rather homogenous distribution (Table 4
and Fig. 4).

The macro physical structure of the
original jointing and rubble filler mortar
samples from the Gate involves a variety of
heterogeneous aggregates of a type that do
not contain the preferred aggregate types as
a result of some sieving. The aggregate
contents involve various types of minerals
and rocks that comply with local formation.
Pieces of rounded marine rock make up the
macro physical structure of the aggregates.
Binoocular microscopic examinations of the
mortar samples indicated that the aggregate
contained quite coarse sized brick particles
at varying ratios (Fig. 4; Photographs of
Mortar Aggregates).

The petrographic characteristics of the
samples were determined by thin cross
section optical microscope analysis; i.e. rock
and mineral composition, type, texture,
deterioration condition, distribution and
grain size. The thin cross section optical
microscopic analysis concluded that all of
the stone samples taken from the stone
blocks constituting the Phaselis Hadrian
Gate can be classified as belonging to two
different sub-types of limestone rock
(sparitic and breccia) (Table 5 and Fig. 2, 5).
The stone samples have been highly
affected by humidity, forming a
deteriorated patina caused by the structural
resolution on the surfaces of stones.
Moreover, the crystallization of the salts
carried to the structure with the effect of
humidity shows that the environment was
suitable for disintegration.

The mortar from the jointing of the stone
blocks of the Hadrian Gate has been
conserved and survived up do date. Samples were taken from it. Furthermore,
rubble filler of the platform, on which the
gate stands, and mortar sampled from
nearby (Mortar Gr1) were also included in
the sampling set. The thin section optical
microscope analysis differentiated the
sampling clearly and the mortar samples
were classified in three groups (Table 6).
The total aggregate content of the mortar
samples range as 35%, 40% and 65%. The
binding structure of the mortar is lime.
Brick particles were seen in the aggregate
content of all mortar samples at ratios of 1%,
1.5% and 2.5% of the total aggregate (Table
6 and Fig. 5).

Point Micro-XRF analysis has been
applied to document the chemical
composition of the metal piece that form the
clamp of one of the stone blocks making up
the Phaselis Hadrian Gate (stone block with
code T-269). It was found that the outer part
was lead (95.87% Pb) surrounding the
original iron clamp (92.27% Fe) (Table 7).
The chemical compositions of the
original stone and mortar samples were
found by means of PED-XRF analysis
(Tables 8,9). The stone samples from the
Hadrian Gate are limestone type of
sedimentary rock origin. Consistent with
this finding, the main structure of the
samples is composed of CaO (at ratios
between 38.02-62.65%) and carbonate (LOI:
Loss on Ignition, at ratios between 36.98-45.72%). Given the main element contents (>1%), rock formation of the same location is determined (Table 8).

Within the stone sample set, the APK-T7 sample has quite different chemical contents than other samples (Table 8 and Fig. 6). The formation of this stone might be different from the others in terms of its main and trace elemental composition. It has higher rates of SiO₂, Al₂O₃ and Fe₂O₃ and lower CaO than other samples. Furthermore, regarding the trace elements (>1%), sulphation (SO₃) is four times higher than other samples and a very high rate of P₂O₅, K₂O and MnO is contained (Table 8). It is highly probable that the stone has come under fire and the elements carried to the stone from the soil reservoir have affected it. This can be related to the deterioration and disintegration of the stone structure.

The jointing mortar taken from the Phaselis Hadrian Gate has chemical components very similar to rubble filler mortar (Table 9). This shows that the samples were applied in the same period. The chemical composition of the APK-D1 soil sample, which can be accepted as a reference about the natural structure, has been examined by means of a PED-XRF analysis (Table 9).

The chemical composition of the main element contents (>1%) of the mortar samples are as follows: CaO between 34.75-48.77%; SiO₂ between 6.54-15.81%; Fe₂O₃ between 1.49-3.20%, Al₂O₃ between 1.28-3.60%; MgO between 2.56-5.76% and total carbonate (LOI) between 34.78-41.89% (Table 9). The variables of mortar samples are aggregate/binder composition (type and ratio), location difference, petrographic characteristics, function, and environmental impacts. Ultrasonic velocity measurements were made and it was determined that some of the stone blocks in the sampling kit were quite competent (APK-T1 and APK-T3) while some were weak (APK-T7). Some of the limestones (APK-T6 and APK-T7) must have been directly affected by forest fires that have been happening in time.

The high rate of salification in the samples was similar and they had been caused by environmental impacts.
proximity to sea, salts carried from the soil reservoir and effect of vegetation) and carried to the original structural materials by humidity. Efflorescence in the samples was caused by the limestone layer formed by the disintegration and recrystallization of stones, and the salts easily carried to the structure from the soil with the influence of the humid environment (such as chloride and phosphate).

The mortar samples were examined for non-carbonated aggregate content and it was identified that their aggregate/binder compositions were quite similar and at low levels. The ratio is 1:4 and 2:3 in jointing mortar sample and in rubble filler sample (APK-H3), respectively. Aggregate size in mortar largely varies (average/coarse/very coarse sand size aggregates). Pieces of rounded marine rock make up the macro physical structure of the aggregates in mortar. The aggregate contained quite large sized brick particles at varying ratios.

Original construction stones of the ancient gate are limestone. Limestone, which is the construction stone, is in the main rock group of local formation. The mortar samples are classified into three original lime mortar groups petrographically. The brick particles were also identified in the aggregate content of the all mortars.

The iron and lead compositions of the metal pieces obtained from the stone clamp cavity and were also identified by non-destructive M-XRF analysis.

The elemental composition of limestone, soil and lime mortar samples were identified by means of PED-XRF analysis. The stones, except APK-T7, from the monument had similar elemental composition and addressed local formation like mortars. The type of the lime and competency of lime mortar samples were assessed by the Cementation Index data. The mortars had hydraulic character from weak to eminent. It was identified that the competency of rubble filler mortar is higher than the jointing mortar that contains a higher ratio of binder (lime) and a lower ratio of aggregate.

Through the archaeometric studies conducted on the construction materials of the Phaselis Hadrian Gate, it has been possible to do research into and document the construction technology of the building and the changes and transformations (deteriorations) that occurred in time. Furthermore, the characteristics of the repair materials were identified so that the materials to be selected are in compliance with the principles and codes of restoration.

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