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MORTAR AND PLASTER ANALYSIS AS A DIRECTIVE TO THE DESIGN OF COMPATIBLE RESTORATION MATERIALS IN FRANGOKASTELLO (CRETE)

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ABSTRACT

In this study the results of physico-chemical analysis for mortar and plaster specimens from Frangokastello castle in Sfakia (western Crete) and the subsequent designing of compatible restoration mortars are being presented, as part of a wider project for the sustainable management of the monument.
In order to compose a compatible restoration mortar or plaster a reverse engineering process has been adopted. Primarily, a study of mortar and plaster specimens, that constitute a representative sampling from the monument, was performed. The analyses included macrosopic characterisation and microstructural examination using microscopy on samples and on fine polished cross-sections of them. Additionally, chemical and mineralogical analyses were executed including Fourier transformation infrared spectroscopy (FT-IR) and X-ray diffraction analysis (XRD). In the framework of thermal analysis, thermogravimetric and differential thermal analysis (TGA and DTA) were performed in order to obtain information regarding hydraulic components of the mortars. Finally, the granulometric curves of selected specimens were produced and contributed to the classification of samples in different groups and construction phases.
Elaborating all these results and the state of the conservation, compatible raw materials were chosen, including hydraulic lime and other binder and aggregates. The designed mortars were subjected to durability tests, so that the mechanical behavior of the restoration mortar could be comparable to the historic ones. Subsequently, colouring experiments were carried out in order to approach one or more existing plasters for partial use. The result of this work aims to constitute a directive for the restoration of the monument, concerning the use of compatible mortars.

KEYWORDS: Mortar analysis, compatible mortars, restoration mortars, monument sustainability, physico-chemical analysis, sustainable restoration

1. INTRODUCTION

Restoration mortars to be used for historic buildings and monuments is a widely discussed issue, wherein solid conclusions have been conducted about the directives for their composition. In Crete, over the past years, the lack of knowledge on the compatibility of the mortars and the raw materials has caused, on many occasions, severe damage on historic textures and structures. Nowadays, analyses of existing mortars and integrated studies on the design of restoration mortars are in most cases included in monuments' restoration programmes (Moropoulou et al. 1998; Maravelaki-Kalaitzaki and Christodoulakos 2008). Reverse engineering approach, used in this study, evaluates the restoration mortars based on the acceptability limits set by the historic composites and has proved helpful in the analysis of historical mortars and design of restoration mortars (Moropoulou et al., 2009; Apostolopoulou et al., 2017).

In the case study of Frangokastello, a Venetian castle in the southern coast of Crete, in the region of Sfakia, (as shown in Fig. 1) an integrated study for the restoration of the monument has been carried out, for first time, including analysis of mortar and plaster specimens and design of restoration mortars compatible with the existing substrate. Many different mortar and mostly plaster specimens were chosen from the structure aiming to represent the numerous restoration phases and different uses of the castle through the centuries (Gerola 1905; Andrianakis 1999; Karakaletsis 2004). Among them, also cement mortars were selected, as a result of partial restorations of the 20th century.

Figure 1. Frangokastello, Crete, Greece (kastra.eu)

The aim of the analyses of the historic mortars was to gain insight into the physico-chemical composition of the mortars and the raw materials used, as well as their production technology (Salama et al. 2017). Having acquired this knowledge, a detailed study on the synthesis of compatible mortars and plasters was carried out, in order to proceed to the restoration of the historic structure (Maravelaki-Kalaitzaki et al. 2003, 2011).

2. EXPERIMENTAL

2.1. *Characterisation of mortars*

Frangokastello has its unique history which is reflected in different construction phases, use of materials and implementation of techniques. These phases are neither easily recognisable nor adequately historically documented. As a consequence, the sampling of mortars and plasters needed to be extensive in order to be representative of all the visible construction phases on the buildings' structure (as shown Fig.2). However, each sample's size was limited, so as to avoid extensive loss of historical material.

Every sample receives a laboratory code. The term FR designates for Frangokastello, followed by a number and at the end "M" or "P" indicates mortar or plaster specimens, respectively. Totally, sixteen small samples were extracted, specifically six mortar and ten plaster samples.

Initially, a macroscopic description of the samples took place in order to classify them into groups with similar generic characteristics. The mortar specimens were divided into: a) lime mortars, with distinctive white colour and many lime agglomerates and b) cement or cement-lime mortars, probably 20th century's repairs. The plasters were divided into: a) uniform plasters, b) layered plasters with fine ochre finishing and c) layered plasters with fine whitish finishing.

Following, the optical microscopy of the samples, gave information about the microstructure of the specimens and also about their grain size, origin and distribution. The equipment used was a digital microscope USB Dino-Lite AM4515T5 Edge with a color CMOS sensor. The captured via the Dino Capture 2.0 software images had 1.3 megapixels resolution and 500x zoom. Fine polished cross-sections were prepared for selected specimens, where it was considered necessary; in order to examine their microstructure in a more detailed level.

Concerning the mortars' grain size distribution, mechanical sieving (ASTM E 11-70 series of sieves, meshes of 4.5, 2, 1, 0.5, 0.25, 0.125 and 0.063 mm of diameter) was carried out for the production of granulometric curves. This procedure required a minimum quantity of 100 gr from each sample.

A basic analysis, which was carried out for every specimen, was the Fourier transformation infrared spectroscopy in order to obtain qualitative information, from a chemical point of view, on some of the characteristic compounds contained in mortars (calcium and magnesium hydroxides and carbonates, gypsum, etc.) and for determining the presence of salts (nitrates, sulphates etc.) as well as organic compounds. FTIR was selectively carried out in specific parts of some specimens, in order to get additional information on the chemical composition of some binders, finishing layers and aggregates (Farmer, 1974). The spectra were recorded, using the KBr (Potassium bromide) Pellet Method, with a PerkinElmer 1000 spectrometer, in the spectral range from 4000 to 400 cm^{-1}.

X-ray diffraction (XRD) analysis (Bruker D8 advance diffractometer) was performed in most of the specimens in order to identify the mineral crystalline phases and to complete the mineralogical characterization. For the XRD measurements, the sample was irradiated with Ni-filtered Cu Kα radiation (35 kV 35 mA) and the backscattered signal was detected and analyzed from a Bruker Lynx Eye strip silicon detector.

Concerning the study of the hydraulic compounds of mortars, simultaneous thermogravimetric (TGA) and differential thermal (DTA) analyses were carried out with Setaram LabSys Evo 1600°C thermal analyser up to 1000°C under nitrogen atmosphere with a heating rate of 10 °C/min. This analysis provides information about the hydraulicity of the mortars, which is a very important factor to decipher the production technology, origin of the raw materials and the overall durability. The procedure followed to estimate the hydraulicity factor of the mortars is documented in detail in international literature (Maravelaki-Kalaitzaki et al. 2003, 2005, 2011, 2013; Maravelaki-Kalaitzaki 2007; Moropoulou et al. 1995a, 1995b, 1998).

Figure 2. Overview of sampling points on Frangokastello castle.

2.2. *Study of restoration mortars*

Concerning the raw materials to be used for the synthesis of the restoration mortars, these should fulfil criteria such as: a) physico-chemical compatibility with the historic ones and the stone structure of the wall, b) sustainability against degradation due to the adverse climate conditions of this coastal area (Galanos et al. 2008a, 2008b, 2011).

In the preliminary phase, restoration joint mortars and plasters were designed and assessed in a laboratory scale aiming to proceed with pilot applications in the monument. The objective was to propose mortars for filling voids and joints or even restore missing parts in the construction with a plaster compatible to the original both from physico-chemical and aesthetical point of view.

The binders which were used were natural hydraulic lime with pozzolanic additions (Lafarge NHL-z 3.5) and metakaolin, which technically constitutes an artificial pozzolan. The use of natural hydraulic lime is firmly favoured nowadays for restoration purposes, as it has similar physical characteristics and mechanical behaviour with the historic binders, does not contain harmful substances, such as soluble salts, and provides hydraulic compounds, ensuring good sustainability against environmental degradation. Metakaolin as an additive binder, enhances the hydraulic behaviour of the mortar and its mechanical strength, but needs to be used always to a controlled level to ensure compatibility to the historic masonry (Moropoulou et al., 1998; Aggelakopoulou et al. 2011; Maravelaki-Kalaitzaki and Christodoulakos 2008; Maravelaki-Kalaitzaki et al., 2005).

The selection of aggregates was mainly determined by their grain size distribution. Several samples of sand were sieved in order to obtain their grain size distribution curves and compare them with the analysed historic mortar's and the standard sand's curve.

An increased binder to aggregate ratio of 0.5 was deliberately selected, in order to impart appropriate strengthening properties to the mortar as a result of the presence of hydraulic components. The water to binder ratio was 0.69 (as shown in Table 3) to ensure a good workability. The designed mortar was named FR-mrt (mortar). The mixing of the mortar was mechanical and always uniform. The total three specimens were moulded in prismatic moulds with dimensions of 4x4x16 cm and kept wet for three days. Afterwards, they were unmoulded and kept in closed environment of 20 °C and 60% relative humidity until the 28th day, when they were tested.

The specimens were submitted to mechanical tests for the evaluation of their compressive and tensile strength. The stress-strain diagrams were also obtained from the above-mentioned tests and the modulus of elasticity was calculated accordingly.

To achieve the desired coloration of plasters, ochre and/or ceramic powder were used as pigments in small quantities in a series of tests. The mix proportions and materials were otherwise identical with the FR-mrt. These formulations were moulded in small pots and also applied on a stone surface, in order to compare the coloration with the original plasters.

3. RESULTS

3.1. *Analysis of the original mortars*

3.1.1. Macroscopic examination

A macroscopic examination of the specimens revealed the main character of the mortars, which was calcareous in almost all cases, containing lots of lime agglomerates. Two mortars seemed to be recent cement mortars, or lime-cement, having much darker colour, while the one contained angular crushed aggregates. Crushed aggregates were not used elsewhere, showing that the use of local natural aggregates was favoured.

The plasters were either uniform with ochre colouring or consisting of layers with different structure. The most common background layer seemed to be almost identical to three mortar specimens (FR10M, FR11M and FR15M). Except from the middle main layer, which had some ochre colour, a very fine finishing layer of almost pure lime occurred, which was pulverised and coated by ochre colours.

3.1.2. Optical microscopy examination

The classification process continues with the examination of samples via the optical microscope. The size and the origin of aggregates as well as the microstructure and the quality of the binders were observed during this process and useful conclusions derived. Most of the plaster specimens contained solely local sea sand from the beach next to the monument. This observation was verified by examining a sample of this sand (FRsand) through the optical microscope (as shown in Figure 9). The grain sizes and types as well as the plethora of sea shells on many of the plasters refer directly to the local sea sand sample. Additionally, ceramic fragments of variable size appear sporadically on many of them. The layering of the plasters was observed, which has a variant thickness, due to the wall irregular surface and the roughness of their application. However, some samples could be regarded as identical, expecting the confirmation of the latter chemical analyses. At this point the observation of the fine polished cross-cut sections of the plasters was useful, as it revealed an identical uniform structure for most of the plasters (FR2P, FR7P, FR12P, FR16P, FR17P), regarding their inner thick layer (as shown in Figure 8). This fact demonstrates a very close technology and production dates for the specific specimens. The rest of the plasters showed more irregular cross-sections, mostly due to improper mixing of the mortars or the irregularity of their aggregates' types and grain sizes.

Regarding the mortar specimens, three of them were grouped based on the microscopy and their sampling location on the towers' interior masonry

(FR10M, FR11M and FR15M). This hypothesis was confirmed later from the chemical examination of the specimens. The specimen FR3M (as shown in Figure 3) was of interest, as it was extracted from the internal layer of the masonry of the south wall. Consequently, it could probably be an original Venetian mortar which survived all the repairs and alternations of the castle. This hypothesis was reinforced by its macroscopic characteristics. The abundance of binder, the whitish colour and the sporadic ceramic fragments made it comparable to other Venetian mortars from similar structures identified and analysed in the past (Biscontin et al., 1993). Moreover, it was the only one that contained plenty of white crushed limestone aggregates, a more demanding practice that involves transportation and processing of aggregates.[1]

3.1.3. FTIR and XRD analyses

The FTIR analysis identified the character of the mortars which have calcareous origin, with notable aluminosilicate compounds. The specimens had similar spectra, so no great differences could be revealed regarding their production technology or the raw material used.

An important finding was the presence of gypsum in some mortars and plasters. Specimens containing gypsum were found in the interior of two towers. The presence of gypsum could be interpreted either as a corrosion product due to the interaction with the marine environment, or as an integral component of the mortar, mostly of its binder. The later assumption was supported by the fact that the local stone in the surrounding area of the monument is an impure calcareous stone containing gypsum. Specimens containing gypsum have a tendency to deterioration because of its solubility and its conversion to anhydrite (Kamel, 2019). The variety of the local bedrock, could also explain, the presence of aluminosilicates, due to the existence of marly limestone.

The mineralogical analysis of the mortars revealed calcite, quartz, dolomite and illite in almost all the specimens. Kaolinite, augite and albite were present in some samples. The presence of these minerals could be simply attributed to the mixed local marly stones. On the other hand, the presence of gypsum is an important finding, grouping these mortars on the same construction phase where the binder is probably originating from the same quarry. Additionally, halite and potassium nitrate salts were detected in some specimens, which could be mostly attributed to the marine salt and to the local intensive cultivation, respectively (Budak et al., 2008). Table 1 presents the mineralogical composition of each sample.

Table 1. The mineralogical compositions of the samples based on the FTIR and XRD analyses.

Sample	Mineralogical composition
FR1P	Calcite, Quartz, Dolomite, Aragonite, Illite, Augite
FR2E	Calcite, Quartz, Dolomite, Aragonite, Illite
FR3M	Calcite, Quartz, Dolomite, Aragonite, Illite, Potassium Nitrate, Halite
FR6P	Calcite, Quartz, Dolomite, Aragonite, Illite
FR7P	Calcite, Quartz, Dolomite, Kaolinite, Illite, Albite, Augite
FR8P	Calcite, Quartz, Dolomite, Kaolinite, Illite, Augite
FR9P	Calcite, Quartz, Dolomite, Illite Hematite, Augite
FR10M	Calcite, Quartz, Dolomite, Gypsum, Albite, Augite, Calcium Nitrate, Halite
FR11M	Calcite, Quartz, Gypsum, Illite, Aragonite, Calcium Nitrate Halite
FR12P	Calcite, Quartz, Gypsum, Illite, Augite, Potassium Nitrate, Halite
FR13M	Calcite, Aluminosilicates, Gypsum
FR15M	Calcite, Quartz, Dolomite, Aragonite, Illite, Augite, Potassium Nitrate, Halite
FR16P	Calcite, Quartz, Dolomite, Gypsum, Aragonite, Kaolinite, Illite, Augite
FR17M	Calcite, Quartz, Dolomite, Aragonite, Illite, Augite
FRleoneP	Calcite, Quartz, Aluminosilicates

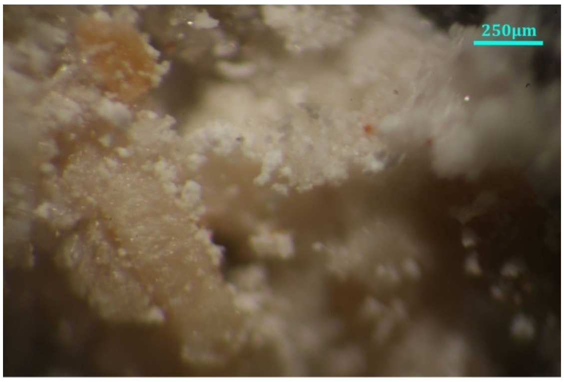


Figure 3. Optical microscopy pictures of mortar FR3M; a whitish mortar with a high content of lime binder and much fluorescence on its surface.

[1] It is considered a fact that the Venetians had an expert knowledge on construction and gave a lot of attention to the quality of their structures, on the opposite to the Ottomans (Bouras, 1998).

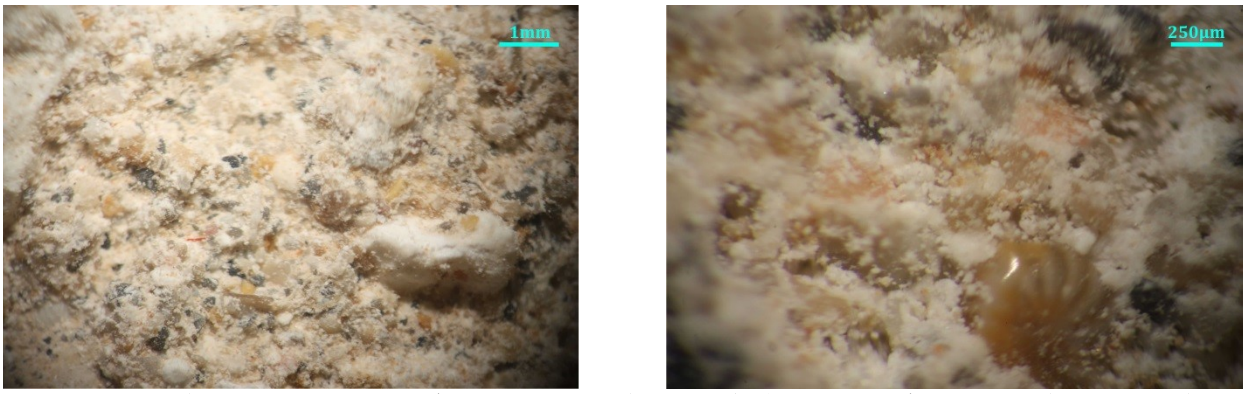


Figure 4. Optical microscopy pictures of mortar FR15M; showing a higher content of aggregates than FR3M. The presence of sea shells in the aggregates' mixture is obvious, as it is also in FR3M and in most of the analyzed specimens. There is clearly less fluorescence in its surface, due to both its position in the inside of building (FR3M is directly exposed to the seaside effects) and/or because it is more recent.

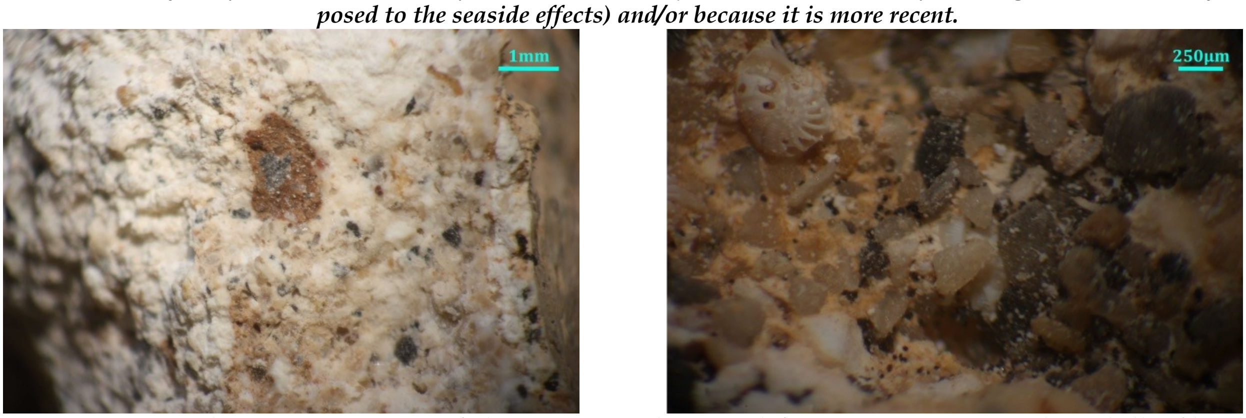


Figure 5. Optical microscopy pictures of plaster FR6P; a plaster with fine-grain aggregates and sea shells of local origin and also a whitish outer thin coating (approx. 0.6 mm) consisting mainly of lime.

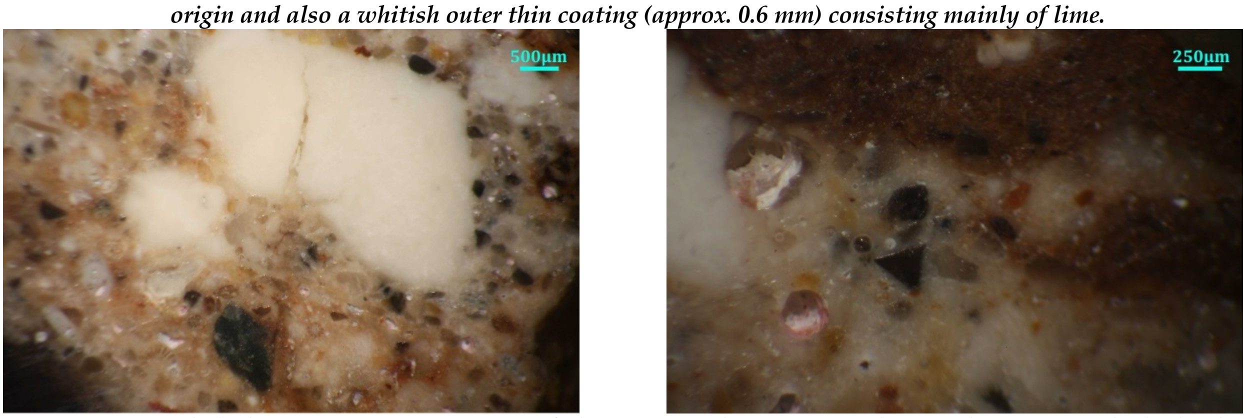


Figure 6. Fine polished cross-cut section pictures of plaster FR6P; demonstrating lime agglomerates and a higher level of carbonation than in the mortar specimens, due to its closer interaction with the atmospheric air. In the right photograph the boundary of lime – ceramic interaction is visible.

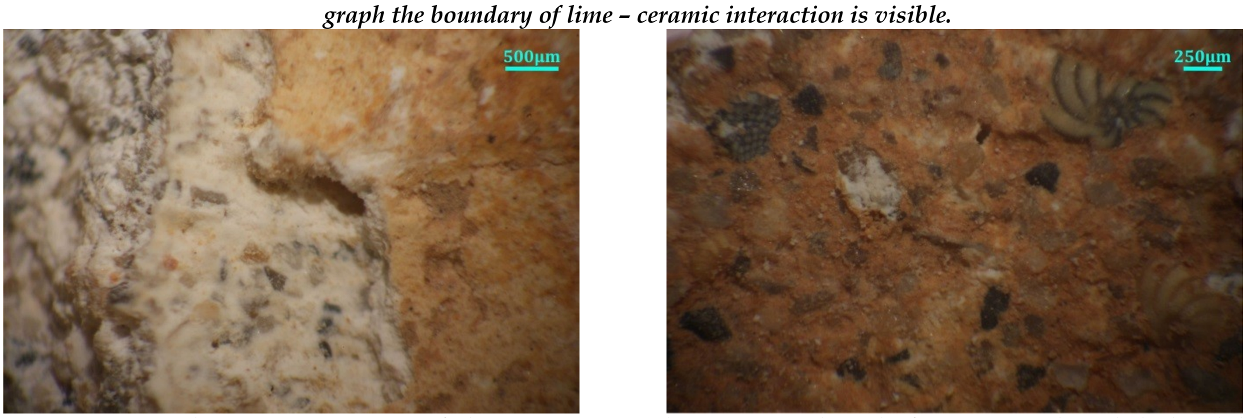


Figure 7. Optical microscopy pictures of plaster FR17P; two layers exist, where the first seems to be polished and the finest second one contains ochre colouring. Sea shells and fine sea sand are obvious here as well.

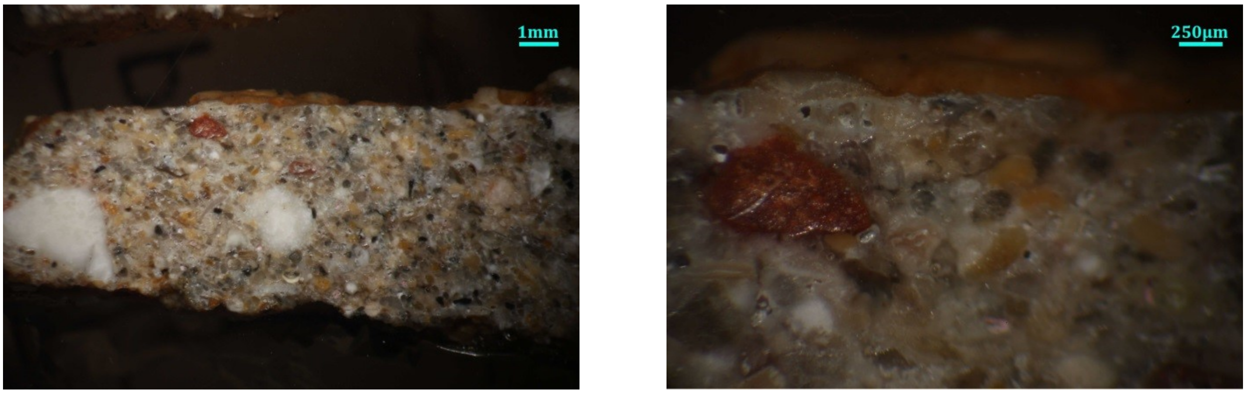


Figure 8. Fine polished cross-cut section pictures of plaster FR17P; a uniform single layer plaster with a fine layer of ochre colouring on its outer surface. Some lime agglomerates and sporadic ceramic fragments are also visible. This uniform structure responds to most of the analyzed plasters, with or without a finishing layer.

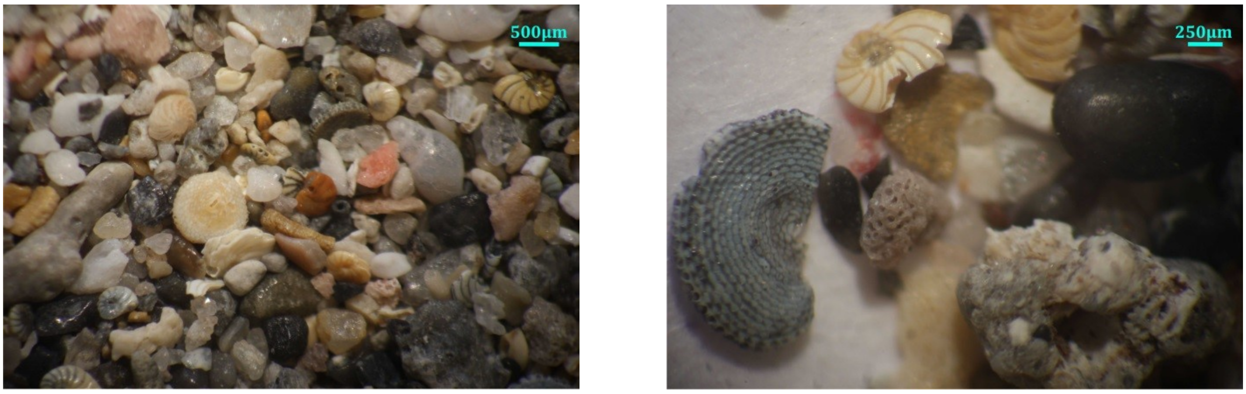


Figure 9. Optical microscopy pictures of the local sea sand (FRsand); displaying a variety of fine up to very fine grains and plethora of sea shells. This local raw material, also due to its vicinity, it is considered to have been used in all the analyzed historic mortars and plasters (except from the concrete ones of the 20th century).

3.1.4. Thermal analysis

The thermal analysis results identified the reactions of the hydraulic compounds in temperature ranges up to 1000°C. The presence of gypsum was confirmed due to the endothermic peak in temperature ranges between 125-135°C for specimens FR10M, FR11M, FR12P and FR16P. Furthermore, the estimation of the CO_2/H_2O ratio, which is in fact the ratio of the carbonates to the hydraulic compounds, constitutes an indicator about the hydraulicity of the mortars (as shown in figure 10). For values 0 to 5 the mortar is regarded as hydraulic, from 5 to 10 as partly hydraulic, while for values greater than 10, the mortar is air-setting (Maravelaki-Kalaitzaki et al. 2005, 2011). All of the mortars were classified as hydraulic (FR3M, FR10M, FR11M, FR12P, FR15M, FR16P), or semi-hydraulic (FR17P). This leads to an assumption that the engineer and the craftsmen of the past had empirical knowledge on the binder production, and the high resistance and adequacy of the hydraulic mortars in marine environments. Table 2 presents the results of the thermal analysis.

Table 2. The results of the thermal analysis demonstrating the weight loss in different temperature zones. Also, the ratio CO2/H2O is given, expressing the hydraulicity of the mortars.

Sample	Mass loss % (g)			CO_2/H_2O
	30-200 °C	200-640 °C	640-870 °C	
FR3M	2.37	10.26	24.85	2.42
FR10M	1.96	8.84	29.38	3.32
FR11M	2.11	10.06	25.33	2.52
FR12P	2.82	11.41	23.41	2.05
FR15M	2.58	7.99	28.07	3.51
FR16P	1.88	8.07	28.69	3.56
FR17P	1.24	5.36	32.16	6.00

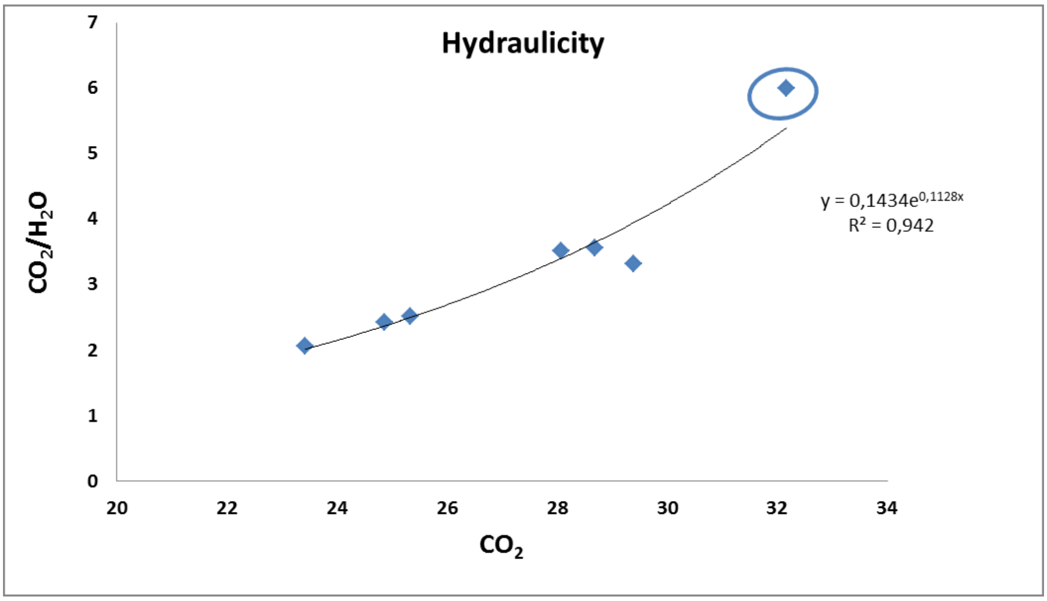


Figure 10. The CO2/H2O to CO2 diagram of the analysed mortars, expressing their hydraulicity.

3.1.5. Granulometric curves of mortars

The grain size distribution of FR3M and FR15M are demonstrated in Figure 11, compared to the standard sand's granulometric curve and also to the local sea sand's curve. There is a clear difference in the production technology and know-how on mortars between them. The granulometric curve of FR3M, which appears to be of Venetian origin, is very close to a standard sand's curve and shows a normal grain size distribution. The curve of specimen FR15M, which is classified as an Ottoman mortar, is rather irregular, showing a high proportion of large aggregates, a low proportion of middle-sized ones, and again a high one of small grains. It is generally accepted that the Venetians possessed a great knowledge on construction technology and materials and a good grain size distribution is expected in their mortars. On the other hand, during the Ottoman domination in Greece the architecture and building quality deteriorated (Bouras 1998; Moropouloou et al., 1998).

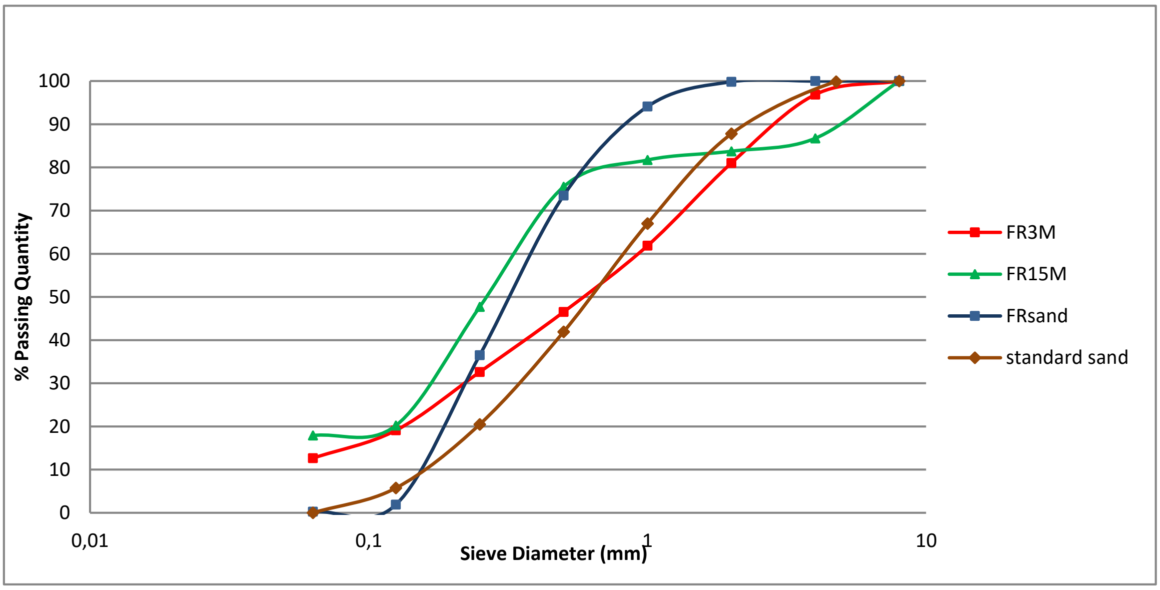


Figure 11. The granulometric curves of the mortar and sand samples, compared to the standard sand's.

3.2. *Restoration mortars*

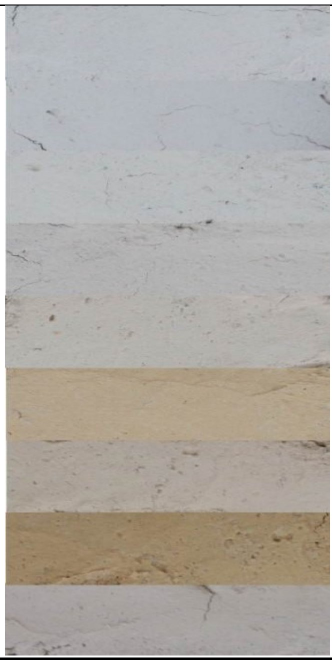
3.2.1. Synthesis of the restoration mortars

The binders selected for the synthesis of the restoration mortar were Natural Hydraulic Lime and Metakaolin. This is attributed to the fact that according to the thermal analysis of the authentic samples the majority of them were characterised as hydraulic mortars. For the selection of the most suitable aggregate the granulometric curve of seven different aggregate samples was developed and compared with the granulometric curves of the authentic samples taken from the castle. The selected aggregate was river sand, which showed a good grain size distribution (as shown in Figure 12), very similar to the grain size distribution of sample FR3M and the standard sand and also containing inconsiderable quantity of powder. Table 3 presents the proportions from each material for the composition of FR-mrt. The colour tests for the plaster were named FR-pls1 up to FR-pls9 and are demonstrated on Table 4. These tests could be further continued in order to result to the most desired colour for every particular use.

Table 3. The raw materials' quantities and ratios for the proposed composition.

Sample	Quantity (g)	Quantity (ml)	Ratios (w/w)
Metakaolin (Mt) (ρ=0.5 g/cm³)	450	900	Binder (NHL+Mt)/Aggregates=0.50 Water/Binder (NHL+Mt)= 0.69
Natural Hydraulic Lime (NHL, 3.5-z) (ρ=0.78 g/cm³)	900	1154	
River sand (ρ=1.67 g/cm³)	2700	1620	
Water (ρ=1 g/cm³)	935	935	

Table 4. The colour tests for the desired restoration plaster. The standard quantity of mortar and those of the colour pigments are given for each experiment.

Experiment	Colour	FR-mrt (g)	Ochre (g)	Brick powder> 63μm (g)	Brick powder> 125μm (g)
FR-pls 1		200	-	-	-
FR-pls 2		200	0.014	-	-
FR-pls 3		200	0.042	-	-
FR-pls 4		200	0.100	-	-
FR-pls 5		200	0.207	-	-
FR-pls 6		200	0.500	-	-
FR-pls 7		200	1.557	-	-
FR-pls 8		200	0.500	1.029	-
FR-pls 9		200	1.550	9.820	5.851

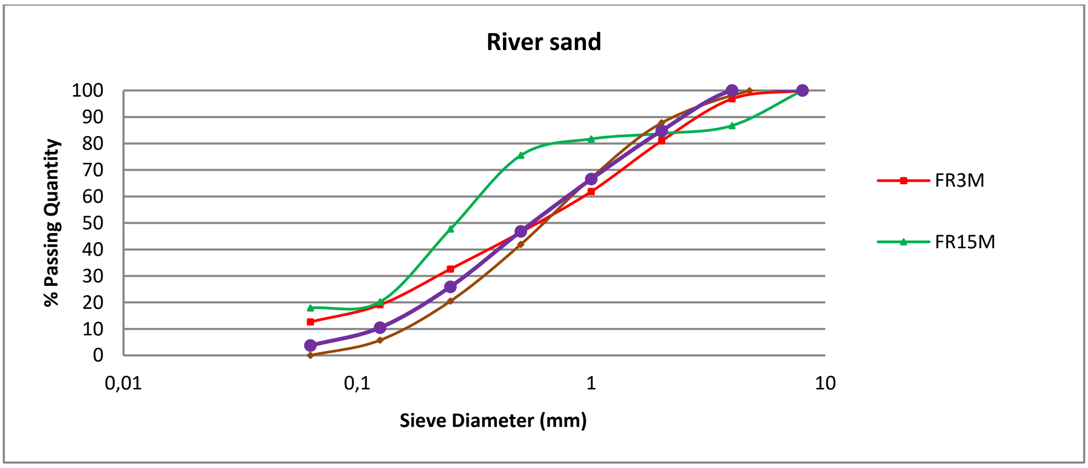


Figure 12. The selected river sand's granulometric curve in comparison with the ones of FR3M, FR15M and the standard sand.

3.2.2. Mechanical test results

The proposed mortar, FR-mrt, after 28 days of setting, was subjected to mechanical tests for the estimation of compressive and tensile strength and also of modulus of elasticity and demonstrated satisfying results. These results are of course attributed to the quality of raw materials, especially metakaolin, their proportions in the mixture, the design process conceived and to the production method used.

In Table 5 the mechanical properties of the specimen are presented. Figure 13 demonstrates the stress-strain curve for the uniaxial compressive strength of the developed specimens. These values classify the specimen as a durable hydraulic mortar and offer compatibility to the masonry's durability. The compatibility between the proposed mortar and the construction materials of the Castle can be guaranteed from their high compressive strength (~16MPa) and modulus of elasticity (~4.5 GPa) compared favourably with the stone and mortar corresponding values, as indicated in the study of Stavroulaki et al. (2017). More specifically, in this study the compressive strength of the stone and mortar were estimated to be 78 and 10 MPa, respectively. However, Fig. 13 and the toughness value reported in Table 5 evidenced that the designed restoration mortars offer not only adequate resistance to the mechanical loading, but also are able to effectively resist in deformation. The latter is an important property for mortars entailed to absorb the deformation energy thus protecting the masonry from collapse in severe external loading.

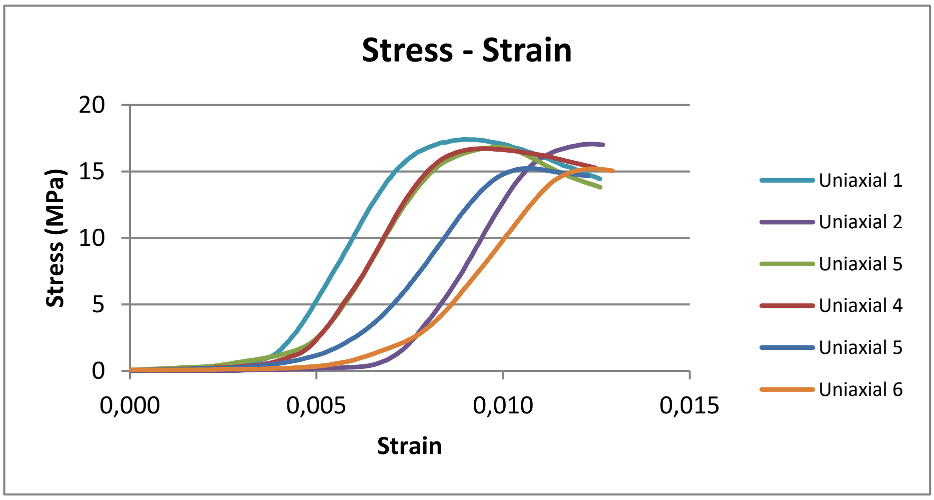


Figure 13. The stress-strain diagram for the tested mortar FR-mrt.

Table 5. The mechanical properties of the proposed mortar.

Proposed mortar	Compressive strength (MPa)	Tensile strength (MPa)	Toughness factor	Modulus of elasticity (GPa)
FR-mrt	16.41 (±0.95)	1.80 (±0.17)	0.13 (±0.03)	4.47 (±0.68)

4. CONCLUSIONS

With a holistic analysis of the representative mortar and plaster specimens, classification and dating of the samples was feasible (as shown in Table 6). The main ingredient of the binder to produce the historic mortars in the case study of Frangokastello was hydraulic lime. The use of pozzolanic binders was not verified and crushed brick was found only in insignificant quantities. Local material was mainly used for the production of plasters and mortars. In particular, the local marly limestone, that was excavated from different quarries per historical period, and the local sand. Mortars containing gypsum were dated in the same construction period due to the use of an impure calcareous local stone containing gypsum.

Table 6. Classification and dating of samples.

Period	Compressive strength (MPa)
Venetian	FR3M/ FR6P/ FRLeonP
Ottoman	FR1P/ FR2P/ FR7P/ FR8P/ FR9P/ FR10M/ FR11M/FR12P/ FR15M/ FR16P/ FR17P
Recent	FR5M

The general good present condition of the monument is attributed to the venetian expertise in construction and to the hydraulic character of the mortars. The coatings are mainly washed out in the southern wall, where the weather conditions are more intense. The masonry and the mortars do not demonstrate significant construction pathology and any existing corruption or cracks are attributed to mechanical faults or the numerous violent historic devastations of the castle.

The above-mentioned findings and observations, and especially the hydraulic character of the authentic samples determined the synthesis of the restoration mortars. The mortars proposed for the restoration of the monument should ensure compatibility with the historic structure and also feature some improved characteristics, for a greater stability and mostly sustainability. These concern basically a higher, but not excessive, compressive strength, an adequate tensile strength, elasticity -so as the stresses and minor movements are absorbed- and an enhanced hydraulic character. The particular novelty of the present study is based on the fact that the developed methodology addresses the special needs of coastal castles providing restoration mortars with enhanced hydraulic properties.

The resulting syntheses of the restoration mortars and plasters constitute a laboratory directive for the composition of the actual restoration material. This practice has not yet been established in the regional scale of Crete and such initiatives are promoting the contemporary trend of Cultural Heritage preservation. The exact raw materials should be carefully chosen and evaluated according to their characteristics, in order to exploit their potentials into making highly sustainable restoration mortars.

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