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Edited by J. Válek, C. Groot, J. J. Hughes

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2nd Conference on Historic Mortars and RILEM TC 203-RHM Final Workshop HMC2010

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An objective of the 2nd Historic Mortars Conference is to bring together scientists, technicians and professionals involved in research and studies of historic mortars to present and discuss advances in this topic. The main theme of the conference is the conservation of historic buildings and works of art, i.e. studying mortars with respect to repair. This is a unifying field where a truly interdisciplinary collaboration is needed and where contributions of archaeologist, architects, civil and structural engineers, geologists, material scientists, chemists, conservation scientists and art restorers interested in mortars should have their place. The special focus of the conference will be on the application of research and technical knowledge to conservation practice and vice versa in its reflection on such recommendations.

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Characterization of mortars in historical modern monuments: a realistic and an analytical approach

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Abstract Structures embedding historical, artistic and scientific values and built after 1830 (the date of the establishment of the Modern Greek state) are defined as modern monuments according to Greek legislation. Although the period of documentation is restricted to the last 180 years, extended field survey and visual examination, traced a wide range of structural mortar mixtures in support of typical bearing masonries. The continuous and successful use of wet slaked lime putties has been documented through historical, socioeconomic and technological analysis of local construction practice combined with applied research (in situ, in the lab, and through market study). The obtained integrated background knowledge, the regular long-term monitoring of the old and repair mortars in a real site environment and the attained overall experience support ongoing conservation projects. Since the analytical chemical approach is too sophisticated and expensive for ordinary conservation work, the least amount of key laboratory tests -adequate to characterize a mortar and to control the available market materials- is crucial to enhance interventions' quality and minimize the cost.

1 Introduction

Structures embedding historical, artistic and scientific values and built after 1830 (the date of the establishment of the Modern Greek state) are defined as modern monuments according to Greek legislation (law No 3028/2002, commonly called "archaeological law"). Considering that the majority of modern monuments are private, Greek Ephorates of Modern Monuments mainly supervise conservation projects financed by the private sector or by individual owners. A limited number of conservation projects of public modern monuments are undertaken by the Greek Ministry of Culture and/or co-financed by the European Community Support Frameworks.

In most private interventions, lack of money - or time or simply unwillingness to carry out any materials' research – merely leads to general recommendations to owners and/or contractors. As a result, the Ephorates' capability in controlling the quality of each conservation project is constrained. However, this approach is definitely inadequate for large scale, or international projects, as for example are the requirements of the National Strategic Reference Framework (NSRF) 2007-13. In this frame of responsibilities, the background knowledge on mortars technology [1-7] aspires to support ongoing conservation projects, private and public.

Indicatively, the present paper focuses on the pragmatic and/or analytical characterisation of masonry mortars -and specifically of the binders- with the aim to contribute scientifically and cost-effectively to their appropriate conservation.

2 Case studies

Typical bearing masonries of the - as previously defined - modern monuments consist of the building units and the bedding mortars. Knowledge on local traditional construction systems and materials are preserved in Greece, and will continue to live on, as long as old masons are still alive. Also, local sources of raw materials can still be identified (e.g. resources for stones extraction to be used as bearing elements or for lime production, earth quarries, wood forests etc). Today, conventional know-how in building construction usually contradicts to current European codes and standards [3] and to common economic immigrant masons' expertise. Since we are standing at a crucial crossroad, we are urged to seek out combined conservation strategies in terms of interdisciplinary perspective and international cooperation network [4].

Regarding structural mortars, three general types can be categorized according to their binder type: a) earthen or weak lime earthen mortars of C19, b) pure lime mortars rarely combined with local pozzolan of C19/C20 and c) lime cement synthesis of C20. At any case, the continuous use of wet slaked lime putties has been documented through historical, socioeconomic and technological analysis of the last two centuries in local construction [2] combined with applied research (in situ [5] , in the lab [6, 7], and through market study [3]).

2.1 Earthen or weak lime earthen mortars of C19

Naoussa, Prefecture of Hmathia • Listed unit of Mathieu's 'House-Mill'

Fig. 1 The storehouse before collapsing

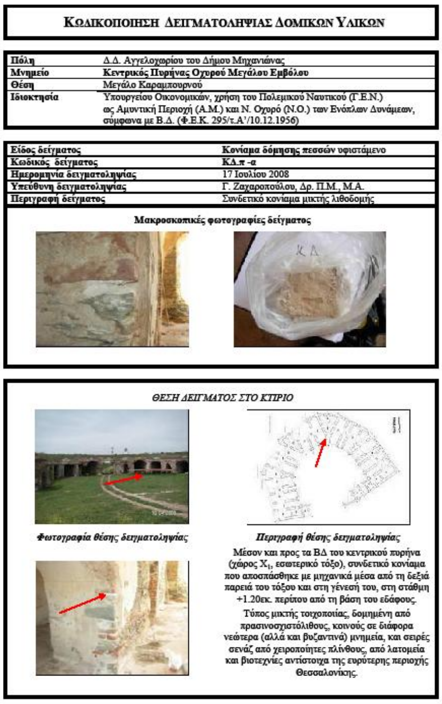
Fig. 2 The storehouse under restoration

Table 1 The key role of local raw materials and know-how in authenticity preservation [3]

Date of construction	late C19
Original use and ownership	Storehouse of the main building unit of Mathieu's 'House-Mill'
Current use and ownership	Redundant, under expropriation by the Greek Ministry of Culture; intended use 'Museum of Tradition, of Historic Archives and Wine Museum of Naoussa town' (Fig. 1, Fig. 2)
Bearing structure	Stone masonries with wooden chainage (ground floor and all north walls) and timber framed (2 upper floors); wooden floors & roof
Study 2002-03 (emergency)	The study was carried out by E. Mavroudi and G. Zacharopoulou
Project 2002-03 (salvage)	Local knowledge was alive; no materials' research was carried out; local masons were aware of the traditional construction system and materials; they gathered earth (called 'pourohoma') from the old quarry and meticulously filled the masonry gaps and also reinforced the wooden structure under Ephorate's supervision & funding

2.2 Pure lime mortars combined with pozzolan of C19/C20

Municipality of Michaniona, Prefecture of Thessaloniki • The fort of Megalo Emvolo (Great Karabournou)



ΚΩΔΙΚΟΠΟΙΗΣΗ ΔΕΙΓΜΑΤΟΛΗΨΙΑΣ ΔΟΜΙΚΩΝ ΥΛΙΚΩΝ

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Είδος δείγματος	**Κονίαμα δόμησης πεσσών υφιστάμενο**
Κωδικός δείγματος	**ΚΔ.π -α**
Ημερομηνία δειγματοληψίας	17 Ιουλίου 2008
Υπεύθυνη δειγματοληψίας	Γ. Ζαχαροπούλου, Δρ. Π.Μ., Μ.Α.
Περιγραφή δείγματος	Συνδετικό κονίαμα μικτής λιθοδομής

Μακροσκοπικές φωτογραφίες δείγματος

ΘΕΣΗ ΔΕΙΓΜΑΤΟΣ ΣΤΟ ΚΤΙΡΙΟ

Φωτογραφία θέσης δειγματοληψίας

Περιγραφή θέσης δειγματοληψίας

Μέσον και προς τα ΒΔ του κεντρικού πυρήνα (χώρος X_1, εσωτερικό τόξο), συνδετικό κονίαμα που αποσπάσθηκε με μηχανικά μέσα από τη δεξιά παρειά του τόξου και στη γένεσή του, στη στάθμη +1.20εκ. περίπου από τη βάση του εδάφους.

Τύπος μικτής τοιχοποιίας, δομημένη από πρασινοσχιστόλιθους, κοινούς σε διάφορα νεώτερα (αλλά και βυζαντινά) μνημεία, και σειρές σενάζ από χειροποίητες πλίνθους, από λατομεία και βιοτεχνίες αντίστοιχα της ευρύτερης περιοχής Θεσσαλονίκης.

Stone: compressive strength fc=68.59 MPa (A.S.T.M. D 2938-71a), bulk density 2.74gr/cm^3, absorption 0.40%

Brick: BxLxH: (10.5-11.8)x(23-25) x(5.3-6.2), compressive strength fc=5.16 MPa, absorption 19.02%

Fig. 3 Sampling of (bedding) **mortars** and natural (stone) and artificial (brick) **masonry units**

Table 2 The need for better documentation of the local materials before restoration

Date of construction	1883-85 by German military engineers and early C20 additions
Original use and ownership	defensive Naval Fort of the Greek Army
Current use and ownership	redundant, Navy of the Greek Army
Bearing structure	brick vaulted, stone masonries with brick layers
Study	2008-09 in the frame of the 3rd Community Support Framework, ENM KM, O. Deligianni, G. Zacharopoulou et al.
Project	intended for the National Strategic Reference Framework (NSRF) 2007-13; the large scale of the monument and the demands of NSRF for using standardized materials requires better documentation of the authentic and new local materials available in the market; standardized materials vs. local materials (usually not standardized)

To identify the texture of the mineral aggregates the shape of the lime grains and their chemistry, Scanning Electron Microcopy (S.E.M) analytical techniques were applied on mortar fragments using the GSM 840A instrument (SEM laboratory of AUTh), after sampling of mortars and building units (Fig. 3). Good cohesion bonds were observed both at the matrix (Fig. 4) and at the binder/aggregate interface (Fig. 5) comparable to those obtain in lab research with lime putty samples [2, p. 200]. Besides, mechanical and physical characteristics were obtained in cooperation with the Laboratory of Public Works of Central Macedonia. Indicatively, the mortar's information is integrated as following:

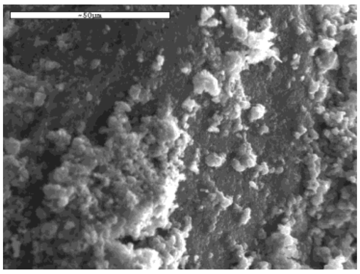

Fig. 4 Cohesiveness of the lime matrix

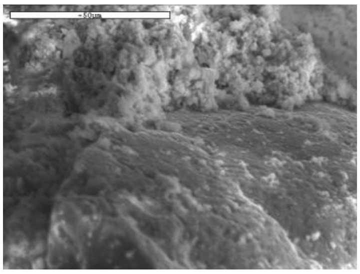

Fig. 5 Binder/aggregate interface

Table 3 Further investigation and interpretation towards authentic mortar's characterization

Sample code & location	**ΚΔ.π – masonry mortar**
Colour	10YR 8/1 white (according to Munsell soil color chart)
Binder	49-61% $Ca(OH)_2$ (or 68-85%, CaO), lime grains dm ~1μm÷5μm; homogeneous without grain aggregations (porous <10μm)
Aggregate	
-characterisation	river sand, siliceous origin, with little amount of added ceramic fragments >3mm from low fired crushed bricks (on going research)
-sieving curve (according to E105-86, tests 6 & 7)	even, 0-4.75mm (63.6% between No 200/7.5μm - No 10/2mm); 6% of grain size >4.75mm with equal amount of crushed bricks and sand
Absorption	19-21% (comparable to the hand-made bricks)
Compressive strength	compressive strength fc<2.5 MPa
B/Ag	binder/ aggregate ~1/2.5 (point counting)
w/b	use of matured lime putty; min. w/b to achieve lime's consistency

2.3 *Lime (pozzolan) cement synthesis of early C20*

Thessaloniki, Prefecture of Thessaloniki • The 'Casa Bianca'

Fig. 6 The 'Casa Bianca', 1994

Fig. 7 Internal bearing structure, 1994

Table 4 Description of the modern monument 'Casa Bianca'

Date of construction	1911-12 (transitional period in the use of binders)
Original use and ownership	lodge of Blanche and Fernandez Diaz (architect P. Arigoni)
Current use and ownership	since 1997, Cultural Centre of the Municipality of Thessaloniki
Bearing structure	stone masonries with brick layers (ground floor) & brick masonries (upper floors) both reinforced with metallic components (beams and anchors); internal wooden floors with the exception of the 'wet' rooms (kitchen and baths) where metallic beams bridged with special large bricks were used; external terrace constructed with a transitional type of 'early concrete – brick' Zöllner slab
Study	1993; research group of the Polytechnic School of AUTh; responsible of the static restoration, Prof. G. Penelis, civil engineer
Project	1994-1997, financed in the frame of 'Thessaloniki, Cultural Capital of Europe 1997'. Consultant engineer (on site), G. Zacharopoulou

Table 5 The supportive role of key laboratory tests in mortars characterization

Sample code & location	**structural mortar of masonries (4 samples)**
Colour	white-grey
Binder	$Ca(OH)_2$ ~40%, CaO: 28-34%, SiO_2: 29-30%, Al_2O_3: 5-7% (~15-18% soluble in 0.1N HCl); lime/pozzolan ~2/1.
Aggregate	
-characterisation	river sand, siliceous origin (with added local pozzolan or cement)
-sieving curve	0-5mm (50% passing 0,5μm) rich in fine particles;
Absorption	~14%
Compressive strength	compressive strength fc<2.0 MPa

After series of relevant research samples, hydrated lime (in dry form), cement and sand were proposed for the repair mortars; Lime/Cement/Aggregate /Water=1/1/6/2.4 per volume, compressive strength fc=3.25MPa, flexural strength f_f=1.05MPa, dynamic modulus of elasticity Ed=8041MPa.

According to current global knowledge and also to the local integrated background research [2-7] some kind of (local) pozzolan should have been added. Furthermore, lime is preferable in the form of matured wet slaked putty [1].

2.4 High calcium lime wet slaking at the worksite

Fig. 8 Asvestochori lime production area

Fig. 9 Wet slaking at the worksite, 2001

In 2001, the 10th Ephorate of Byzantine Antiquities (responsible for the Prefecture of Halkidiki and Mount Athos) was commissioned to restore the ‘Russian Metohi’ at Flogita area and to adapt it to the ‘Christian Culture Center of Halkidiki’ under the name ‘Justinian Center’. Acknowledging the importance of using wet slaked matured lime putty, 10 tones of high calcium quicklime were bought from the Asvestochori lime production area (Fig. 8) and wet slaked at the worksite (Fig. 9) producing about 27 tn of putty.

The water added during slaking has been chosen correctly, as the settled water (w_s) after 24h was ≤40ml, according to EN 459-2:2001 [8], 5.9.2; it was measured w_s=13.5cm^3 (96% of the 30th day). Yield was also acceptable as being ≥26dm/10kg, according to EN 459-1, 4.5.2, Table 4: Physical requirements of quicklime. Also, available lime Ka=74.40% (limits only for dry forms in EN 459) and free water w_F=59%, according to EN 459-2, 5.11, (EN 459-1, Table 5; gives limits 45%≤ w_F ≤70%). Finally, bulk density=1.262gr/ml, acceptable as according to BS 890 ≤1.45g/ml (there are no limits about putties in EN 459).

Since then, lime putty has been successfully matured and used for all restoration works in the area for which the Ephorate is responsible.

3 Discussion and Conclusions

Although the period of documentation is restricted to the last 180 years extended field survey and observation in the Ephorate’s area (Macedonia and Thrace) traced a wide range of structural mortar mixtures of typical bearing masonries. Those historical masonries are frequently and successfully used in mixed structures e.g. timber (Table 1), metal or concrete framed. These are structural components consisting of natural or artificial masonry units, which are commonly laid with mortar (Table 2, 4). As masonries are usually used for components subjected to compressive loading, they either have to withstand weights in vertical direction (walls, columns) or span across spaces and rooms (arches, vaults (Table 2), domes). They have also a limited capacity to support horizontal loads (earthquake, wind action) and bending moments.

During last decades, though, the efficiency of current masonry systems has been considerably improved in terms of higher allowable stresses and/or refined possibilities of design. This involves a more precise analysis, more demanding constructions, and more standardized materials' production. The key role of local raw materials and know-how both in mortars characterization and in monuments' authenticity preservation is usually undermined by the requirements for using standardized materials in interventions. Since local materials are usually not standardized, a further documentation of the authentic - and also new available materials - is needed, where the lab techniques are very supportive (Table 3, 5). The comparative evaluation of the real structural behavior of modern masonry structures with stiff and brittle mortars and of the traditional masonry systems with soft lime based mortars, in terms of tensile strength, fracture energy and ductility, will help to reduce interventions and preserve authenticity in monuments [1].

Towards this aim, the authentic materials of a monument (binders, aggregates, masonry units etc) should be compared to the local available resources and construction know-how. Local integrated background research - incorporated historical, socioeconomic and technological analysis of local construction practice combined with applied research (in situ, in the lab, and through market study) - of the authentic and available today traditional and conventional raw and building materials should be extremely supportive in questioning and interpreting the documentation data of each monument.

Regarding mortars characterization [9, 10] only the absolutely necessary materials' research is then carried out, based on a step by step cost effective plan of research priorities in search of: a) the hydraulicity (or not) of the binder and its form (dry or putty), b) the (inert or active) aggregate nature (origin) and grading (sieving curve) and c) the mixture proportions i.e. the binder/aggregate ratio (B/Ag) and the water/binder ratio (w/b) [1, 9, 10]. Bearing in mind that there is a general consensus on the positive influence of key technological parameters, such as the proper aggregates selection, their even gradation, mortar's high degree of compaction and its low water/binder ratio (differentiating in lime putties [1]), it is derived that the binder form and type is crucial for the mortar's performance [1].

Integrating this approach in binders research, the bedding mortars of modern monuments of central Macedonia are characterized as: a) earthen or weak lime earthen mortars of C19 (Table 1), b) pure lime mortars rarely combined with (natural or artificial) active aggregates (pozzolan) of C19/C20 (Table 3) and c) lime (pozzolan) cement synthesis of C20 (Table 5). The strong and still alive tradition in the production and use of consistent wet slaked lime putties in Greece has been investigated and interpreted as owing to the plentiful, hard and high calcium limestone deposits together with the efficient, empirically developed, know-how on production processes [2-7]. The laboratory research on lime putty product demonstrated the positive effect of the key missing link of maturation process on the service life of lime mortars [1]. It has been highlighted both scientifically [1-7] and pragmatically that the proper use of homogeneously matured lime putties with high water retentiveness capacity may control competently mortars' porosity, strength development rate and durability [1]. Furthermore, the market research revealed that although Greek SME's have developed a significant local know-how, they are hardly compensate the standardisation push that gradually tends to reduce heterogeneity of limes, in the move from (small scale) local towards (large scale) global markets [3, 4]. Considering that the know-how of the dry high calcium lime production was imported at early 70s, the production of natural (or artificial) hydraulic binders in dry form is never documented in Greece and also that the first cement factory constructed close to Athens in 1902 [2-3], as historical market research suggests, it is derived that most modern standardized dry binders – harmonized to European standards [1, 8] and gradually imported in Greece - are not necessarily the best or the unique answer for our interventions. However, the extent of the imported building materials, since 1830, should be further investigated and evaluated.

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