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Full Length Research Paper

A case study about the experimental works on the production of repair mortars to be used in the restoration of Anemas Dungeons

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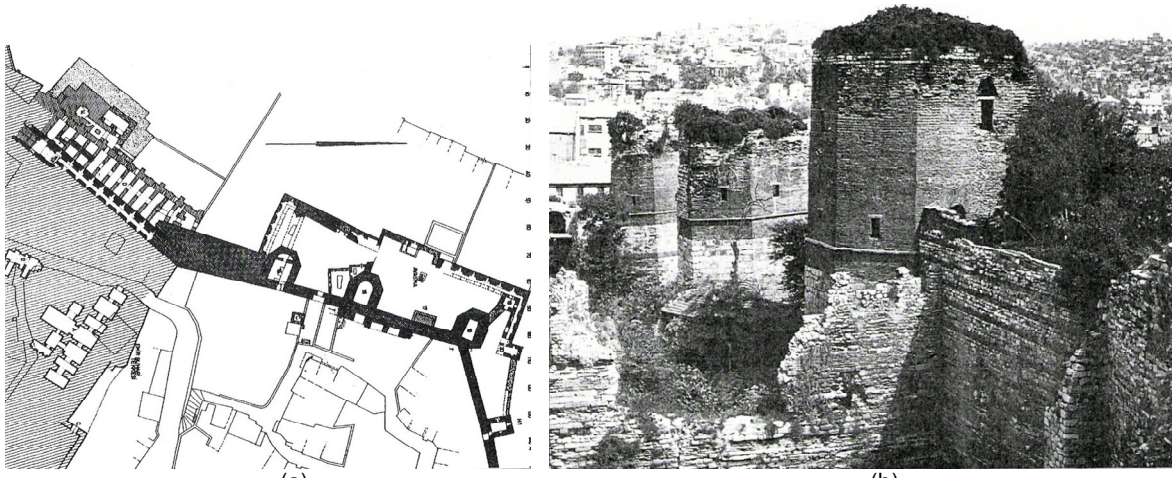
In this paper, the experimental studies conducted to produce repair mortars with local materials for the restoration of Anemas Dungeons located in Ayvansaray-Halic site of Istanbul Land Walls were explained and the results were evaluated. Before these studies, characterization studies of original mortar samples collected from the structure were conducted in detail, then the repair mortar samples were produced in laboratory conditions according to the material type determined as binder, aggregate and the determined ratios in the origins. Together with the physical and mechanical properties of the mortars produced in the laboratory conditions, also properties of their internal structure were determined with experimental studies. After, an evaluation of the test results are promising, the repair mortar was produced *in situ* conditions and applied to an appropriate wall of Anemas Dungeons for pilot study. At the end of approximately 1 year, a sample was collected from this wall and the internal structure and physical properties of this sample was determined by the laboratory tests. After all, the results of experimental studies conducted to the original mortar samples and the repair mortar samples produced *in situ* conditions were compared. As a result of general evaluation, it is been seen that the repair mortars produced with local materials are compatible with original mortars in the scope of color, texture and durability against the atmospheric conditions.

Key words: Anemas dungeons, repair mortars, historical buildings, experimental methods.

INTRODUCTION

It is been stated in the literature that Anemas Dungeons located in Ayvansaray-Haliç is a structure belonging to the beginning of 12th century. These dungeons which are known as Anemas Dungeons are located near Egrikapi which is next to the land walls of Istanbul. The dungeons start from the bastion which includes Ivaz Efendi Mosque and continues towards Halic. It is been also stated that Anemas Dungeons were neighbors to Blachernae Palace (Wiener, 2001). As stated in the literature, Anemas Dungeons had been subject to renovations throughout the history. As a result of this, different types of mortars and plasters belonging to both Early and Medieval Byzantine and Ottoman periods can be seen in the structure. As a result of the previous characterization studies of the 40 jointing and plaster mortar samples taken from Anemas Dungeons, it is seen that all of them are khorasan mortars with lime binder. The characters and composition of mortars vary slightly according to the period and location, state of plaster or joint mortar, and state of wall or arc. In respect of physical properties, most of the mortars are similar to each other. Water absorption ratios change between 38 to 44% and this number decreases to 18% in the ones that are jammed or smashed. Porosity ratios change between 40 and 49%. The fact that specific gravity was between 2.40 and 2.55 g/cm^3 indicates that the same type of materials were used in all mortars, and these materials are lime, crushed brick and brick powder.

The experimental studies which were conducted for the production of khorasan mortars with local materials in order to use in the restoration of the structure by evaluating the result of experimental studies performed on original mortar and plaster samples were explained in the following study (Figures 1, 2 and 3).



(a) (b)

Figure 1. Anemas Dungeons, a) Plan drawing, b) A general view taken 19th century.

Figure 2. The photos of general view of Anemas Dungeons taken currently.

Figure 3. The photos of interior view of Anemas Dungeons taken currently.

MATERIALS AND METHODS

The repair mortar samples were produced by using local pozzolana material whose pozzolanic property was studied previously (Ozgunler and Ozgunler, 2011). Pilot castings were performed for the production of repair mortar using pozzolana. The mixture ratios were determined according to characterization tests conducted for the original mortars. The original ratios of the crushed brick and the river sand were determined by means of evaluation of the data derived from the acid loss and sieve analysis and the petrographic analysis of the original samples. In order to determine the physical, mechanical and interior structure properties; tests were performed on the produced repair mortar samples. On repair mortar samples, the tests for water absorption ratio, density, specific gravity, porosity were performed to determine physical properties; the tests for compressive and tensile strength were performed to determine mechanical properties; the petrographical analyses on thin sections, SEM-EDS analyses were performed to determine interior structure properties. And on the repair mortar sample taken from the wall whose application was made in the construction site, analyses for acid loss and ignition loss, sieve analysis, analysis for physical properties, thin section petrographical analysis and SEM-EDS analyses were performed and the results were evaluated.

RESULTS

The results section consisted of the test results of the repair mortars produced in laboratory conditions and the repair mortars produced *in situ* conditions. All the test results were divided in two groups explained in the following parts.

The results of repair mortar produced in laboratory conditions

In order to design the appropriate repair mortars, many amount of trial mixes were produced according to the properties of original mortars. The mixtures had slaked lime as a binder and crushed brick and brick dust as aggregates and local pozzolana material as an additive. The trial mixes casted in steel casts which have 4 x 4 x 16 cm dimensions. The produced samples were cured according to curing processes stated in TS 25. After curing processes for one week 10 MPa (100 kgf/cm^2) compression strength was found. Then, the samples were kept in a moist environment for 1 month after production. Within this period, it was seen that the mortar did not crack and its strength increased to 14 MPa. It has been concluded that in the case of using local pozzolana material in mortars prepared with lime by grinding to the thinness specified in the standard TS 25, it binds by making calcium water silicates and as a result of these reactions it gains sufficient amount of mechanical strength and does not display the week resistance and dissolution with water contact which are generally seen in lime mortars (Gulec et al., 2003; Gurdal and Acun, 2006).

The physical properties of the repair mortar

As a result of the physical property tests conducted on produced repair mortar sample according to TS standard (1976-2009), the values were found compatible with the original mortar sample as shown in Table 1.

The micro structure of the repair mortar

In order to examine the micro structure of the repair mortar produced in laboratory conditions, the thin section analyses were performed in the laboratory of Protection and Conservation of Immovable Cultural Assets Department in Istanbul University. The petrographical analysis was performed on original khorasan mortar samples and repair mortar samples produced in laboratory conditions. As a result of the petrographical analysis, the textures of repair mortar sample were found compatible with the original mortar sample as shown in Figures 4 to 6.

The results of repair mortar produced *in situ* conditions

After, an evaluation of laboratory results are promising, it was decided to produce the repair mortar *in situ* conditions. The repair mortar was produced according to the same mixture ratios and same type of materials determined in laboratory conditions. And then, it was applied on an appropriate wall of Anemas Dungeons (Figures 7 and 8). After one year, it was seen that the repair mortar was much more similar like the originals as color and texture. Even though the wet weather passed, the durability performance of the repair mortar was much better than the previous.

The test results of the repair mortar produced in situ conditions

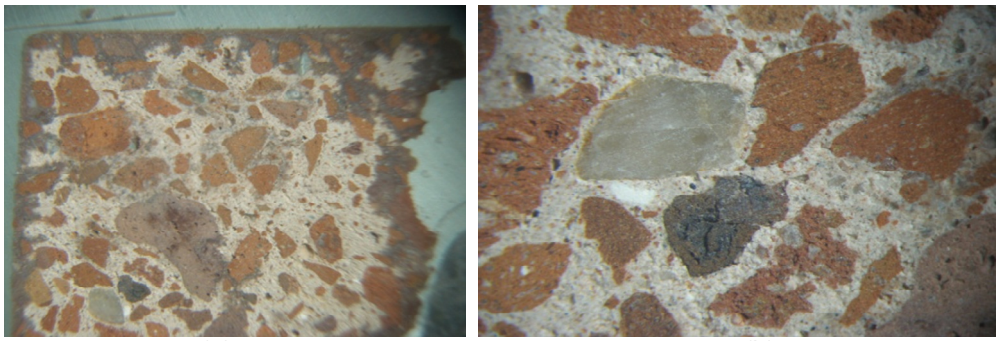
The tests conducted during the previous studies were repeated on the repair mortar samples taken from the structure (Figure 9). These were acid loss, ignition loss, sieve analysis, tests for physical properties and interior structure properties.

The results of acid loss and sieve analysis

The binding medium of the sample was reacted with HCl (10%) and the siliceous aggregates and other insoluble materials were separated. The size grading of the siliceous aggregates were evaluated by sieve analysis (Table 2 and Figure 10). The types, the shapes, the colours and the inclusions, including the approximate ratios of the different types of the aggregates were identified by means of a stereo-optical microscope after the sieve analysis (Borelli, 1999; Gulec and Ersen, 1998; Gulec et al., 2005).

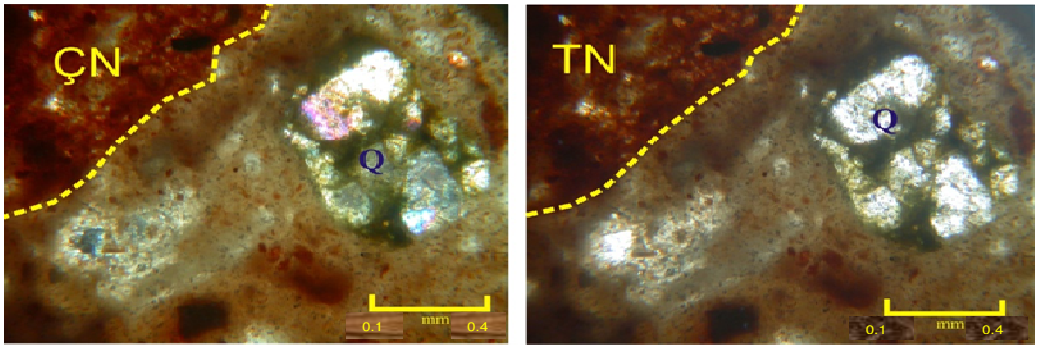
Table 1. The comparative results of physical property tests of the repair mortar produced in laboratory conditions (RM-L) and original mortar (OM).

Sample	Water absorption (by weight, %)	Water absorption (by volume, %)	Density (g/cm³)	Specific gravity (g/cm³)	Porosity (%)
RM-L	29	44	1.51	2.55	41
OM	36	46	1.30	2.41	46



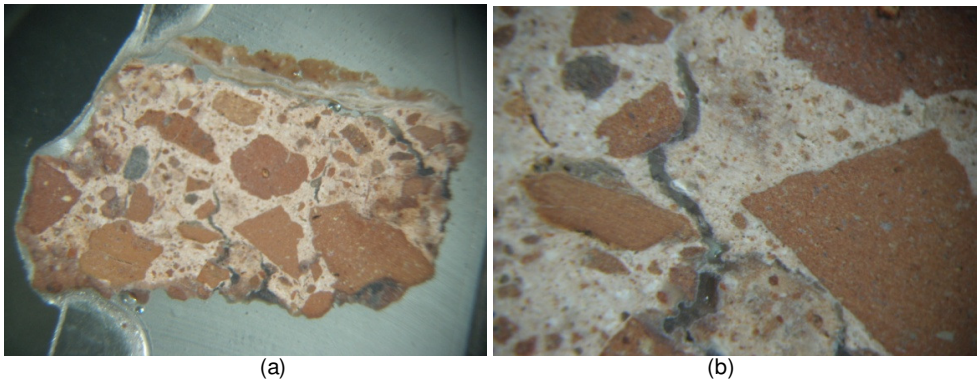
(a) (b)

Figure 4. The stereo microscopic photos of the repair mortar sample from surface, (a) 2X magnification, (b) 4X magnification.



(a) (b)

Figure 5. The thin section photos of the repair mortar sample produced in laboratory condition. (a) Double Nicole, (b) Single Nicole.



(a) (b)

Figure 6. The stereo microscopic photos of the original mortar sample from surface, (a) 2X magnification, (b) 4X magnification.

Figure 7. The photos of the repair mortar used during the restoration of Anemas Dungeons (2006).

Figure 8. The photos of the repair mortar after one year, during the restoration of Anemas Dungeons.

Figure 9. Location of the sample taken from the repair mortar which is previously used in the restoration of Anemas Dungeons.

Table 2. The comparative results of acid loss analysis of repair mortar produced *in situ* and original mortar samples.

Samples	Initial weight (g)	Fine aggregate (retained in filter) (g)	Total material (retained) (g)	Acid loss (%)	Binder/aggregate ratio
RM-IS	31.16	3.78	21.29	32	1/2
OM (original)	38.02	4.99	25.84	32	1/2

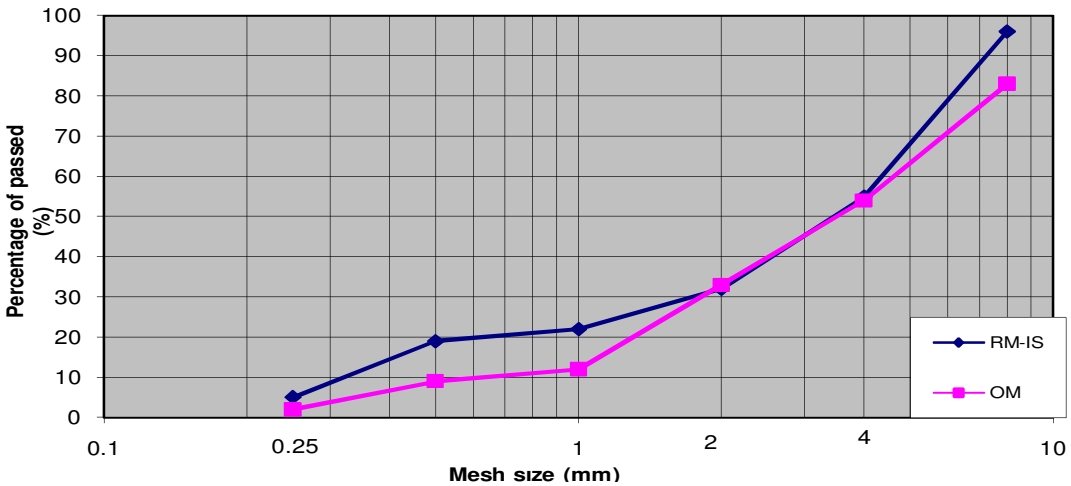


Figure 10. The grading of the aggregates for the repair mortar to match the original mortar samples.

The results of ignition loss analysis

A finely ground sample (500 mg) was placed in a porcelain crucible and weighed. The samples were heated in an oven at 105 ± 5°C, 550 ± 5°C and 1050 ± 5°C for 2, 1 and 0.5 h respectively. After each heating, the samples were cooled in a desiccator and weighed. From the weight differences, percentage moisture absorption, ignition loss at 550°C and calcium carbonate content of the samples were calculated and shown in Table 3 (Borelli, 1999; Gulec and Ersen, 1998; Gulec et al., 2005).

The test results of physical properties

As a result of the physical property tests conducted on repair mortar sample according to TS 699 standard (1976-2009), the values were found compatible with the original mortar sample as shown in Table 4. Water absorption rates in original mortars are between ~ 20 to 40% and porosity values are between 38 to 57%. And repair mortar complies with these properties.

The results of micro structure analyses

For the micro structure analysis of the repair mortar produced *in situ* conditions, the thin section analyses and SEM-EDS analyses were performed as shown in Figure 11. SEM-EDS analysis was conducted on the repair mortar sample taken from the structure after 1 year. The results are shown in Figure 12 and Table 5. As Figure 12 is shown, it is been determined that aggregates and matrixes bonded properly, there are interfaces between and in these sections there are structures composed of reticular texture. This texture shows the composition of calcium silicate hydrate. These reactions increase the mortar's durability against atmospheric conditions.

CONCLUSIONS

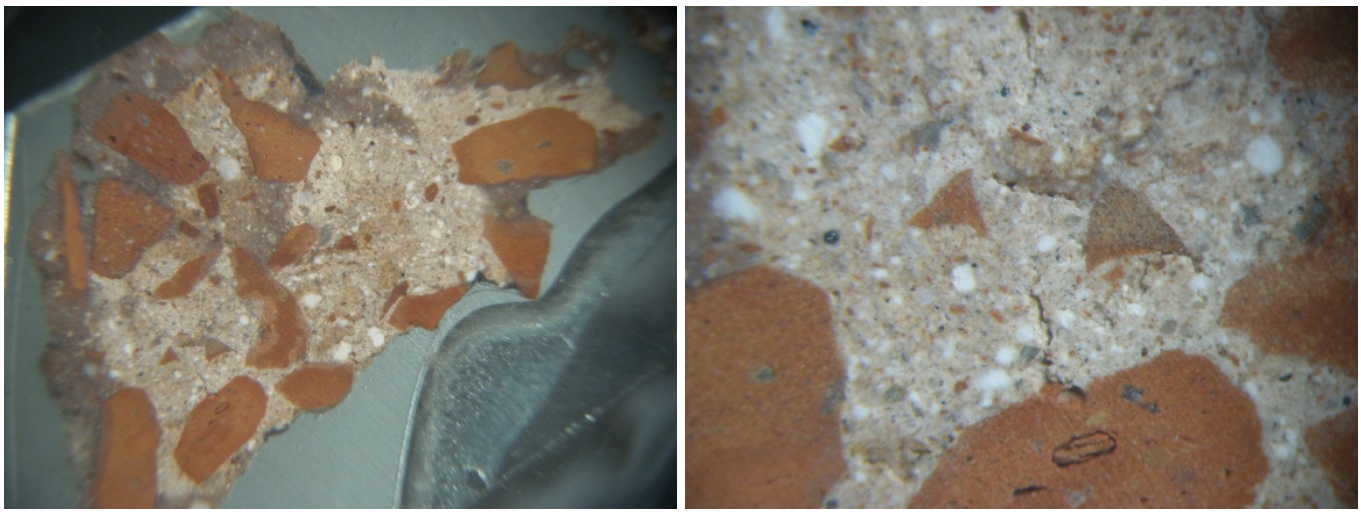
In the context of conservation principles, it is very important to choose the most appropriate construction technique and materials in the restoration of historical buildings. In order to make a decision to use new materials, the original materials must be documented and analyzed. In this case study, before the application of repair mortar, the original mortar of Anemas Dungeons was analyzed by scientific methods and then the experimental studies were conducted to design an appropriate mortar to the structure. With this case study, it was achieved that the repair mortar which is both compatible to original and durable against the atmospheric conditions was produced to be used in the restoration of Anemas Dungeons.

Table 3. The comparative results of ignition loss analysis of repair mortar produced *in situ* and original mortar samples.

Samples	Ignition loss at 105°C (%)	Ignition loss at 550°C (%)	Ignition loss at 1050°C (%)	$CaCO_3$ (%)
RM-IS	0.65	3.43	13.08	29.74
OM	1.05	3.44	13.46	30.59

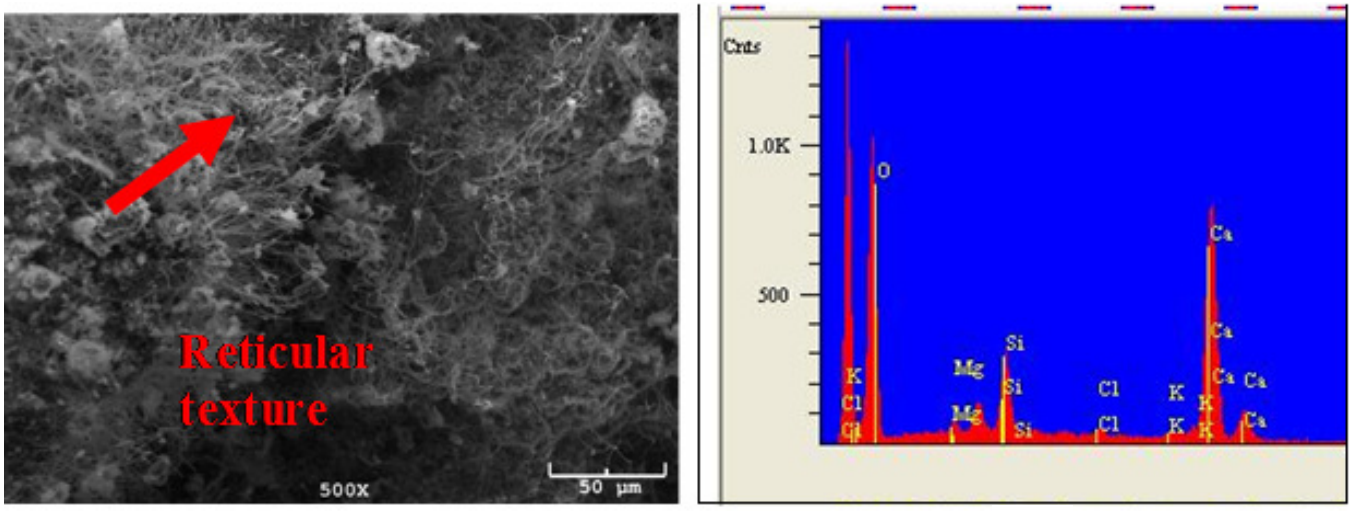
Table 4. The results of physical property tests of repair mortar produced *in situ*.

Water absoprtion (by weight, %)	Water absoprtion (by volume, %)	Density (g/cm³)	Specific gravity (g/cm³)	Porosity (%)
33	50.16	1.52	2.76	45



(a) (b)

Figure 11. The thin section photos of the repair mortar produced *in situ*, (a - b). 2x and 4x magnifications.



(a) (b)

Figure 12. (a) SEM image (500x), (b) EDS graphic of the interior structure of the repair mortar used during the restoration.

Table 5. Compound percentages of EDS graphic taken from Figures 11 and 12.

Compounds	Mole. concentration (%)	Concentration (%)
MgO	22.893	16.534
SiO_2	39.513	42.544
Cl_2O	2.892	4.504
K_2O	2.264	3.821
CaO	32.439	32.589
Total	100.00	100.00

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