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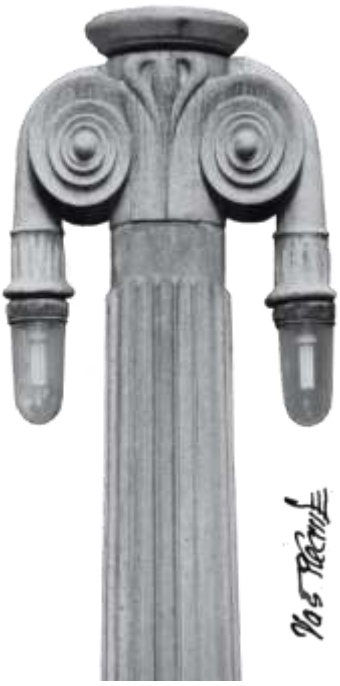

Topic 1: Characterization of historic mortars and masonry structures. Sampling and test methods.

IMPERIAL STYLES, FRONTIER SOLUTIONS: ROMAN WALL PAINTING TECHNOLOGY IN THE PROVINCE OF NORICUM

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Keywords: Roman plaster and paint, pigment morphology and chemical composition, trade in pigments

Abstract: Most of today's Austria (as well as parts of Slovenia and Bavaria) was part of the alpine province of Noricum, formally incorporated into the Roman Empire in the first century C.E. This part of the Alps contained great mineral wealth and controlled many important mountain-passes; as trade flourished the area was quickly Romanized. This is reflected by surviving wall paintings exhibiting high proficiency in plastering technique and utilizing precious and rare pigments. Yet, even in this relatively small section of the Empire, regional differences can be distinguished between the materials and techniques used in the high alpine passes (and northwards) and in the areas closer to Italy. This contribution examines the differences that can be found in roughly contemporaneous Roman wall paintings from Noricum. Cross sections of painting fragments were examined by light microscopy, SEM/EDX and digital image analysis, while the chemical profile of the top paint layers with monochrome and large-scale application of commonly available Egyptian Blue and expensive Cinnabar/Vermillion was determined using in-situ, semi-quantitative elemental analysis by portable XRF. These methods were able to reveal the technical differences in how wall paintings were prepared, from arriccio to final paint application (for example, different methods of producing the intonaco layer(s) and paint layer build-up), as well as which materials were used in which ways, and how these were distinct between two regions and several Roman sites of Noricum. The sites closer to Italia Province, Celeia (Celje, Slovenia) and Flavia Solva (southern Styria, Austria), showed artisanship more closely resembling that used in Pompeii, while those further north, Iuvevum (Salzburg, Austria) and Teurnia (western Carinthia, Austria) evolved a unique style. This finding reflects trade routes and the development of regional techniques in the Alpine area.

A DISCUSSION ON SERVICE LIFE PREDICTION METHODOLOGIES FOR EXTERNAL MORTAR CLADDING IN HISTORIC BUILDINGS

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Keywords: Historic buildings; façade degradation; mathematical models; useful life; indicators

Abstract: The growth of studies in the field of service life prediction and the establishment of parameters described in ISO 15.686 have represented significant advances in obtaining mathematical models for predicting the service life of buildings. The models for studying the degradation of buildings make it possible to estimate the behaviour of the element over time, thus assisting in the economic planning of the maintenance of the asset. However, challenges still arise in determining an accurate and effective method, as there are many uncertainties about the materials and techniques applied and unpredictable variables associated with climate, atmospheric pollution, temperature, among others. Particularly, for historic buildings, the difficulty lies in the need for additional studies that provide data on the deterioration mechanisms acting on these structures, guidelines that include detailed examples of the application of these estimates, a reference database of the useful life of the components and materials used in historic buildings. Among the various parts of the structure of historic buildings, the façade is the element most exposed to the mechanisms of degradation and most visible. Therefore, even if the pathological damage presented in this element does not present a danger of structural failure or progressive collapse, the esthetic damage to the building and the loss of its heritage is evident. In this case, the study of the degradation of external mortar coatings of historic buildings is important and justified by the need for heritage preservation and the increase of information that characterize and complement data about these buildings. For this reason, this paper discusses different methodological approaches used to study the service life of building elements, in particular the degradation of mortar coatings of facades of historic buildings. For this, a state-of-the-art of developed mathematical models is presented with the objective of identifying the main variables or indicators of the models, and confronting them with the indicators of characteristics and performance criteria of the facades of historical buildings. With this, it is expected to contribute with adjustments so that these mathematical models of service life prediction can be applied to historic buildings with greater reliability.

STUDY OF FIRST CEMENTS OF BOULOGNE-SUR-MER USED IN AN HISTORIC AQUEDUCT FROM THE XIXTH CENTURY

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Keywords: Natural cement; Portland cement, optical (OM) and scanning electron microscopy (SEM)

Abstract: Natural cements are generally considered as the first cements used as binders in concrete but their widespread usage was short-lived as they were quickly replaced by artificial cements (Portland), still the most important and predominant today. The Boulogne-Sur-Mer area in the North of France is one of the cradles of the French cement industry, where the first French natural cement was produced in 1802 and the first French Portland cement in 1853. Very quickly, the cements of Boulogne, natural and artificial, know a national and international fame. They have the confidence of the administration which uses them especially in hydraulic works and works of art: docks, sewers, bridges, foundations, railroads. This paper presents a case study of a XIXth century aqueduct, still in operation, with a focus on the binder identification of concretes and mortars. This aqueduct was built with Boulogne-Sur-Mer cements, in 1865 at the request of Napoleon III (1808-1873) to carry water from the North-East of Parisian area to Paris. Because of lack of knowledge and data on cements from Boulogne-sur-Mer, several combined techniques (OM, SEM-EDS, XRD) were carried out to characterize and to determine the composition of the binders present on the aqueduct. The residual anhydrous grains of the binder were identified on polished sections: by optical microscopy (OM) and scanning electron microscopy (SEM) coupled with elemental analysis (EDS). Phenolphthalein tests in order to evaluate the depth of carbonation of the concrete were carried out, knowing that only the presence of non-carbonated zone in a concrete allows to find the original hydrated phases of the hydraulic binder. The hydrated phases of the concrete, resulting from the hydration of the cement, and the products of alterations (salts) were observed by SEM on raw fracture. Then, the crystallized phases of the different concretes collected were identified by X-ray diffraction. The XRD analyses are performed on ground cement paste powders, obtained after separation of the cement matrix from the aggregates by sieving. Several concrete and mortar samples, from pinkish to greyish colors, were taken from the outer and the inter part of the aqueduct. Results of analysis show several clinker morphologies and compositions, and different types of hydrates phases. These results reveal also important differences in terms of microstructure between natural cements and Portland cement, dated from an early period of the cement industry in France. The concomitance of the use of natural and Portland cement, and the good durability of these materials, highlight the know-how of engineers in the 1860's on cements performances and characteristics

CHARACTERISTICS OF BYZANTINE PERIOD LIME MORTARS AND PLASTERS FROM ANAIA CHURCH (KADIKALESI)

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Keywords: Lime mortar, pozzolan, Byzantine mortar, characterization, Anaia

Abstract: Hydraulic, mechanical, and microstructural properties of lime mortars produced by using pozzolanic aggregates provided stability and durability especially to water-related structures; and also enabled the invention of different structural forms like arches, vaults, and wall constructions with facings. Lime-pozzolan mortars were used by many different civilizations like Romans, Byzantines, and Ottomans for centuries until the invention of modern cement. This study aims to determine the characteristics of Byzantine period lime mortars and plasters from Kadıkalesi, Anaia Church in Western Anatolia (Turkey). Anaia Church which was built in 5-6th centuries (Early Byzantine period) had been severely damaged by several earthquakes throughout its history. As a result of these damages, extensive interventions had been done between the 11-13th centuries (Middle Byzantine period) and the 13-14th centuries (Late Byzantine period). Sampling was carried out to compare these periods and to investigate the continuity of lime mortar technology. Results will also contribute to future conservation studies on the site. 6 lime mortar and 5 lime plaster samples were taken from cistern I, cistern II, naos, outer narthex, and substructure of Anaia Church. Mortars were produced with natural aggregates and plasters with brick aggregates. Experimental studies were carried out to determine the basic physical properties, raw material compositions, and hydraulic properties of lime mortars and plasters; mineralogical and chemical compositions, microstructural properties of binders, aggregates, and limes; pozzolanic activities of aggregates via standard test methods, XRD, SEM-EDS and TGA. Analyses revealed that mortars were slightly denser and less porous than plasters. The raw material compositions defined by lime/aggregate ratios by weight ranged between 5/4−3/1 in mortars, and between 1/1−2/1 in plasters. The basic physical properties and raw material compositions of mortars and plasters did not differ between periods. High calcium lime (97−98% CaO) was used in the production of all mortars and plasters. Natural aggregates were mainly composed of quartz, albite, anorthite, muscovite, and wollastonite; whereas brick aggregates were mainly composed of quartz, albite, anorthite, muscovite. The absence of high-temperature minerals in brick aggregates indicated that they were manufactured at temperatures not exceeding 950oC. All aggregates consisted of higher amounts of SiO2, Al2O3, Fe2O3, and lower amounts of CaO, K2O, MgO, Na2O, and TiO2. Natural aggregates were classified as rhyolite and mostly dacite according to their chemical compositions. No significant difference was determined in the comparison of the chemical compositions of brick and natural aggregates within themselves. This was interpreted as raw material sources had been continued to be used in different periods. All aggregates possess highly energetic pozzolanic properties. Mortars and plasters from all periods were found hydraulic which may be attributed to the pozzolanic character of aggregates. Reaction rims were determined at the lime-aggregate interfaces which were free from microcracks or irregularities via SEM-EDS. This study revealed that the lime mortar and plaster properties of the Anaia Church, a Byzantine structure with different construction periods, remained unchanged through the centuries. Lime mortar and plaster production with similar raw materials and characteristics shows the consciousness that was continued during the Byzantine period.

THE DECORATIVE PLASTERED RELIEF IN THE BAROQUE VILLA OF THE ARGOTTI BOTANIC GARDENS, FLORIANA, MALTA: CHARACTERISATION OF ORIGINAL MATERIALS AND TECHNIQUES

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Keywords: Plastered relief, Baroque, plaster characterisation, PLM, SEM-EDX

Abstract: The Maltese Lower Globigerina Limestone is a soft and easy to carve stone, which was and is continuously used on the Maltese Islands (including Malta, Gozo and Comino) for building, from the Neolithic Temples until the modern day (Cassar 2010). Locally, architectural decoration in historic buildings, from low to high reliefs to sculptures, is widely made of such limestone. On the other hand, little is known about plastered reliefs (or 'stuccos') from a material point of view. Studies have focused so far on plastered reliefs in Malta from the XIX and XX c. (Attard 1999, Agius 2014, Spiteri 2015), but they concentrate on art historical and stylistic aspects. The present study focuses on a plastered relief found in the Baroque Argotti Villa, located in the historic Argotti Botanic Gardens, the layout of which dates back to the Knights' period in Malta (1530-1798) and which are situated in Floriana, a town adjacent to the capital city of Malta, Valletta. After having acquired the property, in 1774 the knight Argote et Guzman (Argotti) erected a palace, grottoes and pavilions (Crosthwait & Ellul. 1997, p.29). It is possible that also the Villa was built at that time, but so far just a terminus post quem (after 1715) and a terminus ante quem (before 1827) can be given. The plastered relief in the Argotti Villa, Baroque in style and featuring a rope motif and scallop shells, had not been previously studied. Examination of the original technology and analysis of the original plaster materials were performed, including paint layers present on the relief. This decorative relief is built layer by layer in situ, on the stone primary support, with more than one support system anchoring it to the wall. A total of three main plaster layers were observed to make up the relief, and several overlapping paint layers. Remains of painted plaster above the relief and in the lower register ('dado') suggest the possible presence of a past wider decorative scheme. Examination on-site was complemented with analyses of samples taken from the relief. Unembedded samples were investigated with a stereomicroscope, and subsequently cross- and thin sections were analysed under a Polarized Light Microscope (PLM) and a Scanning Electron Microscope (SEM) combined with Energy Dispersive X-ray Analysis (EDX), with which elemental analysis and mapping were performed. This also allowed to identify crystallised salts in the plaster, driving deterioration of the relief. The plasters are composed of carbonated lime as the binder. Aggregates are of different nature: mainly carbonatic aggregates (possibly from local Maltese limestone, showing fossils), but also gypsum aggregates and to a much lower extent silicate-aluminate aggregates. The dating of the plastered relief is still unknown and further research is required to gather more information on this. This study can hopefully lead to a more systematic survey and research into Maltese plastered reliefs, the study of which is still in its infancy.

PLASTER CHARACTERISTICS OF BYZANTINE WALL PAINTINGS IN WESTERN ANATOLIA

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Keywords: Byzantine wall paintings, lime plaster, intonaco, post-iconoclastic

Abstract: Wall paintings are artworks that are widely used in all cultures and communities. Beside the cave paintings, from Neolithic period to present day, wall paintings were applied on plaster layers of different origin that integrates them to architectural space. In this study execution technique and material characteristics of the plaster layers of Byzantine wall paintings from three archaeological sites (Anaia, Olympos and Aigai) from western Anatolia were determined to provide information for their conservation and fill the gap in the literature about the technique and material use in Byzantine wall paintings in western Anatolia. This study is a part of a more comprehensive study that focused on the material characteristics, painting technique, pigments, and deterioration problems on Byzantine wall paintings. Through the study, mineralogical and chemical composition of the plaster layers of wall paintings were determined by Scanning Electron Microscope coupled with X-Ray Energy Dispersive System (SEM-EDS), X-ray diffraction analyses (XRD). Reflected Light Microscopy (RLM) and SEM studies conducted on polished cross sections of samples revealed the stratigraphy and microstructural properties of plaster layers of Anaia Church (4th-12th centuries), Başpınar Church (13th century) in Olympos and Byzantine Chapel (13th century) in Aigai. Through the research, pure lime and aggregates in the plasters of Aigai, magnesium rich lime and straw in the plasters of Anaia and Başpınar have been determined. Plasters of Anaia and Başpınar Churches represent similar characteristics with the samples from post-iconoclastic period by means of raw material use. In samples of Aigai, plastering practices pointing to earlier dates such as marmorino, intonachino, and cocciopesto are observed. Fine plasters are composed of a single layer in samples from Anaia. In Başpınar Church and Aigai Chapel, superimposed plaster layers were observed. Material quality and workmanship of the walls may be the reason for this difference. Another possible explanation may be to provide the conditions required for the technique of the painting supported by the plaster. Determination of secco technique on thin and single layered plasters, while fresco technique on thick and multi-layered samples supports this. In the XRD patterns of the samples from the Anaia Church and Başpınar Church, CaCO3 in calcite, aragonite and vaterite forms, diopside, and quartz were detected. Quartz peaks are due to small amounts of aggregates present in the plaster. Polymorphs of calcite may be formed as a result of self-healing of plasters in the presence of magnesium. Mineralogical compositions of the plasters of Aigai show differences depending on the type of the aggregates. In marmorinos, sharp calcite peaks derived from carbonated lime and marble aggregates were detected. In Intonachino and cocciopesto samples, quartz, albite and andesine due to aggregates and calcite due to carbonated lime were detected. As a result of this study, it has been determined that the number and characteristics of plaster layers used in the paintings were applied consciously in accordance with the technique of the painting. Plaster characteristics of wall paintings in western Anatolia in Byzantine period were determined to be similar with the ones in İstanbul, Balkans, Crete, and Cyprus. Results of this study will guide the conservation efforts of the wall paintings.

DECOMPOSITION TEMPERATURE OF CALCIUM CARBONATE IN LIME BINDERS AGED AT ELEVATED CARBON DIOXIDE CONCENTRATION MONITORED BY TGA/MS ANALYSIS

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Keywords: thermal analysis, CSH carbonation, CaCO3 decomposition, TGA/MS

Abstract: Calcium carbonate is the main component of lime binders, and the determination of its content is the basis of the chemical-mineralogical analysis of historical mortars. Thermogravimetric analysis is used very effectively for this purpose. In addition to the small amount of sample required for analysis, the advantage is the easy sample preparation and the short measurement time. However, interpretation of the data may be hampered by multiple components or by ambiguous identification of the mineralogical form. Combining thermal decomposition with analysis of the gases released from the decomposed substance by mass spectrometer allows refinement of the analysis results. The study is focused on monitoring the decomposition temperature of calcium carbonate of various lime binders exposed to the conditions of accelerated aging. The samples were exposed to 1% CO2 and periodically saturated with water for 540 days. After 180 and 540 days, thermal analysis was performed to monitor changes in the mineralogical composition of the binders. The content of calcium carbonate decomposing in the temperature ranges 450-650 ° C (CO2 I) and 650-850 ° C (CO2II) and the content of chemically bound water (100-450 ° C) were determined. The obtained results showed that four of the six binders did not show significant changes in any parameter. This indicates the resistance of the binders to both carbon dioxide and water, probably due to the fact that the hydrated phases were carbonated before the start of the experiment. Thus, the chemically bound water probably does not come from the dehydration of the CSH phases but is released from the silica gel, which is the product of their carbonation. At the same time, it was found that the value of the CO2II / CO2I ratio is related to the quality of the lime binder (the proportion of hydrated phases). Accelerated aging of two binders significantly changed the thermal analysis curves. These were experimentally burned binders - natural hydraulic lime and Roman cement. The different behavior of the two mortars is probably due to the different particle sizes of the binders associated with the technological processes in production.

CZECH MOSAIC PIONEER VIKTOR FOERSTER AND THE MORTARS OF HIS MOSAICS

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Keywords: mosaic, mortar bed, Viktor Foerter, SEM-EDS, thermal analysis, x-ray powder diffraction

Abstract: The application of mosaics to architectural structures spans centuries from antiquity to the present. Materials research of modern European mosaics still remains in the shadow of attention given to their ancient or Bysantine predecessors. Understanding the technique and materials of modern mosaics can lead to better conservation treatment of such artworks. In order to propose a good conservation strategy it is necessary to study how mosaic cubes (tesserae) are fixed together. This paper deals with the characterisation of mortar beds applied to several mosaics designed by Czech mosaic pioneer, Viktor Foerster (1867-1915). Foerster opened the first original mosaic studio in the Czech Lands at the beginning of the 20th century. He created both profane and church or funeral mosaics. Mortar beds of five of his exterior mosaics have been characterised by microscopic techniques (SEM-EDX, optical microscopy), thermal analysis and x-ray powder diffraction. In the studied artworks, Foerster did not keep the traditional technique of lime mortar beds. To fix some of his mosaics he used cocciopesto technique (Lauschmann family sepulchre, mosaic of Christ the Good Shepherd). In the samples of other mosaics´ mortar beds the residues of Portland clinkers have been found

A STUDY ON HISTORIC MORTARS FOR RESTORATIVE APPLICATIONS IN PERSEPOLIS WORLD HERITAGE SITE: CURING IN SITE VS LABORATORY

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Keywords: Air lime, Organic additives, Restorative mortars, Hydrophobicity, In-situ application

Abstract: Two types of air lime mortars with inclusion of sesame cooking oil were synthesized. The behavior of mortars in the site conditions and the laboratory can be distinct. Hence, the mortars were cured in laboratory and natural climatic conditions of Persepolis World Heritage Site. The mortars were monitored for two years under both conditions and the results demonstrated distinctions in characteristics of mortars, emanating from curing conditions. The air lime mortars cured in the site conditions exhibited increment in durability and hydric properties. In the natural outdoor conditions, some effects of addition of organics to mortars, such as retarding their setting time were less highlighted compared to laboratory curing mortars.

MAKING ANCIENT MORTARS HYDRAULIC. HOW THE COMPOSITION INFLUENCES TYPE AND CRYSTALLINITY OF CALCIUM-SILICATE AND CALCIUM-ALUMINATE HYDRATES

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Keywords: cocciopesto, volcanic glass, organic ash, C-S-H, C-A-S-H, C-A-H

Abstract: It is well known that the hydraulic characteristics in a lime-based mortar are primarily determined by the occurrence in the raw materials of a variable amount of reactive silica (SiO2) and alumina (Al2O3) that, in presence of water, interact with lime (CaO) to form different reaction products. The target of this research is the analysis and comparison of the characteristics and structure of calcium-silicate and calcium-aluminate hydrates in ancient mortars. We studied by optical microscopy, QPA-XRPD, SEM-EDS and NMR spectroscopy several mortar samples from the sites of Aquileia (Northern Italy), Nora (Sardinia) and Pompeii (Naples), having different composition and collected from structures with different function (i.e. water-tanks revetments, foundations, floor beddings). We examined aerial lime mortars rich in natural and artificial pozzolanic aggregates (volcanic glass, organic ashes, terracotta fragments) and natural hydraulic lime mortars produced by the calcination of cherty limestones. Through OM and SEM-EDS investigations, we detected reaction edges around the pozzolanic aggregates and we investigated the chemism of reacted areas. By QPA-XRPD, we described and quantified type and amount of hydrated crystalline phases. We finally performed NMR investigations to parameterize the pozzolanic character of mortars by observing the degree of polimerization of silica and alumina. Crystalline AFm, having hydrocalumite-like structure, are the most common reaction products we detected in alumina-rich mortars, as the cocciopesto ones. Crystalline Al-tobermorite (tobermorite 11Å) and ettringite have been detected only in those mortars having abundant and finely ground terracotta fragments, while in coarser ones these phases were not attested as C-A-S-H/C-A-H phases, if present, probably maintained a prevalent gel-like structure. Volcanic glass-rich and organic ash-rich mortars display similar features than cocciopesto ones, as tobermorite 11 Å and AFm phases were observed. The only samples in which we detected the formation of pure C-S-H are lime mortars having abundant concentration in the system of free reactive silica and low alumina. These are all the natural hydraulic lime mortars from Aquileia produced by the calcination of cherty limestones. In these samples, crystalline C-S-H is structured in the form of tobermorite 14Å or jennite, a Ca-rich C-S-H (Arizzi, Cultrone 2021), while little AFm was detected. Coupling QPA-XRPD data, NMR results and the HI index of samples, determined by semiquantitative SEM-EDS microanalysis, we evaluated the hydraulic capabilities of the mortars and compared the different recipes. The best ones are those produced for the impermeabilization of structures or those subjected to relevant loads (i.e. foundations). On the other hand, mortars employed in mosaic beddings and wall joints display a feeble hydraulic character. This demonstrates an high knowledge of the properties, mixing and treatment of raw materials. The variable “quality” of the recipes probably was also influenced by the specialization of crafts, as the best hydraulic mortars are those collected from structures of public buildings, i.e. thermae or urban fortifications.

PHYSICO-CHEMICAL CHARACTERIZATION OF HISTORIC MORTARS FROM THE VENETIAN ARSENALS OF CHANIA (GREECE)

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Keywords: Arsenals, Venetian, Ottoman, air-lime, hydraulic, decay

Abstract:The Venetian Arsenals of Chania in South Greece constitute an important monument of cultural and industrial heritage, as well as a key landmark for the town. The Arsenals were elongated vaulted buildings where galleys were constructed or served as storage places from the 15th until the end of the 16th century. In Chania, the Arsenals had a peculiarity as they were built by stone and mortar in contrast with the typical Arsenals of Venice with wooden roof with tiles. After the Ottoman occupation, various interventions were established. Nowadays, the monument is a complex of 7 remaining Arsenals out the total 17 constructed by the Venetians. In the framework of the holistic study for the restoration of the building, various mortars were extracted and analyzed in order to identify the construction phases and evaluate the decay of the materials. The proximity to the sea, as well as the intense north winds play a crucial role in the decay of the materials. The samples were extracted in a gentle way without causing any destroys to the monument, trying to cover various parameters such as the interior or exterior exposure, the orientation, the origin, i.e. Venetian, Ottoman or newer. The open porosity, the bulk density and the w.t. % of soluble salts were identified. Additionally, the mortars were chemically and mineralogically characterized though elemental analysis XRF, infrared spectroscopy FTIR, thermographic analysis DTA/TG and X-Ray diffraction to determine the corresponding building technology and the composition of the raw materials. Furthermore, the granulometric analysis and the optical microscopy study provided information about the size of aggregates used and the consistency of the mortars. The results of the analyses lead to the classification of historic mortars into 3 main groups; the 1st group includes the air lime mortars, the 2nd consists of the moderately hydraulic mortars and the 3rd of the hydraulic ones. The original Venetian mortars seemed to have good consistency and excellent coherence with the building stones. The Ottoman mortars, on the contrary due to their poor consistency, have suffered the greatest decay. Finally, the most recent interventions seemed to be inadequate as well as incompatible, thus failing to protect the monument's masonry. This research will lead to the substantiated proposal for the design of the restoration materials, thus ensuring the sustainable performance of the monument.

ANALYSIS OF THE BEHAVIOR OF ORIGINAL AIR LIME MORTARS USED IN STRUCTURAL BRICK MASONRY WALLS OF ANCIENT BUILDINGS

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Keywords: Air lime mortars; Resistant masonry walls; experimental characterization

Abstract: The growing interest in preserving the built heritage is a driving force on the search for new rehabilitation solutions compatible with the original construction techniques of these buildings. In order to choose an adequate reinforcement solution it is necessary to know in detail the typology, as well as the original constructive solutions and materials of the building to be rehabilitated. In Portugal, as in many other countries, in the masonry walls of ancient buildings, prior to the advent of reinforced concrete, air lime was used both as laying mortars and wall coatings. The old lime and sand mortars functioned both as an element of the structure, joining the stones or the bricks, and as coatings, for the protection of masonry. In coatings' external fine layers they could also have a decorative function, imitating noble materials such as marble or tiles. Wall coatings, due to their great exposure to external actions and their role of protection of masonry, are very subjected to degradation and therefore they are frequently included in the rehabilitation interventions. However, the same reasons that lead to repair or replace them, also justify great care in these interventions, and a sound knowledge of the constitution and behavior of old coatings is fundamental. The characteristics of the laying mortar have a very significant influence on the overall behavior of the masonry wall, as they influence the strength and the collapse mechanism of the wall itself. This aspect is particularly important when the masonry walls are demanded in their own plane, in shear, especially due to seismic actions. In this paper, the results of an experimental campaign on samples of air lime-based laying and coating mortars, removed from an old masonry building in the historic center of Lisbon, built in 1910 and currently undergoing rehabilitation works, is presented. The different parameters analyzed allow the compositional characterization and evaluation of their mechanical, physical and chemical properties. In this context, the following tests are performed: X-ray diffraction, thermogravimetric analysis, compressive strength, modulus of elasticity, water absorption by capillarity, open porosity and apparent bulk density. Based on this characterization, the influence of these mortars on the overall behavior of load-bearing walls of buildings belonging to the typology in study is also evaluated, by performing compressive strength tests and diagonal compressive strength tests of wall specimens.

MINERAL, CHEMICAL AND PETROGRAFIC CHARACTERIZATION OF HYDRAULIC MORTARS & CHRONOLOGICAL BUILDING CORRELATION OF THE BATHS OF PORTA MARINA IN OSTIA ANTICA (ITALY)

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Keywords: Roman pozzolan, Petrography of volcanic aggregates, Ancient Roman mortars, Coating and bedding mortars, Ostia Antica, Porta Marina

Abstract: The Baths of Porta Marina (Regio IV, X, 1) are located in the maritime suburban district of Ostia (city harbor of Rome, Italy) and they were an imperial public complex built during the city expansion in its economic apogee in the 2nd century AD. During its large period of use – from the thirties of the 2nd century AD till at least the beginning of the 6th century AD – several modifications of capacity and of thermal path took place, resulting in architectural modifications. Previous studies based on archaeological evidences, written sources (such as epigraphic documentation) and architectural and stratigraphic analyses have provided thorough chronological data for construction phases. Characterization of hydraulic mortar coatings has been carried out in order to look into waterproofing processes of antique hydraulic facilities and propose a timeline of raw materials uses for this particular building. Mineralogical, chemical and petrographic analyses (such as X-ray diffraction, SEM-EDX and Raman spectroscopy) were performed on several samples from pools and cisterns from different construction phases of the baths of Porta Marina. They confirm that mortars of Roman waterproof coverings, made with pozzolanic aggregates, show a persistent composition over centuries, hardly distinguishable macroscopically. Nonetheless, petrographic examination of volcanic aggregates used in the mortars has been an interesting tool to highlight differences among the samples. Volcanic components were examined considering specific characteristics such as vesicle shapes, color of glassy matrix, nature, occurrence and development of minerals (phenocrysts), degree of alteration and secondary minerals. All materials present within the aggregates (such as limestone and dolomitic fragments and associated volcanic rocks) have been also considered. Some distinctive features of volcanic aggregates allow us to identify different depositional units from Alban Hills volcanic district as sources. The same study has also been performed on bedding mortars from pools' masonry to correlate the used raw volcanic materials to construction phases. In summary, the present study aims to confirm or precise the chronological link, in the construction phases, between coating and masonry at the baths of Porta Marina, in addition to bring out specific data on mortar composition and specify provenance on volcanic raw materials employed in Roman hydraulic mortars.

CHARACTERIZATION OF LIME MORTAR AND PLASTERS OF THE FORTRESS OF CONCEPCION DE LA VEGA, FIRST MINING TOWN IN AMERICA

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Keywords: Lime mortar, Plaster, Fortress, 16th century, La Vega, Dominican Republic

Abstract: The arrival of Christopher Columbus in America supposed the creation of new settlements in which materials and construction methods coming from Spain and those existing in the area were used. Those first sites were built in the Hispaniola Island (today Dominican Republic and Haiti), so it is of great importance to know the materials and methods used in that area. The first village was La Isabela established by Columbus in 1494, where the Spaniards found good limestone for ashlars and to make lime, as well as good clay for earth-walls, masonry walls, bricks, and tiles. There was also plenty of wood to make beams and feed the kilns. The Europeans built in the Hispaniola the first lime kiln and made the first lime mortar and plaster in the Caribbean, because the indigenous people who inhabited the islands did not use lime in their constructions, which were all based on vegetable materials. After La Isabela, the cities of La Vega (1495) and Santo Domingo (1498) were established, where kilns, mortars and lime plaster were also made. These villas still have vestiges of these building materials that are a source of information to know their composition. In this occasion, the study is focused on the fortress of Concepcion de La Vega, located in the second European settlement and first mining town in America that was established by Christopher Columbus in 1495 and relocated in 1504 at its current location, about 2 leagues from the original site. The city had a fortress, a gold foundry, a church that later became a cathedral, as well as houses and a monastery. At present, only ruins remain because an earthquake in 1562 destroyed the city, leaving only part of the fortress and some walls of the church and of other buildings. For this reason, the aim of this research is to characterize the mortar and plasters of the fortress of Concepcion de La Vega in the Hispaniola Island. To determine their chemical and mineralogical composition, was used X-ray Diffraction (XRD), Fourier-transform infrared spectroscopy (FTIR), Raman and Thermogravimetry-Differential Thermal Analysis (TG-DTA) were used. The results showed that most of the mortars had CaCO3 as the major component, which indicates that they are lime plasters. Additionally, a microstructural and colorimetric study was carried out to complete the characterization.

CHARACTERIZATION OF NATURAL CEMENT IN THE BUILDINGS OF THE BEGINNING OF 20TH CENTURY IN PORTUGAL: CASA BARBOT

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Keywords: Natural cement; historic buildings; 19th and 20th century; architectural heritage

Abstract: Natural cement was the main binder used in the majority of buildings in Portugal from the second half of 19th until the beginning of 20th century. Natural cement (also referred to as Roman Cement) was patented in 1796 by Reverend James Parker, by calcination of high clay content marls without changes in the composition after extractions. These cements were produced at lower temperatures than that of Portland cement which might leave some gains unburned due to nonuniform heating. This may result in high diversity in the characteristics of Natural cement from one case to another. Therefore, understanding the true type of binder used in the historic buildings will help the conservation engineer make the best decision on the development of compatible mortar for historical conservation purposes. The present paper studies one of the stylish cultural houses in Vila Nova de Gaia, Porto, known as Casa Barbot which was built by Bernardo Pinto Abrunhosain in 1904. The paper aims at investigating the characterization of Natural cement used in the construction of cave, arbor, dovecote and other elements in the garden of this palace using several techniques. The samples are collected from the parts that had fallen or removed from the structure. The samples are carefully inspected in terms of detecting different applied layers and then are prepared for the tests. The experimental results are presented in terms of chemical composition and phase identification of cement in the mortar samples using analytical tools such as XRF and XRD. Mineral components, textures and microstructure of hydrated and unhydrated binder, the porosity and type of aggregates used in the mortar and their proportion in the mortar composition are studied using petrographic analysis and SEM.

CHARACTERIZATION OF OLD MORTARS FOR THE FORMULATION OF REPLACEMENT MORTARS

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Keywords: Characterization of mortars

Abstract: The exterior coatings of old buildings were mostly made with lime-based mortars. As coverings for the external facades of buildings, they are elements that are highly exposed to several actions such as climate actions, mechanical actions, etc., and therefore, they are the first ones to need conservation, rehabilitation or replacement interventions.
The conservation, rehabilitation or replacement of lime-based coatings are actions that involve the complicated task of choosing a new mortar that should not only be compatible with the existing mortar, but also compatible with the substrate itself.
There are two possible ways to properly choose the mortar to use, whether you choose to reproduce the old mortar, thus seeking to ensure its compatibility and its proper functioning or you formulate a compatible mortar with an adequate behaviour for the building in question, with an appearance that preserves the building's image.
In practice, the first way is impossible on its own as it is not yet possible to accurately determine the "evolution" of the mortar (dynamic processes in constant evolution - crystallization, dissolution and recrystallization, etc.) and it is also difficult to identify the technologies used in its execution and application and we are also unaware of the climatic conditions that may have influenced the curing process. The ideal will be a process involving the two mentioned ways.
For this, the first task should be to know the characteristics of the existing mortars and then select a similar mortar with an adequate behaviour for the building.
What is presented in this work is a campaign carried out in order to choose replacement mortars for several old buildings located in the centre of Portugal. For this, the existing mortars were characterized, suitable replacement mortars were selected and applied to the existing buildings. After they had been cured, an in-situ experimental campaign was carried out in order to assess the suitability of the chosen mortars for the walls of the buildings.

CHARACTERIZATION OF "TERRANOVA" RENDER SAMPLES AS A CONTRIBUTION TO XX CENTURY HERITAGE CONSERVATION

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Abstract: The "Terranova" render was a ready-mix dry render which diffused mostly in Europe during the 1920s and 1930s as a finishing solution for the façades of rationalist architecture. It quickly became very popular thanks to its excellent aspect (many colours and surface finishings were available) and high durability (even when exposed to direct rain). Despite its wide diffusion, its formulation and technical properties remain basically unknown, also due to some patents protecting it. Due to this general lack of knowledge, Terranova renders are often not recognized in restoration interventions and mistaken for normal 'out of fashion' cement renders, hence they are frequently demolished and substituted with commercial renders that seldom exhibit the same compatibility and durability.
In this study, different samples of supposedly Terranova render were collected in three rationalist buildings in Ferrara and Forlì (Italy) and a thorough characterization was carried out to investigate their formulations and features. A comparison was also made with a Terranova sample collected from a building in Bologna (Italy), characterized in a previous study.
The results highlight that some common features exist among the renders, indicating the presence of dolomitic compounds in the binder and air voids in the mixtures, but there are also differences, which could suggest that alternative formulations were used in the manufacturing of this industrial render.

PRE-SCREENING OF LIME MORTARS FOR 14C DATING – PRELIMINARY RESULTS

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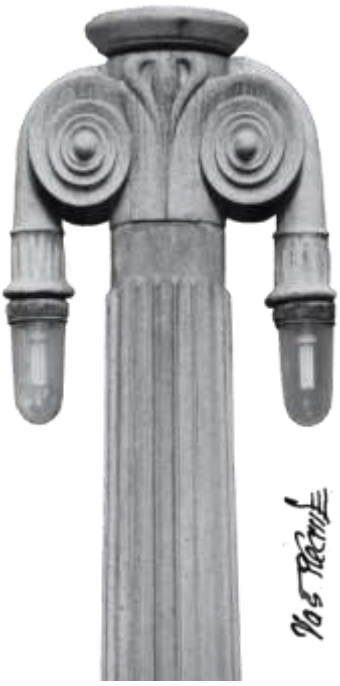
Keywords: Lime mortars, AMS radiocarbon dating, stepwise acid hydrolysis, thin section petrography, FTIR spectroscopy

Abstract: Radiocarbon dating of anthropogenic lime carbonates such as lime-based mortars was first developed in the 60's on the basis that 14C decay should act in the same way than for living organisms after their death. These first results were very promising and the authors already pointed out that microscopic observations should be performed to check out the eventual presence of Foraminifera (microfossils) susceptible to false the date result, since they are made of very ancient carbonates. Foraminifera and other types of carbonates can be present in lime mortars because of their formation process and possible subsequent weathering. For this specific reason, even though some datings have been successful, other tests have failed, and the process remains intricate. Reference materials such as charcoal dated with 14C or roof frames allowing dendrochronology and contextual information are needed to confirm the 14C dates obtained for a mortar sample. In addition, using stepwise acid hydrolysis to date lime mortars, several CO2 extractions, graphitisations and AMS datings need to be performed. The overall process is time and cost consuming and hence developing a pre-screening protocol to select samples which could give reliable results is of great interest. For this, the knowledge about AMS radiocarbon dating and mortar characterisation need to be combined, which is the objective of this research project. Techniques such as thin section petrography, Fourier Infrared spectroscopy, simultaneous thermal analyses, cathodoluminescence, etc. are being implemented on samples having a well-known context and, if possible, containing organic material suitable for 14C dating. Based on the results provided by these different analysis techniques, we try to identify for each mortar sample all the possible contaminations and/or processes able to disrupt the 14C dating of the initial carbonation (i.e. presence of underburned or overburned lime lumps, fossil carbonates in the aggregate, secondary carbonate deposits, dissolution, etc.). The archaeological sites and monuments investigated have various ages and are mainly from Belgium.



Topic 2: Historic production, processing and application of mortars, renders and grouts. Lime technologies.

ATLAS OF TRADITIONAL LIME KILNS IN THE SPANISH TERRITORY: SETTLEMENT, CONSTRUCTIVE TYPOLOGY AND PRODUCTION PROCESS OF LIME AS A HISTORICAL MATERIAL

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Keywords: traditional lime kilns, Spanish geography, constructive typology, production of lime, heritage situation

Abstract: The irruption of Portland cement and its widespread use since the second half of the last century in the Spanish territory, caused a decrease in the production of lime in a traditional way. The disappearance of this production process and, consequently, of the lime activity has led to the loss and/or abandonment of lime kilns in many towns. Along with them, the knowledge and know-how linked to the production of this material is also forgotten. Throughout the Spanish geography there are still visible remains of artisan lime kilns that supplied, in an earlier time, such a versatile material as lime, whose use is very varied: construction, whitewashing of walls and trees to protect them from insect attack, as a disinfectant against epidemics and in burials, material for medical purposes, among other multiple applications. These kilns are testimony to a vernacular architecture that shows a clear organization of work and space through the construction of outbuildings closely related to the work of the lime workers. Its analysis will be carried out by means of bibliographic and audiovisual documentation and testimonies, as well as the use of architectural drawings in order to recreate the volumes of the original architectural structure of the lime kilns. This work aims to establish a reference about the place of settlement, constructive typology and production process of the traditional kilns (raw material used, "assembling" of the kiln, firing of the limestone, tools and materials used, cooling and emptying of the kiln, and slaking of the lime) in the three geographical regions into which the country is divided: northern, central and southern peninsular area, including the Balearic and Canary Islands archipelago. The study will include the different types of kilns in each region, creating in parallel a glossary of terms associated with lime activity. In addition, it will make it possible to observe their heritage situation and the different conservation and/or safeguarding actions that have been carried out in order to maintain such a living historical tradition as the production of lime.

FROM HIGH-PERFORMANCE POZZOLANS TO PROTO CEMENTS: 1500 YEARS OF HYDRAULIC BINDERS IN PADUA AND ITS SURROUNDINGS

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Keywords: Padua, Pozzolanic reaction, Natural hydraulic lime, Calcium-silicate-hydrate (C-S-H), Rietveld quantitative phase analysis

Abstract: Located in north-eastern Italy, the city of Padua gained importance in the Roman Republican age, becoming one of the wealthiest cities of the region during the Imperial period. After the fall of the Roman Empire, the city flourished in the Middle Ages, also thanks to the establishment in 1222 of one of the first universities in Europe, becoming a centre of crucial artistic importance during the 14th Century, as testified by the occurrence of several cycles of mural paintings by the most renowned artists of the time, recently recognised as UNESCO World Heritage. After the conquest by the Venice Republic in the 15th Century, the city experienced several phases of building expansion during the Renaissance, testified by the construction of one of the better-preserved systems of city walls in Europe.

Due to the unfavourable geomorphological characteristics of the territory, characterized by unstable, heavily water-saturated soils, ancient building technology always pushed for optimizing the composition of structural materials and the layout of architectural structures, to guarantee proper structural stability over time for public buildings and infrastructures.

In this contribution, a comprehensive characterization study was performed on the structural binders employed for the construction of the most important structures of the city and its surroundings, including public Roman buildings (theatres, amphitheatres, temples, thermal baths) and several Medieval and Renaissance defensive systems and religious complexes. Furthermore, Roman maritime concretes were analysed, employed to build marine infrastructures in areas of the Venice Lagoon within the influence of the city.

The materials were studied through an integrated multi-analytical approach developed by the research group, including X-ray powder diffraction (XRPD), magic angle spinning nuclear magnetic resonance spectroscopy (MAS-NMR), and scanning electron microscopy coupled to energy-dispersive microanalysis (SEM-EDS), correlating the compositional and microstructural information with the results obtained from mechanical tests. Furthermore, the reaction kinetics of the binding systems were parametrized through dedicated studies on experimental replicas of the determined mix designs.

The results obtained demonstrated constant research by the ancient crafts of the best hydraulic performance of the structural binding composites, to deliver adequate static behaviour to the structures, without relevant loss of strength due to water percolation and deterioration. This was obtained during Roman times by employing a local, highly reactive volcanic pozzolan, conferring excellent mechanical performances to the manufactured concretes, widely surpassing mean compressive strength values determined so far in materials of similar nature. Then, after the end of Roman domination, a natural hydraulic lime obtained by calcination of local marly limestones started to be employed, with a period of crossover with the previous technology in early Medieval times, and

became the key material for the construction of the Renaissance city walls during Venetian domination.

The detailed studies on the crystal-chemical nature of the hydraulic phases, complemented by a parametrization of the degree of polymerization of silica and alumina in the binding systems, clearly demonstrated from a structural standpoint the advanced degree of optimization of the binding materials, giving novel insights on pozzolanic and hydraulic systems useful to optimize modern formulations of sustainable binders.

CHARACTERISTICS OF TRADITIONAL KOREAN LIME PLASTER AFTER THE ADDITION OF PERILLA OIL

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Keywords: Aerial lime, Organic additive, Perilla oil, Carbonation

Abstract: Aerial lime is traditionally used in various fields such as buildings, castles, tombs, and murals in Korea. However, most of the traditional lime manufacturing and construction method were cut off during the Japanese colonial period and the modernization process. According to the records of the ancient literature, it is confirmed that various organic ingredients(straw, Korean paper, rice glue, oil, etc.) are added to traditional lime depending on the use, but it is difficult to confirm the specific manufacturing method. In this study, aerial lime plaster specimen containing perilla oil was prepared by securing evidence from Oegyujanggak Uigwe(records of the State rites of the Joseon Dynasty) books When perilla oil is added, the flow rate of the lime material is reduced and workability can be adjusted. However, just adding only a small amount of perilla oil will change the color of the lime material. Therefore, it is necessary to control the amount of perilla oil used when adding perilla oil to the lime material used at the site of preservation and repair of cultural properties. In addition, it was confirmed that carbonation of lime material to which perilla oil was added was delayed through neutralization test and μ-CT image analysis. As a result, when perilla oil was added, The strength of lime material at the beginning of curing was reduced. However, lime material added with perilla oil showed an effect on strength improvement after long-term curing. Moreover, the addition of perilla oil imparts moisture resistance. Since freezing and thawing of moisture is the main cause of damage to the lime material, it is judged that the performance of the lime material can be improved by adding perilla oil.

AUSTRO-HUNGARIAN FORTIFICATIONS IN MONTENEGRO FROM THE 19TH CENTURY: MORTAR VARIETY AS A RECORD OF INDUSTRIAL DEVELOPMENT DURING THE 2ND HALF OF THE 19TH CENTURY

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Keywords: Military Fortresses, 19th century, Montenegro, mortar microscopy

Abstract: A number of military fortresses today situated in the Republic of Montenegro had been built between 1853 and 1914 by the Austrian-Hungarian Empire as part of a defensive system to secure their Adriatic fleet based in the Bay of Cattaro (Kotor). After the fall of the Empire in 1918, most of these constructions remained unused and abandoned until today and they preserve valuable information not only about the range of designs of military fortresses in the second half of the 19th century, but also on the building materials of that period which, due to the high strategic importance of the buildings, likely represent the most advanced products of their time. By initiative of the Ministry of Culture of Montenegro, the Austrian Archaeological Institute started an extensive survey of the stock of these fortress buildings in 2018-2019, at first focusing on three sites, namely Kosmač (1858), Goražda (1884–1886) and Vrmač (1894–1897). They are all situated on mountain ridges high above the sea and the Bay of Kotor, they yet implemented different principles of construction. While most of their masonries consist of ashlars of compact local limestones, mortars had been diversely used in all of the sites, either as bedding mortars, as fill material in cavity wall construction, for renders and plasters, and finally in the form of tamped concrete. The surveys performed on these fortresses included analysis of the most relevant building materials to characterize their nature and composition. This was done for a set of mortar samples, using methods of polarizing thin-section microscopy and SEM. The results reveal a number of air lime, “pozzolanic” lime, natural cement, and early Portland cement materials, clearly depending on their use in the building and on the period of construction. Thus, the oldest of the fortresses (Kosmač) contains mainly air lime mortars as bedding of the ashlars, though certain elements were also executed by use of Portland cement, presumably amongst the first applications of this binder in the whole of the Austrian-Hungarian Empire. The microscopic features of the cement clinker in those mortars point to the use of shaft kilns probably using natural cement stones as raw material. Goražda, built 25 years later, on the contrary reveals the use of NHL and natural cement mortars along with Portland cement employed in exterior pointing as well as in tamped concrete. Constructed just 10 years later, i.e., by the turn of the century, Vrmač no longer contains natural cement, thus Portland cement – still produced in shaft kilns – prevails, even in exterior render work. Our contribution aims at a short presentation of the almost unknown fortresses and their principles of construction, followed by a discussion of the mortars by their microstructure and the major binder constituents through microscopy and SEM. The latter will be set in the context of the state of the Austro-Hungarian cement industry, which had experienced a rapid development during the 40-year of construction history of the fortress buildings.

PROCESSING WHILE SLAKING? HOT APPLIED LIME MORTAR AND HOT LIME WASH REVISITED

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Keywords: dry slaked lime, hot applied lime mortar, HAM, lime wash, scanning electron microscope

Abstract:In the past lime was widely used as a binder for masonry structures or for coatings to protect and decorate plaster and render surfaces. Also today this environmentally friendly material that may improve the indoor climate is appreciated for healthy building and restoration work. For the use as building material the burnt quicklime has to be slacked, and normally the slaked lime is stored to cool down and is then processed as mortar or lime wash. Beside this common practice there exists a traditional technique, where the lime is already used during the slaking process. The transformation from quicklime to calcium hydroxide is accompanied by rising temperature, up to more than 100°C, and a volume expansion of about the double. If the binder is processed hot within that chemical reaction it will lead to special properties in the mortar or the lime wash, respectively. Detailed research on historic literature showed that these qualities of hot applied lime mortar (HAM) were well known in the past. They are rediscovered today by some enthusiasts who use lime in a traditional way to obtain unique properties. Empirical assessments of craftsman working with HAM claim a faster development of strength and a higher final strength as well as a better cohesion and water vapour diffusion. These claimed properties of HAM were investigated in the laboratory and could be confirmed by analytical results. However, no evidence for hydraulic reactions with the siliceous aggregate due to the hot environment and high PH-value could be provided. The hot lime washes showed a lower viscosity and offer therefore a better workability. They also develop a higher opacity due to the formation of a thicker layer. All the research was carried out by comparing mortar or lime wash processed in hot and cold condition, mixed and worked in the same recipe and water content. The used binder was a commercial available CL90 quicklime in powdered form. It could be shown that analysing the microstructure of mortar and lime wash by microscopic techniques was crucial to understand the described phenomena. For SEM investigations, the mortars had to be kryo-prepared within several time intervals. The measured physical properties after application can be explained by the crystal shape and size of portlandite and calcite formed at different stages of the reaction.

LIMEWASHES WITH VEGETABLE OILS: WATER TRANSPORT CHARACTERIZATION

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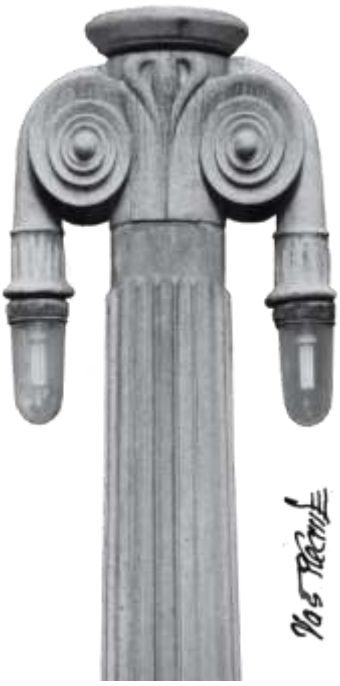
Keywords: lime, additive, water-repellency, hydrophobicity, permeability, durability

Abstract: Limewashes are lime-based paints that have been used since Classical times as finishing coats for walls. Its protective, aesthetic, antiseptic properties and cost-efficiency are the ground for its worldwide application. With the advent of the Industrial Revolution, the use of these traditional paints has been progressively substituted by synthetic ones. However, synthetic paints are not always compatible with traditional porous materials, mainly because they tend to lower the water vapor permeability of the old materials. This aspect may worsen dampness problems and consequently the need for new interventions. Usually, damaged synthetic paints need to be entirely removed before applying a new one, whereas, with lime-based paints, only the damaged parts need to be removed before reapplying new coats. The main drawback of using lime-based paints for the protection of walls is its low durability towards the action of water, particularly wind-driven rain, which mainly results in the loss of cohesion of the paint, e.g., by chalking. To overcome this issue, additives that can improve the cohesion and grant water-repellent properties have been added to these paints since ancient times. Among these additives, vegetable oils have been reported worldwide in ancient documents to improve the durability towards the action of water by imparting water-repellence to the paint. The oils were naturally selected by their local availability (e.g., linseed and olive oil in Europe, Tung oil in China, Areca nut in India). In this work, three types of vegetable oils have been selected as water-repellent additives for improving the durability of limewashes towards the action of water while ensuring that the paint does not block the drying capacity. The oils were selected based on their composition, global availability, and cost-efficiency: rapeseed oil, sunflower oil, and sunflower oil with high oleic acid content. The paints were prepared by mixing 1.5% of oil with pure lime putty (by mass). A commercial lime putty with olive oil was also included to prepare a limewash and compare it with the lab-prepared paints. Two types of natural stone from the Czech Republic with very different porous structure were used as case study substrates to compare the effect of the paints on the water transport properties: Mseno stone with an open porosity of 22% and a unimodal pore size distribution centred at 27 µm, and Opuka stone with an open porosity of 32% and a unimodal pore size distribution centred at 0.1 µm. The results showed that the different types of oil grant very different properties to both substrates. The most porous substrate showed the best results in terms of water-repellence and drying, whereas the stone with lower porosity did not show promising results, which was probably assigned to the fact that the paint did not adhere well to the substrate, as could be observed by the peeling of the paint during the absorption by capillarity test. Based on this study, suggestions for further research to improve a better performance of the paints in substrates with low porosity and narrow pore size distribution (> 0.1 µm) are given.



Topic 3: Mortars in archaeological sites. Construction history. Archaeometry. Dating of historic mortars.

REVISITING THE CHRONOLOGY OF EARLY CHRISTIAN ARCHITECTURE THROUGH MORTAR DATING: THE CASE OF PALEOCHRISTIAN CHURCH IN BORDEAUX

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Keywords: mortar dating, building archaeology, medieval architecture, single grain, optically stimulated luminescence

Abstract: With the beginning of the 21st century, the methodologies used in archaeology of architecture noted considerable transformations with an increasing role of natural science disciplines in the analyses of building materials. It has become evident that the interdisciplinary research is the most secure way to avoid potential misinterpretations and to reach reliable and objective results in the study of old monuments. In particular, substantial advances were made in the field of absolute dating methods, which allow from now on not only the dating of organic and heated materials used in the construction of buildings, but also the dating of mortar as the most representative element of the construction. The aim of this paper is to show the impact of the modern dating methods on the re-examination of chronology of early medieval architecture. The study brings us to the south-western France, to Bordeaux. According to the historical record, between 549 and 567 AD the thirteenth bishop of the city gave order to construct the Church dedicated to Saint Mary. For many decades, the historians led discussions about the localization of this edifice. It was presumed that it might have been situated near the central city square Pey Berland under the foundations of the medieval church Notre-Dame since both terms “Notre-Dame” and “Saint Mary” refer to the Virgin. Indeed, in 1983, a small apse was discovered on the position suggested. The context of the discovery as well as numerous circumstantial evidences led archaeologists to identify these remains as belonging to the church Saint Mary, as mentionned by the written sources. However, more than thirty years after the discovery, some discrepancies started to appear in the conclusions that have been drawn. In order to test the validity of the dating hypothesis based on historical and archaeological interpretations, several archaeometric dating methods were involved in the study of the monument in the framework of two subsequent research projects between 2008 and 2018. In particular, mortar dating through optically stimulated luminescence by using the “single grain” procedure was performed on the samples originating from all key stratigraphic units of the site. All dating results were integrated into chronological modelling in order to establish a robust chronology of the edifice. Apart from the fact that the findings allow reassessing differently ancient interpretations, the study has a great impact on dating of early medieval architecture at a regional scale as for several decades the monument served as a reference for dating of building heritage of the Aquitania region.

CHEMICAL AND MINERALOGICAL CHARACTERIZATION OF LIME PLASTER FROM 6TH CENTURY STONE-CHAMBER TOMB OF BAEKJE, REPUBLIC OF KOREA

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Keywords: Baekje Hanseong era, stone chamber tomb, finishing material, lime plaster, shell

Abstract: This study investigated the finishing materials used in ancient Baekje stone chamber tombs excavated in Hanam, Korea. The finishing materials were used for the walls and floors inside the tomb. As a result of the analysis, the material was confirmed to be lime plaster and was manufactured by shell. In addition, herbaceous organic matter was added to supplement durability. This suggests that construction technology with the use of a shell lime is contributed to form of part of the burial culture in Baekje Hanseong era.

CHARACTERISATION OF HISTORIC MORTARS RELATED TO THE POSSIBILITY OF THEIR RADIOCARBON DATING, MIKULČICE AND POHANSKO ARCHAEOLOGICAL SITES

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Keywords: Historic mortars, archaeological sites Mikulčice and Pohansko, hydraulic properties, limestone raw material, mortar 14C dating

Abstract: The archaeological sites of Mikulčice and Pohansko (South Moravia – the Czech Republic) belong to the oldest and the most important localities of Slavic settlement in the Central Europe. They are related to the existence of the Great Moravian Empire in the 9th century. Their considerable importance is attached to the preserved masonry remnants, which are also one of the oldest lime and stone masonry remains in the Czech Republic. A number of historic mortars sampled from the archaeological sites in Mikulčice and Pohansko were collected in order to study their composition, mortar structural characteristic and raw materials provenance. The aim of this study was not only the comparison and characterization of the historical mortars from these archaeological sites, but we also evaluated the suitability of these mortars to be dated by 14C analysis. The samples of historic mortars were characterised by several analytical techniques. Polarized light microscopy (PLM) and scanning electron microscopy with energy dispersive spectrometer (SEM-EDS) were used to determine petrographic characteristic and mineralogical composition. Thermal analyses (TA) and quantitative X-ray diffraction (XRD-QPA) were used to determine the chemical and mineralogical composition and hydraulic properties of the studied mortars. Particle size distribution and mineral content of the non-carbonate filler were also described. Stable isotope analyses (δ13C‰ and δ18O‰) and cathode luminescence (CL) were performed to detect carbonate filler and underburnt lime particles containing geogennic carbon. The collected mortar samples contained a considerable amount of lime particles that can adversely affect the possibility of 14C radiocarbon dating. According to the results of the analyses, the samples from Mikulčice and the samples from Pohansko had a similar character. Mortars were very rich in binder and contained unburnt limestone fragments that occurred frequently. Unburnt fragments were classified as a micritic limestone and contained sparite rich zones and bioclastic material. According to the composition and structure, this material was determined as Ernstbrunn limestones. Stable isotope analysis also suggested that all lime used in the studied samples came from a single source. The presence of geogenic carbonates (not fully burnt lime) affects the resulting 14C age of the analyzed samples fundamentally. The character of mortars leads to a discussion how to adapt the separating procedures of the individual fractions and how to avoid the geogennic carbon contamination.

PULVIS PUTEOLANA BEYOND THE MARITIME ARCHITECTURE. THE USE OF PHLEGREAN PYROCLASTS IN STRUCTURAL MORTARS OF ROMAN NORA (SARDINIA, ITALY).

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Keywords: pumice, tuff, pulvis puteolana, Nora, Sardinia

Abstract: Vitruvius is the first ancient author mentioning in the De Architectura the incredible properties of a "genus pulveris", sourced in the "regionibus Baianis", at present corresponding to the Phlegrean Fields north of Naples, "quod conmixtum cum calce et caemento non modo ceteris aedificiis praestat firmitates, sed etiam moles cum struuntur in mari, sub aqua solidescunt" (Vitr. II, 6, 1). In this sentence, the Roman author states that mortars and concretes mixed with this particular pulvis develop an excellent structural strength in such a way that even piers can be built underwater (Gros, Romano, Corso 1997). It is well known that the pulvis mentioned by Vitruvius corresponds to the lithified pyroclastic products of the Phlegrean eruptions of the NYT and post-NYT; in accordance with the De Architectura, the presence of pumices and tuff fragments in the concretes of Roman harbors has been analytically proved in many studies (Brandon et al. 2014; Marra et al. 2016). Therefore, these materials were transported, probably by boat cargoes, for kilometers all over the ancient Mediterranean for the construction of sea piers. In this paper, we discuss the presence of pumices and tuffs in the mortars of several Roman buildings of Nora, in Sardinia. OM, XRPD, SEM-EDS, XRF and LA-ICP-MS investigations, performed in the laboratories of the Department of Geosciences of the University of Padova and of the Department of Biology, Ecology and Earth Sciences of the University of Calabria, demonstrate the provenance of these materials from the area of the Phlegrean fields. The pyroclastic rocks are abundantly used in structural lime-based opus caementicium and joint mortars of masonries built overground and in structures not connected with water management. In the revetments of some cisterns, pumices are also present, but in this latter case, they represent a secondary aggregate in combination with terracotta fragments (Secco et al. 2020). Therefore, the import of pyroclastic rocks in Nora could be mainly aimed at strengthen the masonries while the impermeabilization is a subordinate capability. This figure is in perfect agreement with the Vitruvian statement, as the use of the pulvis was recommended, in the very first instance, to reinforce mortar-based materials in constructions and, secondly, for the hydraulic properties the material confers. The presence of Phlegrean pyroclastic rocks in mortars of non-hydraulic structures is common in the sites around the Gulf of Naples, as the material was locally sourced and widely available (Rispoli et al. 2019; 2020). On the other hand, its demand for the construction of overground masonries seems less frequent elsewhere and this opens new questions on the trade of these volcanic pozzolans in the Mediterranean.

MORTARS OF THE ROMAN FRONTIER ON THE DANUBE

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Keywords: Roman mortars, Danube Limes, mortar characterization, conservation mortar, conservation science

Abstract: The mortars have been always one of the most interesting topics for the researchers of Roman building constructions. The knowledge on this complex building material used in Roman architecture is mostly based on the research of the monumental structures in the territory of today Italy. However, many mortar examinations were executed by the researchers of provincial Roman archaeology as well, who tried to find evidence of the quality of building activities in the provinces. The territory of today's Serbia, except for the existence of scarce studies, was never in the research focus. Even the monumental bridge over the Danube, built at the beginning of the 2nd century that made Trajan's conquest of Dacia possible, was not researched thoroughly enough when we speak of its building materials. During the last few years, the interest in the Roman buildings at the Danube territory has grown. Mortar Design for Conservation – Danube Roman Frontier 2000 Years after (MoDeCo2000) project is funded by the Science Fund of the Republic of Serbia. Its aim is to investigate the mortars used in Roman buildings along the former Danube Limes in Serbia, as well as to offer mortar recipes for building conservation practice. The project includes 24 archaeological sites, dating to the period spanning from the 1st to the 6th century, with more than 120 different mortar samples that originate from 40 buildings of military and civilian function. The project results are intended to be an important contribution to the nomination dossier of a cultural property tending to be included in the UNESCO World Heritage List, named "Frontiers of the Roman Empire – Danube Limes in Serbia". Conducted laboratory analyses showed a great diversity of mortar samples. Immensely important are the results offering the characterization of some local raw materials known to date as used for masonry, as important components of the mortars, but also the possibility to conclude that the mortars for the most important buildings in this territory were made using the rare or imported raw materials. After sampling and research, laboratory models of mortars were done, the most promising recipes were chosen, and the application of new mortars was performed in real environmental conditions and on historic walls. The project results formed a database on archaeology, architectural and construction history, conservation science, technology, geology, and chemistry of raw materials and mortars, that will contribute to heritage protection in Serbia, as an exceptionally important input for conservation practice. The objectives of the MoDeCo2000 project are connected to the research of physical elements and social aspects of the creation of Roman fortresses and cities in Serbia, as well as to the conservation practice and contribution to contemporary engineering. Its biggest scientific significance is in the revealing of different aspects of building technologies in the Roman period at the mentioned territory, but also of the economy, trade, and everyday life of its inhabitants. **Acknowledgements: This research was supported by the Science Fund of the Republic of Serbia, PROMIS, #6067004, MoDeCo2000.**

PLASTERS OF AUGUSTA RAURICA ROMAN THEATRE: A PETROGRAPHIC CHARACTERISATION

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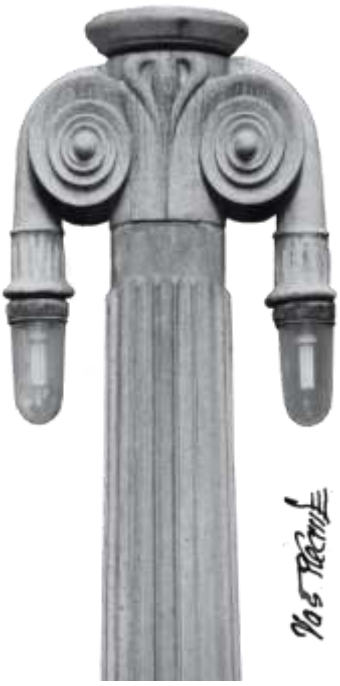
Keywords: Ancient Roman plaster, mortar technique, chemical-mineralogical characterisation, hydraulicity, Roman construction, Augusta Raurica

Abstract: Augusta Raurica is located on the south bank of the Rhine river ~15 km east of Basel near the villages Augst/Kaiseraugst, Switzerland. Founded ~44 BC, is the oldest known Roman colony on the Rhine. Between 70 and 180 AD three theatre buildings of the "Gallo-Roman" type replaced each other, starting at the early Flavian period with a multifunctional arena and ending late 2nd century AD with a monumental stage theatre with seating for roughly twice as many spectators. The youngest theatre was probably destroyed ~280 AD, likely used as construction material source during late antiquity. The Roman theatre has been extensively studied over decades. Yet there are still some gaps of understanding and open archaeological questions associated to the mortars, partially due to a lack of archaeological evidence (e.g. oven remains), limitations of science or past scope of analysis. Previous studies focused primarily on construction techniques and physical-chemical properties of plasters with little attention to the production technology of burnt lime and mortars themselves. No in-depth characterisation of specific binder features and no comprehensive evaluation of cement recipes, their associated quality and technical applications were done. Likewise, no perspective was developed on the chronological evolution of the local cement technology and associated raw material choices. The present study focused on complementing the existing plaster studies with a deep dive of the petrographic analysis using polarised light microscopy in thin section, as well as a re-assessment of the existing geochemical data, embedding samples from various masonry structures and all construction phases. Main goal was to identify the technological footprint associated to the multiple cement recipes and theatre phases, adding material science insights to the archaeological interpretation. These analyses are supplemented by detailed archaeological investigations on the Roman construction levels within the theatre's perimeter. The analytical refreshment indicated that the theatre plasters present a set of singular characteristics related to raw material, mortar technique and hydraulic character, surfacing important cultural history considerations related to the skills of the local construction masters and to which extent the resulting plaster features were intentional. We could detect directional trends specific to the construction phases, providing also a perspective of the logistics strategy across time.



Topic 4: Historic renders and plasters. Gypsum-based plasters and mortars. Adobe and mud mortars. Rammed earth constructions. Natural and Roman cement mortars. Assessment.

REPAIR MORTAR FOR A COLOURED LAYER OF SGRAFFITO RENDER – A TECHNOLOGICAL COPY

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Keywords: repair mortar, technological copy, sgraffito, limestone provenance, lime burning and production methods

Abstract: Sgraffito technique was used to decorate renders by scratching the top layer of lime wash in the Renaissance time. This technique required both artistic and craft skills and its quality and durability relied on the selected materials. In order to contribute to the preservation of surviving sgraffiti in the town of Slavonice in the Czech Republic a study was carried out assessing the possibility to replicate the original materials and the application techniques. Historical sgraffito layers were sampled in situ and studied in a laboratory by commonly used analytical methods - OM, TA, XRD, SEM-EDS. The raw materials, lime binder and sand, were characterised and the mixing proportion app. 1 to 1 (vol.) of dry slaked lime to sand was determined. The character of the raw materials was compared with the locally known resources and their probable provenance was localised. Based on the character of the local limestone a similar raw material was obtained and burnt in an experimental lime kiln to produce quicklime. The sand was obtained locally from an old and disused pit quarry. The possibility to obtain the raw materials that came from similar sources as the historic ones allowed us to study possible production technologies and application techniques. The way the raw materials were processed and the mortar applied were verified by a series of practical experiments. These included the use of lime putty v. dry slaked hydrate, thickness of a layer, trowelling and final finishing, time span before application of lime wash, timing of drawing and scratching. In addition, the performance of the produced mortar mix was assessed by mechanical and physical tests. Compressive and flexural strengths, capillary absorption, drying index, open porosity and water vapour diffusion coefficient were determined on standard prism specimens as well as on mortar specimens cut from wall panels. The mortar was tested in two sets with different consistencies due to mixing water content. The tests pointed out the influence of application methods on the performance. The mortar properties were positively evaluated especially in terms of porous structure and water vapour permeability. The mortar, designed as a material replica of the original, was used in a conservation project on a façade of a house, where missing parts of a sgraffito render were reconstructed.

EVALUATION OF THE HYGROSCOPIC AND CO2 CAPTURE CAPACITIES OF EARTH AND GYPSUM-BASED PLASTERS

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Keywords: CO2 capture, clayey earth, gypsum hemi-hydrate, hygroscopicity, indoor air quality, mortar

Abstract: Earth mortars and gypsum mortars present ecological advantages compared to mortars made with other common binders. When applied as plasters, they are also referred as having advantages in improving comfort and indoor air quality. For earth plasters, this improvement is associated with the hygroscopic capacity of the clay minerals, which promotes high sorption and desorption capacity of water vapour. So, earth plasters can contribute to the regulation of the indoor relative humidity. Another important advantage of plasters could be their ability to capture carbon dioxide (CO2). In the present study, the sorption and desorption performance, and the capacity to capture CO2 by earth and gypsum plasters are evaluated. It is confirmed that the earth plaster has the greatest sorption and desorption capacity, but also higher CO2 capture capacity than gypsum plaster. This confirmation opens new perspectives for the use of functionalized plasters that guarantee greater control of air quality inside buildings.

CHARACTERIZATION OF TAPIA MATERIALS FROM THE HOSPITAL SAN NICOLAS DE BARI, FIRST HOSPITAL IN THE WEST INDIES (1503).

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Keywords: Tapial, Rammed earth, 16th century, hospital, Dominican Republic

Abstract: Since ancient times, earth has been used in many ways as a building material to make walls, brick, or adobe among other products. Tapia, Tapial or Rammed earth is a very ancient earth construction technique that uses a wooden formwork, that serves as a mold. A soil kneaded mixture consisting of earth and water, with or without aggregates, lime, and even organic components, is rammed down in the mold repeatedly to make the wall piece by piece. Although this technique is very common in Europe, it was unknown in America, and it was the Spaniards who introduced it in the New World. Its popularity is due to its quick, easy, and economical manufacture and to the strength of the resulting material. This construction method was used in the construction of the first hospital in the New World, the Hospital of San Nicolás de Bari, founded in the city of Santo Domingo, on November 29, 1503, by order of the Catholic Monarchs. The hospital was built in three stages: from 1503 to 1519 when construction began, and some rooms were built; from 1519 to 1533 when the rooms and other rooms were enlarged; and from 1533 to 1552 the enlargements were completed. The hospital was incorporated in 1541 to the Sancti Spiritus in Saxia an Order that provided care and assistance to pilgrims. In the hospital there are two types of earth walls made with different materials and techniques: Monolithic wall or common Tapial, in which the molds are overlaid with a simple line of lime or without any element of other material to articulate them; and Mixed Tapial, which incorporates a stone or laterite material. This incorporated material has a double purpose; on the one hand, to facilitate and accelerate the construction process; on the other hand, to mechanically strengthen the structure. In the hospital we identify three types of mixed Tapial: reinforced, chained, and of Fraga, which is both reinforced and chained. The methodology used was the analysis of the Tapias by nondestructive techniques as visual analysis, documentation, and photographic record, as well as the chemical, mineralogical and physical-mechanical analysis of representative samples of the walls, using X-ray Diffraction (XRD), Fourier-transform infrared (FTIR) and Raman spectroscopies and Thermogravimetry-Differential Thermal Analysis (TG-DTA). Additionally, the Rock Schmidt hammer was used as a material characterization tool.

INFLUENCE OF NATURAL SAND REPLACEMENT BY MINERAL WASTES ON EARTH AND AIR LIME PLASTERING MORTARS, AND PROFESSIONALS TRAINING

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Keywords: air lime mortars; earth mortars; red ceramic waste; excavation earth; natural sand

Abstract: The use of environmentally friendly materials is increasingly important to help reduce the environmental impacts of the construction industry. Earth is a natural building material, non-toxic and reusable (provided it is not chemically stabilized). This material requires low energy for its extraction, transport and preparation, compared to cement and air lime, and consequently, presents low embodied energy and CO2 emissions. It is also available when excavation works occur. The use of by-products and wastes in mortars promotes a decrease in the use of natural resources and a reduction in the volumes of the waste to be managed, promoting a reduction in environmental impacts of the construction industry. Both earth and red ceramic waste have been used for millennia to produce mortars. For highly clayey earths, additional aggregate is added. In the present study, the influence of replacing natural sand by red ceramic waste or by clayish earth was analysed in the fresh state and the mechanical strength of air lime mortars. The influence of replacing added natural sand by red ceramic waste was also analysed on earth mortars, using the same test procedures. Five different mortars with clayish earth and air lime as binders, and natural sand, clayish earth and brick waste as aggregate were produced and characterized: two earth mortars with added sand and with brick waste instead of sand; three air lime mortars with sand, with clayish earth instead of sand and with brick waste instead sand. The earth and air lime mortars were formulated with a volumetric ratio of 1:0.5 and 1:2, respectively, and the water was added so they present a similar flow. The replacement of sand by the brick waste in the earth mortar promotes a decrease in the dry bulk density and flexural and compressive strength. The air lime mortar with clayish earth instead of sand presents higher flexural and compressive strength comparing to the air lime mortar with brick waste. On the other hand, the air lime mortar with clayish earth presents lower dynamic modulus of elasticity comparing to air lime mortar with brick waste. It is known that, for the conservation of historic heritage, mortars must not exceed the mechanical properties of the substrate on which they will be applied, ensuring the long-term compatibility between the mortar and the substrate. That is easily achieved with earth and air lime mortars. However, without jeopardising the previous, mortars durability is also needed and that will be further discussed in the article.

EVALUATION OF PHYSICAL AND MECHANICAL PARAMETERS IN COMMERCIAL NHL-BASED GREEN PLASTER FOR THE PRESERVATION OF HISTORICAL BUILDINGS

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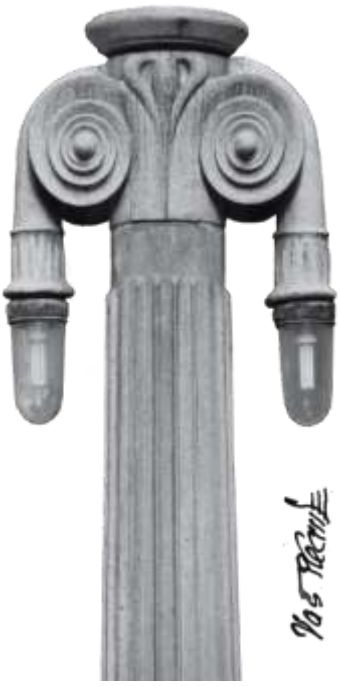
Abstract: The need to develop products for the conservation of the architectural heritage, in particular binders for plasters, is increased nowadays and those products are required to be in line with green production system and materials in full compliance with current environmental sustainability criteria. It has already been established that Natural Hydraulic Lime (NHL) is a good material for restoration; it is compatible with ancient materials and respect the environmental requirements. The use of green technologies often involves the partial use of environmental low impact materials that do not always find practical use in restoration. Therefore, the research is aimed at raising awareness of the green world with use in the common practice of restoration. It is also urgent, to verify the actual physical and mechanical compatibility of these products with the characteristics of the architectural heritage and the materials that compose it; this necessity is due to the extensive use of incompatible materials, like Portland Concrete, which could cause an acceleration in the formation of degradation products. On the other hand, it has been noticed that the extraction process and the production of cement based mortars have a high environmental impact.
The starting point of the research is the selection and study of NHL-based commercial plasters used for the conservation of historic masonries and their optimization through additives cement-free in order to create green products for applications in the conservative restoration of historical heritage. The six different type of formulations chosen for this work has been evaluated and analyzed from a physical and mechanical point of view, through dynamic elastic module, compression and flexion tests, porosity and density analysis.During the execution of the research, the focus was on the effect of microstructural features of porous material, investigated in laboratory with porosimetry test as they are fundamental parameters for studying compatibility with pre-existing materials and durability over time.



Topic 5: Historic Portland cement-air lime mortars. Historic Portland cement mortars.

HISTORICAL AND PRODUCTION STUDY OF THE CEMENT AND HYDRAULIC LIME FACTORY Nª SEÑORA DE LOS DOLORES IN ATARFE, GRANADA (SPAIN)

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Keywords: cement, hidraulic lime, historical binders, factory, industrial heritage, Atarfe, Granada

Abstract: In this work, a historical study of the cement and hydraulic lime factory Nª Señora de los Dolores, located in Atarfe (Granada, Spain), has been carried out. A characterisation of the raw materials and products manufactured in these facilities has also been conducted. This factory, inaugurated at the end of the 19th century, closed in the 70s of the 20th century and currently in a state of abandonment, is the only example of a Portland cement production centre that has existed in the province of Granada, and therefore constitutes an interesting testimony of industrial heritage whose study has been overshadowed by the large sugar industry present in the area surrounding the city of Granada. The objectives of characterising the raw materials used and the products manufactured in these facilities are, on the one hand, to determine the precise uses of the different areas of the factory and, on the other, to broaden our knowledge of the historical binders with a view to studying the restoration mortars used in the interventions on architectural heritage during the 20th century. The chemical and mineralogical analyses carried out by means of X-ray fluorescence and X-ray diffraction on the different materials found in the factory installations have made it possible to identify the storage areas of the raw materials and the finished binder products, as well as to determine the types and characteristics of the latter.

CHARACTERIZATION OF MORTARS AND CONCRETES FROM THE MIRANTE OF QUINTA DA AZEDA, SETÚBAL (PORTUGAL). A CASE STUDY FROM THE BEGINNING OF THE 20TH CENTURY

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Keywords: 20th Century, mortars, concretes, characterization, Portugal

Abstract: The built heritage of the early 20th century is characterised by a diversity of architectural styles ranging from Art Nouveau and Art Deco to Modernism. This was a time of transformation in construction practice, fostered mainly by changes in binders, from air lime to the use of cement, which is distinct from today's cement. In Portugal few buildings from this period have been studied and the lack of specific details of mortars and concrete used makes it essential to know the characteristics of these materials, including the type of binder used. The Mirante of Quinta da Azeda, in Setúbal (Portugal), is a peculiar observation tower built in the early 20th century, and one of the first examples in which reinforced concrete was applied in Portugal. It has an unusual architectural configuration, displaying elements of great slenderness. In the scope of the CemRestore research project - Mortars for the conservation of early 20th century buildings: compatibility and sustainability, several mortar and concrete samples were collected from this structure and were characterized using a combination of mineralogical, microstructural, physical and mechanical techniques, including XRD, TGA-DTA, petrography, SEM-EDS, open porosity, capillarity coefficient and compressive strength. In this paper the main characterization results are presented and discussed. The results show that all structural and ornamental samples are made with a hydraulic binder, the sand is mostly siliceous whereas pebbles and crushed limestone can be found as coarse aggregates. This characterisation allows broadening the scientific knowledge about the materials of that period in Portugal, also enabling the establishment of the requirements to be met by mortars and concrete to be used in the repair of this distinct structure.

CHARACTERISATION OF CONCRETE FROM THE RUPNIK MILITARY LINE

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Keywords: historic concrete, military bunker, NDTs, ultrasound, Schmidt hammer, optical microscopy, image analysis

Abstract: The Rupnik military line was established in about 1935 in the Kingdom of Yugoslavia as a defence system against the Kingdom of Italy. It consists of more than 4,000 reinforced concrete military bunkers positioned on the eastern part of the Rapallo border, varying in size and purpose, and was a top secret project at the time. Different non-destructive and non-invasive techniques were used to characterise the selected bunkers and carefully conceived concrete samples to gain insight into the concrete technology used to build these historic military infrastructures. The results of the non-destructive techniques were further compared to those of destructive techniques for a given property. It was established that very different concrete compositions were used to build the bunkers, and extensive dispersion of properties was confirmed for each composition. The average compressive strength of the Schmidt hammer for a given position is an acceptable estimate of the actual concrete compressive strength without destructive intervention into a bunker. It also enables the estimation of the secant modulus of elasticity using the ModelCode2010 approach. Cylinders drilled from a bunker provided additional information about concrete petrography, its physical and mechanical properties and the durability of reinforced concrete.

EARLY AGE PROPERTIES OF HYDRAULIC LIME MORTAR PREPARED USING HEAVY METAL CONTAMINATED AGGREGATE

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Keywords: hydraulic lime, heavy metal contaminated aggregate, XRD, early strength, ultrasound

Abstract: Traditional stone aggregates used to prepare mortars are generally considered inert fillers that do not interact with a binder. The European Green Deal, on the other hand, encourages the use of secondary material as aggregate. This secondary material is rarely an inert part of lime-based composites. This study focuses on heavy metal contaminated aggregate, for which it was already confirmed that it alters microstructure development and lowers the early strength of cement composites. Its influence on the hydraulic lime mortar's early age properties was studied through microstructure development recorded using transmission ultrasound technique and tensile and compressive strength after 1, 3 and 7 days. Results are then compared to those of cement composites. Obtained results show that heavy metals delay microstructure development of hydraulic lime mixture during the first 60 hours but do not decrease the tensile and compressive strength of the mortar after 3 and 7 days, as is the case for cement mortar.

MINERALOGICAL-PETROGRAPHIC STUDY OF TERRAZZO FROM SELECTED WORKS OF PLEČNIK HERITAGE (LJUBLJANA, SLOVENIA)

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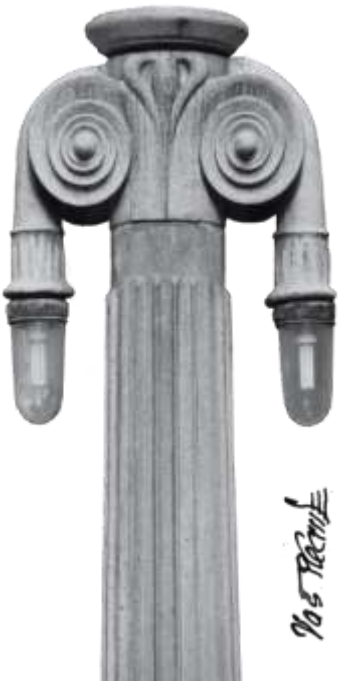
Abstract: This contribution presents the preliminary results of characterisation of cementitious terrazzo from selected 20th c. monuments in Ljubljana, Slovenia. Terrazzo was particularly widely used in public and private spaces from the 1920s to the 1950s because of its durability, for economic reasons and aesthetics. In Slovenia, the extensive use of terrazzo was promoted by the internationally-renowned Slovenian architect Jože Plečnik (1872-1957) who had a major impact on the modern identity of Ljubljana. The sampling for the present study was performed on outdoor terrazzo elements of various monuments, among them being The Triple Bridge, The Križanke outdoor theatre and The Cobblers' Bridge. These monuments, built between 1931 and 1956, have been declared as cultural monuments of national importance, some of them are on the UNESCO World Heritage list. Elements such as columns, pillars roof tiles and other elements of the city equipment were sampled. The study was focused on the characterisation of materials used for the production of precast terrazzo elements, such as the type and provenance of aggregate, the type of cement and the possible presence of mineral additives. The investigated terrazzo is characterized by angular or subangular elongated aggregate grains, up to 6 mm in diameter. In general, two types of terrazzo were recognized according to the colour of aggregate grains: the white-grey terrazzo with white and light grey grains and the black-white terrazzo with black, dark grey, light grey and white grains. The terrazzo samples were characterised by optical microscopy, SEM/EDS, X-ray powder diffraction and DTA/TG. The results showed that the terrazzo differed in the type of aggregate used - samples could be divided into groups with predominate limestone grains, predominate dolomite grains or mixture of dolomite and limestone grains. Furthermore, numerous residual unhydrated cement clinker grains indicated use of ordinary Portland cement either alone or blended with ground granulated blast furnace slag. However, results also revealed that not all samples were original as presence of numerous pores in some samples indicating use of aerated concrete of past restoration-conservation intervention. This study contributes to our knowledge of the terrazzo composition, and thus to that of the technology of terrazzo manufacture used by the architect Jože Plečnik. Furthermore, this study indicates the provenance of the raw material used and it will eventually enable us to select the appropriate conservation-restoration intervention.



Topic 6: Conservation issues concerning mortars, plasters, renders and grouts. Diagnosis. Decay and damage mechanisms. Case studies.

GAJI, A GYPSUM-EARTH PLASTER IN THE WALL PAINTING TECHNOLOGY OF THE CHURCH OF ST. DEMETRIOS OF THESSALONIKI, DAVID GAREJI, KAKHETI, GEORGIA

Mariam Sagaradze [1], Joshua A. Hill [2,3*], Sophia Mikaberidze [1], Nana Khuskivadze [1], Manana Kavsadze [4], Stephen Rickerby [5], and Lisa Shekede [5]

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(5) Rickerby and Shekede Wall Painting Conservation, UK

Keywords: gypsum, earth, clay, plasters, wall paintings, conservation, condition, technology

Abstract: Gaji is the Georgian name both for a gypsum-and-clay-containing soft rock found in the Samegrelo-Zemo Svaneti, Kvemo Kartli and Kakheti regions, and for the plaster traditionally derived from it. Using the Church of St. Demetrios of Thessaloniki at the monastic complex of David Gareji as an example, this paper explores the use of gaji plaster technology and the conservation challenges it presents. Gypsum-earth plasters have a long history of use across Caucasia, central Asia and the Middle East. In Georgia, Gaji has been traditionally used in the preparation of mortars, plasters and decorative finishes, and as a support for ecclesiastical wall paintings spanning C9th – C20th. Little research has been conducted into its properties, however, and within the context of wall painting conservation neither its influence on condition nor its implications for treatment have been adequately explored. The need to address these omissions came into focus in 2015, when the Church of St. Demetrios of Thessaloniki was discovered. Condition and technical examination of the paintings identified a gaji plaster support in a critical state of delamination and decohesion. In response, a research project was launched to investigate the composition and properties of both the original plasters and currently produced gaji as a basis for creating compatible grouts and repairs. Qualitative and semi-quantitative data were obtained on porosity and geological components using X-ray diffraction, petrographic and chemical techniques. Historic gaji plasters were found to have a higher clay content than modern gaji, also significant feldspar, and charcoal inclusions, which are absent in modern gaji. Also, approximately 12-13% calcite is added during modern gaji production, while historic plasters contain no more than 1% calcite. These findings indicate significant differences in both provenance and processing. This project has laid the foundations for understanding historic gaji plasters, and highlighted significant differences between historic plasters and contemporary gaji sources. Future research will extend the sample base to historic gaji plasters from different sites and periods and investigate historical geological sources and production methods, with the ultimate aim of establishing appropriate conservation materials and methodologies.

PERFORMANCE EVALUATION OF PATCH REPAIRS ON HISTORIC CONCRETE STRUCTURES (PEPS): AN OVERVIEW OF THE PROJECT METHODOLOGY

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Keywords: Historic concrete, concrete repair, portland cement, mortar, patch repair

Abstract: The development of reinforced concrete through the 20th century has resulted in a wealth of historically and culturally-significant concrete structures around the world. However, past understanding and consideration of durability issues were lacking, and many of these structures require ongoing interventions as a result. While there is now a general acceptance of the importance of concrete heritage from this era, there are few widely accepted guidelines on the approach to its preservation and conservation. In particular, despite many studies on the performance criteria of concrete patch repairs, there are no specific studies on the long-term performance of patch repairs designed to preserve the aesthetic significance of the original fabric. As a response to this specific challenge, three institutions, the Getty Conservation Institute (GCI), Historic England (HE) and Laboratoire de Recherche des Monuments Historiques (LRMH) are collaborating on the research project, 'the Performance Evaluation of Patch Repairs on Historic Concrete Structures (PEPS)', which aims produce practical guidance that will help those repairing historic concrete. This paper provides an overview of the assessment methodology that has been developed as part of this international collaboration.

INFLUENCE OF THICKNESS OF COVERING AND BOUNDARY CONDITIONS IN BONDING OF REBARS USED TO REPAIR AND REINFORCE MASONRY STRUCTURES

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Keywords: Masonry repair, reinforcing bars, steel, bonding, covering, boundary conditions, Finite Elements

Abstract: Repair and reinforcement of masonries by introducing reinforcing bars is a common well-stablished practice. It has been used for decades in historical and historic buildings, as well as in recent masonry structures. The most common way to put it into practice is by inserting rebars between masonry units, in grooves or by attaching renders to external wall surfaces, as well as by tying external leaves of masonry walls by means of anchors usually along with grouts. In all these cases, bars are embedded into thin layers of grouts or mortar, never in concrete. Recently, this technique has been improved by the introduction of glass or carbon fibers in substitution of steel rebars. Fibers present the main advantage of the rectangular shape that the plates present in substitution of the circular shape of the steel bars, what implies the necessity of small cavities to introduce them. This is a great advantage when dealing with the restoration of historical masonries since finally result less invasive. On the contrary, the use of fibers supposes the increase of the cost of materials, even if stainless steel has been chosen instead of Tempcore steel. This fact makes this technique unaffordable in many cases in which the budget available is reduced. Taking into account that there are many historic or recent masonries that cannot be repaired by insufficiency of funds, it is compulsory not to dismiss the use of steel rebars to this end. Steel rebars, which geometrical design comes from the field of reinforced concrete, must comply with some limitations when used in this context: (i) stainless steel is recommended because of the great majority of historic masonries are affected by rising damp; (ii) coverings will be under 10 mm since rebars are inserted in joints, drills, grooves of superficially attached to walls and; (iii) boundary conditions are different than those present in the case of reinforced concrete. These limitations strongly influence the bonding behavior of the rebars, so that this research emerge to characterize bonding behavior of steel rebars when perform under these circumstances. The characterization of bonding behavior of rebars is carried out by means of Finite Element analysis. Rebars are analyzed in different situations: (i) embedded in prisms made of hydraulic material of different sections and (b) different boundary conditions applied to these prisms. Numerical analysis takes into account non-elastic behavior of the hydraulic medium and contact between both solids thought Microplane model and a Cohesive Zone Model respectively. Results in terms of bonding behavior will be compared with the theoretical situation of the pull out test, this is, being the rebar embedded in a prism of dimensions extensively higher than the diameter of the rebar and with fixation only if over the frontal face. This paper deals with the efficiency of the pull out test for the specific use of rebars as reinforcement of masonries as well as identify the different bonding behavior that rebars present when used in this way.

SPANISH POST-CIVIL WAR RECOVERY OF LIME MORTARS

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Keywords: Lime mortars; Preservation; Tradition vs Innovation; Lime mortars; Spain;

Abstract: Lime mortars had been traditionally used in building construction. However, the rise of cement at the beginning of the XX century provoked its obsolescence at the beginning of twenty century. The development of the Spanish Civil War (1936-1939) together with the later insolation of the country because of the new regimen defined the autarky period in which the recovery of traditional techniques was boosted. Indeed, during the 40-50's, lime mortars revive with a definition of new styles. This period is of great interest because of the combination of tradition and novelty in Architecture. An example of this revival is the Obra Sindical del Hogar pavilion, at Casa de Campo exhibition area in Madrid. This pavilion was part of the International Exhibition Site of the Country Fair widening at the end of 1948 in which novel architects such as Alejandro de la Sota, Miguel Fisac, Rafael Aburto or Francisco Asís Cabrero worked. In 2006, a restoration plan was approved for the recovery of those buildings as an emblematic case. Obra Sindical del Hogar pavilion is another singular example of this site. This building designed by Francisco Asís Cabrero and Felipe Pérez Enciso counted with a ceramic mural by Manuel Suárez Molezún and Amadeo Gabino artists is a striking feature. In spite of its modernity in the graphical representation of the scenes, it was based on the use of traditional techniques among others, the use of lime mortars and porous ceramic. As part of the restoration of this mural, a complete analysis of the original mortars and ceramic had been performed. The results showed a careful selection of the materials and the knowledge of the workforces. Porous ceramic calcined at low temperature as support of the glassy treatment and their compatibility with the aerial lime mortar defined its state of conservation in spite of the abandon suffered for more than 40 years. Finally, aerial lime mortar were used as joint mortar to the brick masonry. It showed a high compactness and a reduced porosity mainly because a careful selection of the aggregates without washing them. It explained the presence of small percentage of bicalcium silicate found.

MEASURING WATER ABSORPTION IN REPLICAS OF MEDIEVAL WALL PAINTING PLASTER TO ASSESS THEIR SUITABILITY AS RELIABLE MODELS FOR CONSERVATION TRIALS

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Keywords: water absorption, medieval wall paintings, replica production, contact sponge, binder to aggregate ratio, hot-mixed mortar

Abstract: This study applies the contact sponge method to compare the water absorption of limewashed lime plaster in Gothic wall paintings and replicas with varying compositions. Based on this comparison, the study evaluates the replicas' suitability as test specimens for wall painting conservation trials. Testing new materials and methods on plaster replicas prior to in on-site implementation is considered a vital part of wall painting conservation practice. This is particularly significant for cleaning, desalination and consolidation, treatments which are often irreversible. For laboratory tests to be relevant, it is important that replicas, often comprising smaller lime plaster models, are similar to historical plaster, not only with regard to material composition, but also to physical characteristics, such as permeability and capillarity. This paper focuses on water absorption, as this characteristic plays a significant role in cleaning or desalination treatments on porous objects, such as lime-based wall paintings, especially when conducted by poulticing. In such cases, the water absorption during a specified contact time has a determinant effect on the amount of liquid that penetrates the object, affecting the performance of the poultice and the outcome of the treatment. The water absorption was initially measured in situ on a blank whitewashed area on a Gothic wall painting in a medieval church in Denmark. The procedure was subsequently repeated on models produced with three different mortar compositions. The use of models with different compositions made it possible to evaluate how the binder to aggregate ratio and type of limewash impacts the water absorption rate. The first group of models was produced using a standard, commonly used lime putty mortar with a 1:3 binder to aggregate ratio. For the other two groups, the hot-lime technique was used to obtain high lime content plaster models with a binder to aggregate ratio of 1:1 and 1:1.5, which is similar to plaster supporting Gothic wall paintings in Denmark. The study showed that the samples with high lime content had the fastest absorption rate. The study also demonstrated that the closer the binder to aggregate ratio of the models is to the historical plaster, the more similar the values are. The poorest correlations were found for models heretofore used in conservation trials with 1:3 binder to aggregate ratio. This contributes to the ongoing discussion of the importance of using laboratory models with same composition and properties as the objects they are replicating instead of using standard models. The study further revealed that the type of limewash has a significant influence on absorption rate. The limewash produced from a more mature lime putty resulted in the highest absorption values. Finally, the experiment indicated that the contact sponge method can be used for measuring water absorption of lime plaster, both in the laboratory and in situ, but that it is reliable only for initial water absorption, as longer contact times produce overly high variations in measurements.

THE SGRAFFITO IN KRIŽANKE - INTERDISCIPLINARY APPROACH TO THE CONSERVATION-RESTORATION OF COLOURED HISTORIC PLASTER

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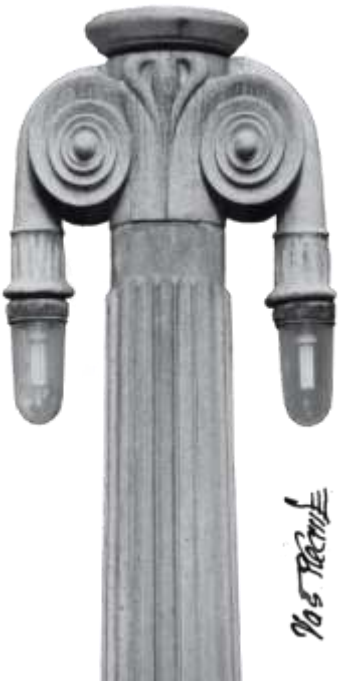
Keywords: Sgraffito, Jože Plečnik, coloured plaster, pigments, reconstruction plaster

Abstract: The sgraffito in Križanke - interdisciplinary approach to the conservation-restoration of coloured historic plaster Maja Gutman Levstik, Anka Batič Institute for the Protection of Cultural Heritage of Slovenia, Restoration Centre, Poljanska cesta 40, 1000 Ljubljana; maja.gutman@rescen.si, anka.batic@zvkds.si The Križanke Outdoor Theatre is a theatre in Ljubljana, Slovenia, used for summer festivals, built in the courtyard of the former Monastery of the Holy Cross. Between 1952 and 1956, architect Jože Plečnik converted this former monastery into one of the city's main cultural venues. To the left of the entrance to the courtyard stands a small triumphal arch flanked by two niches containing statues by the Austrian sculptor Leopold Kastner, named Learning and Progress. The arch and the columns supporting it are decorated with sgraffito. This is an old decorative mural painting technique in which an image is created by scratching away one or more layers of different coloured plaster. There is no paint layer or protective coating only plaster, which is subdued to environmental and other factors of deterioration. Conservation and restoration of the sgraffito was carried out in the summer of 2021. During the investigation of the historical documentation and the first stages of surface cleaning, it was discovered there had already been an intervention in the past. Plečnik's original sgraffito was left only on the columns and a small part on the top of the arch, otherwise the sgraffito and also the mortars were completely reconstructed. The motif, colours and technique used were roughly the same, there were some differences in the aggregates and other additives in the plaster. Microscopic analysis showed that a lime-cement mortar was used for the triumphal arch, the aggregate of which consisted mainly of predominant rounded carbonate component. The original and the "new" sgraffito plaster were made of pigmented lime binder. The black pigment in the grey plaster was identified as a carbon black. Pigments such as iron oxide (hematite) and iron hydroxide (goethite) with some carbon black are present in the red coloured plaster of the original sgraffito. In the "new" red coloured sgraffito plaster only hematite was used. The mineralogical-petrographical composition of the aggregate in the two (original and "new") sgraffito plasters is similar and consists mainly of carbonate components. There are some differences in the size and sorting of an aggregate. There was a layer of gypsum on the surface of the original sgraffito plaster as a weathering product. The aim of this research was to investigate and characterise the plasters used in sgraffito decoration. The information was crucial for processes such as the development of reconstruction plasters for the damaged parts. There was also an addition to the new mortars that led to a different approach to cleaning and consolidation.



Topic 7: Preservation. Consolidation materials and techniques. Development of new products. Preventive conservation.

EXPERIMENTAL STUDY ON PROPERTIES OF HYDRAULIC MORTARS WITH MIXED IN CRYSTALLISATION INHIBITORS

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Keywords: crystallisation inhibitors, salt damage, cultural heritage, restoration mortars, natural hydraulic lime

Abstract: Sodium chloride (NaCl) is one of the most commonly occurring weather agents responsible for a progressive damage in porous building materials like mortar. Current solutions to mitigate salt damage in mortar, such as the use of water repellent additives, have often exhibited low compatibility with the existing building fabric. In the last years, researchers have shown promising results in alleviating salt decay by making use of crystallisation inhibitors. Sodium ferrocyanide is one of the inhibitors that has proven to be particularly effective in limiting the damage due to sodium chloride crystallisation. This positive effect is possibly related to the changes in the crystal habit and to the promotion of salt crystallisation as efflorescence instead of crypto-florescence. Most of the past studies have focussed on the use of this inhibitor in building stones and air hardening lime mortars. In this research the possibility of developing hydraulic mortars with mixed-in inhibitor (sodium ferrocyanide) for an improved resistance to sodium chloride crystallisation damage is investigated. As a first step, the interaction between the inhibitor and the natural hydraulic lime (NHL) was studied; the results are presented in this paper. Various concentrations of sodium ferrocyanide were tested (0%, 0.1% and 1% by binder weight). The effect of the inhibitor on several physical (hydration, water absorption, pore size distribution) and mechanical (compressive and flexural strength) properties was experimentally assessed, using several methods and techniques. The results show that the addition of the sodium ferrocyanide does not affect the fresh and hardened properties of mortar. These results are promising and open new possibilities for the application of inhibitors to improve the durability of hydraulic mortars.

UTILIZATION OF LAVENDER WASTE IN TRADITIONAL MORTARS

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Keywords: bio-fibres, lime mortars, thermal properties, strength

Abstract: To minimize waste and meet the EU targets, the construction industry is making efforts to embrace sustainable development and utilize bio-based materials instead of using less environmentally friendly conventional ones. In this frame, the research is focusing on the utilization of bio-fibres in mortars. It is well known that the most effective method to improve the internal tensile strength of lime-based mortar, and minimize plastic shrinkage, is the incorporation of fibres as reinforcement. Nowadays, commonly used fibres in lime-based mortars are polymeric or synthetic ones, while only lately the building industry's current trend to develop sustainable materials, brought natural fibres to the forefront. Natural fibres are abundant, low-cost, renewable, with a CO2-neutral life cycle and high filling levels possible, sustainable, energy efficient, biodegradable, non-toxic, of nonabrasive nature, and of low weight and density, yielding lightweight composites of low environmental footprint. Even though the practice of using biomaterials in the construction sector highly attracts the interest, minimal efforts have been implemented to date towards the utilization of aromatic plant residues in bio-synthetic materials. Lavender is considered a shrubby, multi-branched, aromatic plant that grows from 20 to 60 cm. Once the extracts of the lavender plant become isolated through the process of distillation, the solid residual material of distillation process remain unutilized, commonly allowed to be decomposed in fields neighboring to the distillation units or is being burnt. Since the boiling point of lavender oil is lower than that of water, the distillation process is conducted at low temperatures (<100ºC), and therefore, this solid waste biomass material has not been severely thermally degraded or chemically modified during the treatment. In this sense, the current research aims to examine the possibility of utilization the solid wastes from the lavender oil extraction plants in lime-based mortars. In this frame, the plants were cut and their water absorption capacity was recorded. The lavender fibres were introduced in the lime mortars' structure in two ways: the first concerns their use as additives in 1% b.v of the mortar. The second way concerns their use as a layer (a net) between two mortar layers. Both techniques were often met in historic structures. Different specimens were produced in order to test mechanical, thermal, physical and microstructure characteristics of the composites. The results indicate the possibility of utilization of aromatic plants' wastes in the building sector after taking into account their organic and hydrophylic nature. This research field is wide and different sustainable approaches can be followed to elaborate the surface of the plants to increase their adhesion capacity, hydrophobicity, hardness and make them efficient to function in a highly alkaline environment.

RESTORING HISTORICAL BUILDINGS AMID CLIMATE CRISIS: HYDRAULIC, WASTE-BASED LIME

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Keywords: Wood biomass ash, hydraulic lime, alternative binders, industrial waste, sustainability, cementless binder

Abstract: Bringing together the cultural dimension and sustainable innovation is integral to creating a dialogue between the built environment and the planet's ecosystem. Just as the reuse of waste is at the top of the European waste hierarchy and prevention itself is prioritised, the maintenance, repair and restoration of existing buildings must be favoured over new construction. At the same time, preserving historical and cultural integrity remains imperative. To mitigate damage to cultural assets as well as the effects of climate change, the right choice of repair materials is vital. As for the "right choice," traditional and modern materials are often incompatible, making the selection of an appropriate, like-for-like material particularly challenging when renovating buildings of historical and cultural significance. For this reason, the use of state-of-the-art materials in compliance with current regulations and the preservation of cultural and historical values often remain unreconciled. Nowadays, as circular and sustainable architecture becomes mainstream, renovation materials that are compatible with those originally used in construction are in demand. The building materials available at the time of construction inevitably shape the architecture itself. Since early building materials such as stone and clay bricks were bonded with lime mortar, lime-based materials are key to achieving material compatibility while preserving historical structures. At the same time, the European Union (EU) is turning to renewable energy and sustainable options that address complex local conditions and growing energy and material needs. Bioenergy is the main renewable energy source in the EU, accounting for more than 2/3 of the renewable energy mix. As wood is a carbon neutral energy source, it is one of the predominant sources of biomass for energy production in the EU. However, the continuous expansion of wood biomass power plants leads to the formation of wood biomass ash (WBA), a solid by-product of wood combustion, on a large scale. Although WBA contains numerous nutrients such as calcium, potassium, and phosphorus that could be useful in agriculture, the ash also contains heavy metals that pose a particular risk to the environment. While these facts clearly point to the need for strategic foresight in the management of WBA, the common practise in dealing with WBA is to dispose of it directly in landfills or to use it as a soil amendment, often without any monitoring, resulting in clogged and illegal landfills. The disposal of WBA should not be overlooked, especially considering the continuous rise in WBA volumes and disposal costs. So, by highlighting the health benefits of reusing WBA instead of simply sending it to landfills, we are promoting environmental change through tangible experiences at the local level. Using locally sourced WBA eliminates industrial waste while conserving natural resources. Although previous research has identified WBA primarily as a raw material substitute in cementitious composites, this research focuses on the potential use of WBA in the development of artificial hydraulic lime due to the similarities between the chemical composition of WBA and lime. The interaction of WBA and other industrial wastes would lead to an increase in hydraulic capacity while creating a 100% waste-based, cement-free binder.

CRITERIA FOR THE UTILIZATION OF PERLITE BY-PRODUCTS IN TRADITIONAL MORTARS

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Keywords: perlite, by-products, traditional mortars, sustainability, lime

Abstract: Climate change has become the main problems of humanity, affecting all our everyday actions and habits. The decrease of CO2 emissions is mandatory for the protection of the environment and the construction sector has a 36% share of the global problem. On the other hand, conservation of cultural heritage remains one of the main targets in European level. Materials and techniques used in conservation and preservation of monuments should meet certain criteria and be compatible to the existing ones as well as durable. In the case of conservation works, the materials and the techniques used are following specific regulations included in relative EN norms. At the same time, RILEM technical committees are publishing guidelines indicating the quality criteria that should be followed for a successful intervention. The aim of this work is to combine the needs mentioned above for sustainable and qualitative materials that can be used for restoration works. In this frame, the properties of five perlite by-products were tested and their suitability in traditional mortars was tested in order to produce compatible restoration materials with low environmental footprint. Perlite is a volcanic mineral (alumino-silicate in origin) used mainly in agriculture and in special applications in building materials (gypsum plasters, cement boards, light-weight concrete). Greece is among the first countries in perlite production with 25000 to 30000 tones per year. During its industrial process, an increasing amount of by-products results (around 10% of the material is a waste) that mainly remains unexploited causing severe environmental problems due to their fineness and the difficulty in storing. The properties (chemical, physical, mineralogical) of the five perlite by-products were studied. Fineness of the binders was measured with Malvern P.S.A Mastersizer 2000 - laser scattering technique. Chemical analysis of the raw materials was determined by Atomic Absorption Spectrometry and X-Ray Fluorescence. X-Ray Diffraction identified the crystallographic structure of the binders and finally, their pozzolanicity index was measured according to ASTM C 593-95. The suitability of the perlite by-products in traditional mortars was evaluated based on the combination of the analysis results. These by-products were incorporated in lime-based mortars and the properties of the raw materials were correlated to the achieved mortars' properties. The research results to the possibility to follow specific criteria in order to evaluate industrial by-products for the production of traditional mortars, saving natural resources and increasing the environmental profile of lime-based mortars. At the same time high quality lime mortars can be produced that can be safely used in restoration works

DEVELOPMENT AND TESTING OF LIME-BASED MORTARS USING PERLITE BY- PRODUCTS

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Keywords: mortars; sustainability; perlite process; mechanical strength

Abstract: Perlite is a volcanic rock containing high amount of amorphous material as well as alumino-silicate minerals. The 95% of the worldwide production is coming from Greece, China, Turkey and the US. The outcoming product (expanded perlite) is often used in construction, due to its light weight and insulating properties. During its industrial process, an increasing number of by-products results that mainly remains unexploited as the fineness of these materials renders them difficult to store. Perlite is a very promising industrial material as during the last 60 years less than the 1% of the existing deposits have been mined. In this study, an effort has been made to experimentally study the influence of two by-products (D1S, D1C), coming from the second stage of the perlite process (heating), in lime-based mortars. These materials have been used as binders. To this direction, 7 mortar mixtures where manufactured and tested (including a reference mortar containing lime and natural pozzolan), where natural pozzolan was gradually replaced by the perlite by-products. The Binder/Aggregate ratio in all mixtures was maintained at 1/2, whereas aggregates were natural of siliceous origin and gradation 0-4mm. In order to reduce the water demand, a small proportion of polycarboxylate superplasticizer (1% w/w of binders) was added. The physico-mechanical properties of the specimens were tested at the age of 28 and 90 days, including shrinkage deformations (due to volume and weight changes), porosity, absorption, apparent specific gravity, water absorption coefficient due to capillary action, dynamic modulus of elasticity, flexural and compressive strength. From the correlation of the results, it was asserted that the partial or even total substitution of natural pozzolan by perlite by-products, enhanced the mortars' physical and mechanical properties. It maybe therefore concluded that the exploitation of waste perlite in the construction sector is feasible, leading to the development of effective, low-cost and environmentally friendly products for specific applications.

DURABILITY OF LIME MORTARS TREATED WITH AMMONIUM PHOSPHATE

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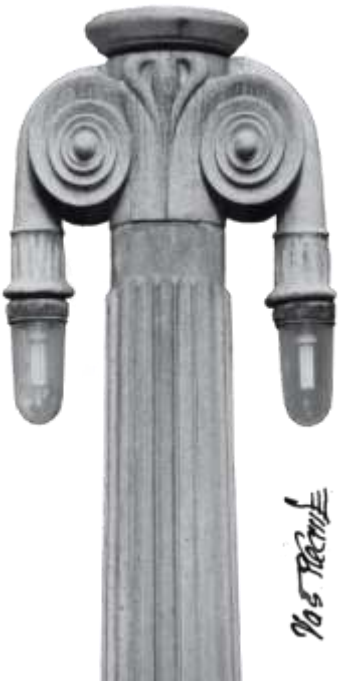
Keywords: Freeze-thaw; Salt crystallization; Consolidation; Hydroxyapatite; Nanolime

Abstract:The use of aqueous solutions of diammonium hydrogen phosphate (DAP) for consolidation of carbonate stones has been explored in recent years with very encouraging results. In the light of the good performance showed on stones, the present study aimed at evaluating the effectiveness and the durability of the DAP-treatment when applied onto lime-based mortars. For comparison's sake, the performance of DAP was evaluated against that of a commercial consolidant based on nanolimes. The durability of the two consolidants was evaluated in terms of resistance to freezing-thawing cycles and salt crystallization cycles. Mortar samples were prepared using slaked lime and calcareous aggregates according to historic recipes. After curing for 4 months, the specimens were treated by brushing until apparent refusal with: (i) a 3 M DAP solution, followed by a limewater poultice (samples labeled as "DAP"); (ii) a commercial nanolime dispersion in ethanol with 5 g/L concentration (samples labeled as "NL"). After curing for 4 weeks, the effects of the consolidants were evaluated in terms of cohesion by ultrasonic testing, compressive strength by double punch test and pore size distribution by mercury intrusion porosimetry (MIP). The composition and the morphology of the new consolidating phases were assessed by FT-IR and SEM-EDS, respectively. Afterwards, untreated and treated specimens were subjected to durability tests. As for freeze-thaw, 28 cycles were carried out, alternating 2 h of immersion in water at 20°C and 2 h at -20 °C. As for salt durability, 6 cycles were carried out, alternating immersion in a 14 wt% Na2SO4·10H2O aqueous solution for 2 h and drying at 40 °C for 20 h, followed by cooling for 2 h. After each cycle, the variations in weight and dynamic elastic modulus (measured non-destructively) were monitored. At the end of the cycles, the salt-contaminated specimens were desalinated by poulticing. Then, the residual compressive strength of the artificially aged samples was assessed by double punch test, while the possible formation of new cracks was evaluated by MIP. The results of the study point out that, after treatment with DAP, new calcium phosphate phases are formed, which act like bridges among the grains and increase the mortar cohesion. At the same time, these new phases are responsible for a shift of the pore size distribution towards smaller pores. Compared to the untreated reference and also to the NL-treated samples, DAP-treated mortar showed much improved resistance to freezing-thawing cycles. A lower benefit was found in the case of salt crystallization cycles, as DAP-treated samples exhibited a substantially similar behavior as untreated and NL-treated ones. The different improvement in durability observed for freezing-thawing cycles and salt crystallization cycles could be ascribed, on the one hand, to the slight modification of the pore size distribution after treatment (which may lead to increased crystallization pressure) and, on the other hand, to the severity of the salt weathering test (involving the use of a concentrated Na2SO4·10H2O solution). All things considered, the potential of the DAP treatment for the conservation of lime-based mortars seems confirmed.



Topic 8: Repair mortars and grouts. Requirements and design. Compatibility issues. Durability and effectiveness. Adequacy of testing procedures.

LONG-TERM MECHANICAL PROPERTIES AND DURABILITY OF LIME-SPONGILITE MORTARS

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Keywords: spongilite, lime mortar, pozzolanic material, mechanical properties, frost resistance, porosity, salt crystallization resistance

Abstract: Spongilite – the technical geological name of the sedimentary rock of the Upper Cretaceous, a siliceous calcium marlite more commonly but incorrectly called marl, marlstone, or clay marl – is a typical representative of organogenic pozzolans. Triaxial needles of dead microscopic marine fungi of the Porifera strain, so-called spongies, play a significant role in the heterogeneous structure of spongilites. The needles of these fungi are formed by opal, but during diagenesis the opal recrystallizes to chalcedony and quartz. The secondary components are usually clay minerals, mica, and calcite. In the Czech Republic, there are several localities of spongilite in the overburden of high-quality foundry sands. They are often mined and stored without further use. This paper presents a study on partial replacement of lime binder with fine spongilite with the purpose of exploring a new application of this natural material as lime mortar additive. By partially replacing of the binder with a fine natural material with pozzolanic properties, lime savings are expected while improving the performance of the prepared mortars. Standard air lime mortars were made by incorporating from 0% to 40% of spongilite powder in replacement to lime and their mechanical performances, microstructure, and durability were determined. The spongilite powder showed similar pozzolanic activity as natural zeolite or waste brick powder predicting an improvement in the mechanical properties and durability of lime mortars. As the replacement level in lime mortars increased, the amount of mixing water needed for the same mortar consistency decreased, and the performance properties of the mortars improved. The increase in strengths of mortars was manifested mainly in the long term of 180 and 365 days. The incorporation of fine spongilite led to the formation of slightly denser, more water absorptive, however, more frost resistant and salt crystallization resistant structure in air lime mortars. The effective use of spongilite powder as a supplementary material in air lime mortars was assessed to enhance their performance in building practice or to prepare feebly hydraulic mortars used in the past in constructions nowadays considered built heritage.

ON THE EFFECT OF POOR-QUALITY AGGREGATES ON THE PHYSICO-MECHANICAL PERFORMANCE OF REPAIR LIME-BASED MORTARS

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Keywords: fine aggregates, lime mortars, soundness, micro-deval, water absorption, mechanical properties, porosity, capillary absorption, MIP, TG/DTA, SEM

Abstract: The selection of building materials for any restoration project presupposes knowledge of their physico-mechanical properties, as compatible materials with the authentic ones need to be chosen at all times. In the case of composite building materials, such as lime-based mortars, the constituent raw materials, especially the aggregates which comprise the largest proportion of their volume, may affect the physico-mechanical performance of the end-product, both in the fresh and hardened states. It is therefore essential to identify the properties of the aggregates before these are incorporated in the mortar mixture. This paper reports on the effect of two different limestone crushed fine aggregates quarried in Cyprus on the physico-mechanical properties of repair lime-based mortars. The aggregates have been subjected to a series of standardized experimental tests (i.e., soundness, micro-deval and water absorption) to identify their properties, before being used to produce lime-based mortars with fixed binder:aggregate ratio and workability. The results confirm the negative effect of poor-quality aggregates on the mechanical strength, the porosity and capillary absorption of the hardened end-products; this is corroborated through supplementary Mercury Intrusion Porosimetry (MIP), thermogravimetric (DTA/TG) analyses and Scanning Electron Microscopy.

FINE PUMICE AS POZZOLANIC ADDITIVE IN RESTORATION LIME MORTARS

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Keywords: pumice, lime mortar, pozzolanic material, mechanical properties, frost resistance, porosity, salt crystallization resistance

Abstract: In order to improve the properties of fresh and hardened lime mortars, inorganic substances of a hydraulic or pozzolanic character have been added to the air lime already in the ancient times. The builders mainly used natural pozzolans of volcanic or sedimentary origin in the form of dust, large grains or aggregates. The most commonly used natural pozzolans included tuffs, tuffites, diatomaceous earth, zeolitic rocks, trass or pumice. Although the use of natural pumice in lime mortars is known from history, professional work on the influence of finely ground pumice on the properties of air lime mortars is almost non-existent. Rather, the effects of coarse natural pumice used as aggregate in lime and cement mortars are described in the literature. For this reason, this paper aims to describe the effect of partial lime replacement with finely ground natural pumice on the mechanical, microstructural and durability properties of air lime mortars. The pumice powder showed similar pozzolanic activity as trass or natural zeolite predicting an improvement in the mechanical properties and durability of lime mortars. As the replacement level in air lime mortars increased, the amount of mixing water needed for the same mortar consistency decreased, and the performance properties of the mortars improved. The increase in strengths of mortars was manifested mainly for the 40% lime replacement. This mortar reached at 28 days of age the compressive strength comparable with hydraulic lime-based mortars. The incorporation of finely ground pumice led to the formation of slightly denser, less water absorptive, and more frost resistant and salt crystallization resistant structure in air lime mortars. Lime-pumice mortars showed improved properties in all important aspects from the point of view of the utility of these mortars in restoration and conservation interventions on historic buildings. Based on the achieved results, the 40% lime replacement was found to be optimal.

THE RELATIONSHIP BETWEEN NATURAL STONE JOINT DESIGN, SURFACE AREA AND THE PROPERTIES OF LIME MORTAR JOINTS

Matthew Cook

Keywords: Stone conservation, Lime mortar adhesion, Stone surface area, Bond wrench, Stone joint design, Stone surface roughness

Abstract: Historically, building stone was extracted and shaped by hand. To produce a flat surface using a mallet and chisel requires the time and energy of a skilled mason. As such, the highest level of workmanship was generally reserved only for the seen faces of stones. The joint surfaces were given less attention and would subsequently be “rougher”. In the modern era, diamond tipped gantry or wire saws are the standard equipment for stone processing. For the purposes of building conservation, the seen face of replacement stones are usually hand chiselled in keeping with the original design. However, it has become increasingly common for the joints of the new stones to be left as a clean diamond sawn surface. This paper examines if and how the difference in surface area between various stone surface finishes changes the characteristics of the lime mortar joint. The paper includes a surface area comparison of modern and historic stone surface finishes. This is followed by practical testing to ascertain how lime mortar joint/adhesive bond strength changes in relation to amount of stone surface area available for adhesion. The results of the testing suggest a direct relationship between stone surface finish, joint surface area and lime mortar adhesion.

COMPARATIVE EVALUATION OF REPAIR MORTARS FOR THE CONSERVATION OF HISTORIC MASONRY

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Keywords: low strengh mortar, composite mortar, historic masonry, blended cements, pore size distribution

Abstract: Lime was the principal binder for masonry construction in India since ancient times. However, in the selection of binder for repair, ordinary Portland cement has gained undue importance due to its high mechanical strength and lower setting time, allowing a faster completion of the repair works. More recently, the ill effects of using a strong binder have been realised from past experiences and the importance of ensuring moisture diffusion and breathability in historic buildings has put more emphasis on the compatibility of restoration mortars. Lime-based mortars have regained an increasing interest in this scenario. Nevertheless, lime is a slow hardening binder. The non-availability of good quality lime and the required expertise/craftsmanship is yet another hurdle in extensively using this material in repair. To overcome some of the drawbacks with lime, traditional builders had used volcanic ash, crushed bricks, pottery and clay tiles as pozzolans in their mortars. The 'masonry cement' that was available in the past had a mixture of blended binder, consisting of ordinary Portland cement, limestone, hydrated or hydraulic lime, and aggregates along with additives. Also, several studies have explored the possibility of adding supplementary cementitious materials like fly ash, metakaolin, slag, silica fume etc. in lime-based mortars. This paper presents selected results of comprehensive investigations on the effect of different binder types (dry hydrated lime, lime putty, dry hydrated lime with organic additives, lime-cement, cement-flyash, cement-limestone calcined clay and cement-flyash-limestone) on the physical and mechanical properties of potential repair mortars. The mortars were designed with the same binder/aggregate ratio of 1:3 to obtain a flow of 165 ± 5 mm and evaluated up to a period of 365 days of curing. The results project the superior workability and better rebound of lime-based mortars, especially with aged lime putties. The mechanical characteristics were studied by measuring compressive and flexural strengths, stiffness through ultrasound technique, the pore structure by mercury intrusion porosimetry and the hygric properties via sorptivity measurements. It was observed that the cement-based systems become suitable (or compatible) for repair only when there is a high degree of replacement of cement, nearly up to 80%. A blended cementing system with 20% OPC clinker, 20% limestone and 60% fly ash had comparable performance characteristics as that of lime-based binders, with respect to overall porosity and pore size distribution. The results are also compared with typical values of mortars (reported in literature) often used in conservation.

DEVELOPMENT OF A GYPSUM-BASED GROUT FOR STABILISATION OF GYPSUM-BASED PLASTERS

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Keywords: Injection grout, gypsum-based, gypsum plaster, site-specific, design, water-reduced

Abstract: Lack of adhesion between plaster layers, resulting in delamination, is a widespread deterioration phenomenon in wall paintings. Research on injection grouting for the stabilisation of delaminated wall paintings and historic plasters mostly focuses on hydraulic lime/lime-based and/or earthen-based grouting; in the literature, such binders may be used in combination (ex. earth-lime) and also for original materials even with a different chemical composition. Studies on historic gypsum-based plasters focus on their characterization (Freire et al. 2012, 2020) and compatible repair plasters (Freire et al. 2011, 2013, 2021). To the authors' knowledge, the design and study of injection grouting compatible with gypsum-based plasters has not been addressed and is absent in the literature. Gypsum has never been considered for grouting of gypsum-based plasters even if it has been used as a constituent material of wall paintings since ancient times. This paper presents the investigations on the use of gypsum as the binder for injection grouts to be used in the conservation of gypsum-based wall paintings. Grout mixtures were specifically designed for the stabilisation of the gypsum-based plaster in the Ateni Sioni church in Georgia. The building itself dates back to 7th-century while the wall paintings are from the 11th-century. The study started with the definition of the problem and, based on the characterization of the original materials included the identification of the site-specific requirements for the grouting materials. The grout mixture design involved extensive laboratory testing to assess the working properties (in the fluid state) and the performance characteristics (in the hardened state) of the grouts, including injection into replicas simulating horizontal delamination present in the ceilings and vaults of the church. General requirements for a grout include adequate adhesion properties: in the case of Ateni where semi-horizontal and/or horizontal surfaces suffer from severe delamination, good adhesion, but also low wet and dry densities, were particularly important. In addition, due to the gypsum sensitivity to water (it is slightly water-soluble), it was important to reduce the water content of the grout, partially substituting it with an alternative liquid, i.e. ethanol (Pasian et al. 2018). The paper will present the methodology, the process followed and the results obtained, which for now are limited to laboratory testing on replica plaster. This research proposes for the first time the use of gypsum as the binder for a grout aiming to stabilise gypsum-based plasters, and it also assesses the use of a water-reduced dispersion medium in a gypsum-based system.

MORPHOLOGICAL EVOLUTION OF CALCIUM CARBONATE CRYSTALS IN DRY HYDRATED LIME MORTAR

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Keywords: Dry hydrated lime, lime mortar, morphology, carbonation, calcium carbonate crystals, characterization

Abstract: Heritage lime mortars, prepared by slaking quicklime for an extended period, are widely used in historic masonry structures. They are highly porous, flexible and allow the egress of moisture from the structure by the property of breathability. Although there are numerous advantages to using lime mortars in masonry buildings, repairing the existing masonry structures with lime mortars involves several practical challenges, including longer setting time, higher shrinkage and slower stiffness gain. Moreover, the ingredients of the mortar are used based on local practices and not with stringent quality ratification. The commercial dry hydrated lime mortar is widely used as an alternative to the air lime mortars to repair and restore heritage structures. It is manufactured by adding water to the crushed quicklime. On application, hydrated lime gets converted to calcium carbonate (CaCO3) by absorbing atmospheric carbon dioxide. Calcium carbonate exhibits different morphology such as calcite, vaterite and aragonite, depending on the local conditions of temperature, pH, carbon dioxide concentration etc. Calcite is the most stable form which can exist in scalenohedral {2134}, rhombohedral {1014} and rosette-shaped crystal habits. During the early stages of carbonation, the polymorph present could be acicular aragonite. Vaterites, the least stable form of calcium carbonate, are spherulites. Amorphous Calcium Carbonate (ACC) could also exist initially as small spheres (size < 1µm), which converts to calcite at a later stage. The present study focuses on carbonating the dry hydrated lime mortar in natural (0.04% CO2) and accelerated carbonation conditions (1% and 3% CO2) to investigate the effect of CO2 concentration in the morphology of calcium carbonate formed. During accelerated carbonation, the excess CO2 molecules which have not already reacted with the portlandite penetrate deeper into the mortar, producing a thicker carbonated area and leading to faster carbonation. When the paste is carbonated naturally, the CO2 molecules immediately react with the surface-portlandite resulting in the slow movement of the front inwards to the core. The study examines the extent of carbonation at various depths and ages of the paste specimens using X-Ray Diffraction (XRD) and Thermo Gravimetric Analysis (TGA). The morphology of the calcium carbonate crystals is examined using Scanning Electron Microscopy (SEM) and XRD. Porosity and pore size distribution of the mix plays a vital role in ensuring breathability to the lime mortars. The influence of carbonation conditions in the porous structure of the mix is examined. Hence, the study aims to reveal the relation between the calcium carbonate polymorph and the resulting breathability of the lime mortar. The study is expected to contribute insight into the relationship between CaCO3 polymorph, carbonation condition and porosity in dry hydrated lime mortar mixes.

AN INVESTIGATION OF THE SALT WEATHERING RESISTANCE OF HERITAGE REPAIR MORTAR MIXES

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Keywords: Salt attack, Repair mortars, Accelerated weathering, Durability, Lime mortar, Characterization

Abstract: Heritage masonry structures are vulnerable to physical, chemical and biological attacks during their long service life. Coastal heritage monuments experience severe deterioration due to their continuous exposure to salt, moisture, wind and temperature variations. The mechanism and extent of damage of the structural components depend on the temperature, humidity and the nature of salt the structure is exposed to. The transformation of sodium sulphate salt from thenardite to mirabilite under favourable temperature and humidity conditions is accompanied by volumetric expansion. The deleterious agents degenerate the structural components and curtail their durability. Hence, along with the physicomechanical requirements, the repair mortar design needs to accommodate resistance to the salt-laden atmosphere. The present study examines the resistance of repair mortar mixes exposed to accelerated weathering. Five mortar samples - dry hydrated lime, lime slaked for one year and one month, and lime with cement replacement (20% and 50%) were considered for the study. The physicomechanical characterization of the mortars, including compressive strength and density, was carried out before exposing the mortars to accelerated weathering conditions. Mortars cubes of size 50 mm x 50 mm were introduced to accelerated weathering. They were subjected to alternate wetting drying cycles by immersing in 10% anhydrous sodium sulphate solution followed by drying in an oven and air for a fixed period. Surface changes in the mortar systems were examined visually after each weathering cycle. The mineralogical alterations in the mortar were studied using microanalytical techniques like X-Ray Diffraction and Thermogravimetric Analysis before and after weathering. The results suggest that the replacement of lime with cement increases the weathering resistance of the mortar mix. The study would contribute to the understanding of the influence of slaking age of lime and cement content on the weathering resistance of the repair mortar mixes. It is expected to provide new insights on the salt weathering resistance of the repair mortar compositions.

DESIGN RATIONALE AND FIELD TESTING OF A GYPSUM-BASED GROUT FOR WALL PAINTING STABILIZATION IN THE CHAPEL OF NIKETAS THE STYLITE, CAPPADOCIA, TURKEY

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Keywords: Gypsum, injection grout, wall paintings, field testing

Abstract: The interior of the rock-cut chapel of Niketas the Stylite (also known as the church of Üzümlü, in Kizil Çukur, Cappadocia, Turkey) is decorated with 6-8th C CE wall paintings on gypsum plaster, applied directly to a volcanic tuff support. As part of a broader program to develop conservation strategies for the external rock fabric and interior wall paintings (conducted between 2015-16), it was found that the gypsum plaster was affected by extensive detachment which required stabilization through injection grouting. This paper presents the rationale which guided the preliminary development of calcium sulphate hemihydrate (CaSO4·0.5H20)-based injection grout formulations for this purpose and their testing in the field. Research into the development of appropriate materials for the conservation of gypsum-based wall paintings is limited compared to studies focusing on lime-based paintings. In particular, there are very few examples of the development of proprietary gypsum grouts for the conservation of wall paintings on gypsum plaster, and most are not published. This study therefore began with a review of existing literature to support the selection of gypsum-based materials for the conservation of paintings on gypsum plaster, exploring the possible risks of using lime-based repair materials, and potential risks and benefits of working with gypsum instead. Aspects of original painting technique, environmental conditions at the site and an assessment of causes of deterioration of the wall paintings were factored into decision-making. Following this research phase, an initial treatment development campaign focused on field testing to evaluate grout mixes containing hemihydrate combined with a range of aggregates, fluidizers and set retardants. The grout mixes were tested in the field against clearly-defined working properties and, where possible, some of the performance characteristics for the intervention. Existing field-testing protocols were followed but adapted as necessary to the working conditions, context and materials of the site and paintings. This paper will describe this process, focusing on the rationale behind the materials selection and testing phases, as well as presenting the methods and results of testing. The need for a subsequent phase of laboratory testing, focusing on grout performance characteristics, will be emphasized. Particularities and difficulties of working with calcium sulphate hemihydrate injection grouts will be discussed, and specific risks associated with the use of the various grout constituents highlighted.

COMPARATIVE EVALUATION OF PROPERTIES OF LABORATORY TEST SPECIMENS FOR MASONRY MORTARS PREPARED USING DIFFERENT COMPACTION METHODS

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Keywords: Lime-cement mortars; mortar compaction methods; hardened mortar properties

Abstract: Lime and lime-based materials have been integral parts of masonry construction for thousands of years. In the most recent times, cement-based materials have dominated the masonry market, specifically in the mortar production and use. However, the growing concern regarding sustainability in the built environment along with the compatibility issues of the modern cement and historic structures started shifting the mortar industry's focus towards alternative, more compatible binder solutions. A well-rounded example is SUBLime, a Marie Skłodowska-Curie Action European Training Network. This project combines both industrial and academic efforts dedicated to developing innovative and sustainable building lime solutions. Among others, one of the project's main goals is to transfer laboratory-made lime-based masonry mortar developments to the practical application level. Robust experimental methods are needed to ensure that laboratory-developed products are representative of the real-life structures. For masonry mortars, there are two identifiable sets of properties: fresh-state properties, when the mortar is in its workable life period and hardened-state properties, when the mortar has already set and hardened. In laboratory-scale experiments, some of the hardened-state properties are tested using standard prismatic samples, 160x40x40 mm3 in dimensions as specified in EN 196-1. When moulding, the fresh mortar mixes have to be compacted in order to fill the mould volume completely along with reducing the presence of air gaps and pores. However, there are four different compaction methods applied in laboratory practice. Two of them are cement mortar specific, based on EN 196-1, namely mechanical compaction by jolting, or vibration. The other two are presented in EN 1015-11 standard concerning masonry mortars, and involve manual compaction by either stroking the fresh mortar with a tamper, or tapping the mould on a horizontal surface. This study presents an experimental campaign designed to compare the aforementioned compaction methods based on their effects on the hardened mortar properties. The test masonry mortar is a 1:1:6 mix based on the volumetric proportions of lime, cement and sand, respectively. The fresh mortars are prepared and compacted using the four methods, followed by curing periods of 7 and 28 days. At both of these ages, the prismatic samples are measured to determine their hardened bulk density and then tested for flexural and compressive strengths to evaluate time-dependent density changes and strength gain. Furthermore, at the age of 28 days, mortar specimens are also tested for porosity, pore size distribution and volume using mercury intrusion porosimetry and water absorption capacity by capillarity. The results of density, strength, porosity and water absorption are used to facilitate the comparison between the compaction methods. In general, denser, stronger and less porous samples are produced by means of mechanical jolting or vibration as opposed to manual compaction by tamping or tapping. Nevertheless, drawing conclusions on the selection of a representative compaction method requires thorough consideration of the underlying conditions in the building industry, and in the case of masonry mortars which do not get compacted mechanically during construction, the manual compaction choices may be more comparable to real life.

THE CHALLENGE ON DEVELOPMENT OF THE REPAIR MORTARS FOR HISTORICAL BUILDINGS IN SEVERE MARINE ENVIRONMENT: PAIMOGO FORT, A CASE STUDY

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Keywords: conservation, durability, lime, mortar, performance

Abstract: Portugal has an extensive coastal area where several military fortifications were built with the intention to protect the Portuguese coastline territory from the constant maritime threat. These historical constructions, located near the sea, have been subjected, during centuries, to a very aggressive environment of salty water spray, high humidity, intense sun radiation, large thermal variation, strong wind and sometimes, even to waves' strength. Paimogo Fort is one of these Portuguese fortifications, built in 1674 and located in the cliffs of Paimogo beach, near Lourinhã City. The Fort is classified of public interest since 1957 and, as other coastal Forts from the 17th and 18th centuries has proved to be very well constructed, with well-selected materials and craftsmanship. However, the original air lime renders and plasters had been restored in an intervention of 2006, using hydraulic lime mortars, which present nowadays some surface degradation, especially erosion and loss of cohesion. The Municipality of Lourinhã, who owns the Fort presently, is developing a restoration project with the objective of using the construction for exhibitions and other cultural events. In the scope of this project, an extensive characterization of the existent mortars was made and new repair mortars are being developed. In this study, the development of the durable and compatible new repair mortars for this case study is described. Several innovate compositions, based on the original mortars' composition and characteristics, are briefly described and their main physical characteristics – as capillary absorption and open porosity – and mechanical characteristics – as flexural and compressive strength, dynamic elastic modulus and surface hardness – are analysed and compared in successive ages. Applications of the same mortars on porous composite substrates (bricks with large joints of lime-based mortars) were subjected to real environmental conditions, both in the Fort external area and in a more protected Lisbon urban environment, to check their performance and durability. Conclusions are drawn and the viability of the application of these mortars in coastal environment is analyzed.

PRACTICAL TEST FOR POZZOLANIC PROPERTIES BY A. D. COWPER: IMPLEMENTATION AND INNOVATION

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Keywords: Pozzolanicity reaction, Cowper Method, Repair mortars design, On site test

Abstract: The "ASTM c618" standard defines pozzolans as aggregates for mortars of siliceous or alumino-siliceous origin, which by themselves have little or no cementing value, but when they have been finely divided and in the presence of water, they react chemically with the hydroxide of calcium Ca(OH)2 at room temperature to form compounds with cementitious properties [1]. To confer hydraulic properties to air lime mortars, pozzolans are added to develop formulated aerial lime mortars. The property that made pozzolana precious in the classical age and still quite useful today is the ability of the vitreous material to react with lime and water [2] where the setting reaction of lime with some pozzolans does not require the presence of air, so it can occur in a humid environment, even under water, or in the center of a thick wall. Such characteristics allow the use of a construction technique named by Vitruvius opus caementicium, something very similar to modern concrete technology. In the course of history and in various parts of the world, other volcanic materials were found to possess the same properties as the italian pozzolans. Pozzolans, having different origins, have a variable chemical composition and their reactivity not only depends on this but also on their crystalline structure and their degree of fineness [3]. The degree to which a pozzolan reacts with lime is known as pozzolanicity. The pozzolanicity of a material can vary significantly, even among the same class of materials. Various tests have been developed to evaluate the reactivity of some pozzolans in order to study the feasibility of using an accessible pozzolanic deposit as an addition that can develop formulated aerial lime mortars. Many tests specified in both the literature and international standards require sophisticated and expensive laboratories. For the development of some projects, this type of analysis is out of reach due to the complexity of analysis, their elevated cost and the time it takes to carry out the studies[4]. This research is centered in the review, application, evaluation, and implementation of a simple and on field test to determine if a material has pozzolanic activity. The method was proposed by A. D. Cowper [5] in 1927 in which samples of materials with possible hydraulic action can be tested, after seven days in a qualitative indication of hydraulicity. The efficiency, economy, and the technological transfer impact of this procedure is discussed.

[1] DOI: 10.1520/C0618-19. 2 [2] ISBN 978-0-9827668-3-5 [3] https://oa.upm.es/264/ [4] http://69.63.68.22/practical_action/Construction/Cement%20and%20binders/KnO-100366_Testing%20Methods%20for%20Pozzolanas.pdf [5] ISBN 978-1-873394-29-8 (pbk)

DETERMINATION OF SALT DISTRIBUTION IN THE COMPOSITE LIME MORTAR SAMPLES USING XRF AND SEM - EDX CHARACTERISATION

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Keywords: lime mortars, salt resistance testing, composite samples, salt distribution

Abstract: Although, the salt crystallization is one of the most common causes of the deterioration of lime-based mortars, testing of their resistance to the soluble salt action has not yet been standardized. The problems following the development of the globally accepted testing method are, among others: defining the type of mortar samples, ways of samples' contamination, the type and the concentration of the salt solutions used, environmental conditions during testing, determination of the damage development and the durability assessment. Another task of the testing method is to explain and connect the processes developing in the materials when they are applied in laboratory and real conditions. In this paper, soluble salt resistance testing of lime mortars on the composite samples is presented. The main focus of the paper is on the determination of the salt distribution in this type of samples after the five wetting and drying cycles. Samples consisted of two lime rendering layers (inner – 1/3 and outer -1/1), both prepared according to the experiences found in the literature for these types of lime mortars when applied on historical structures, placed on the natural stone bases. They were cured in laboratory conditions for 90 days, before drying and exposing to soluble salts action. Two types of 10% salt solutions were used for the test: sodium-chloride and sodium-sulfate. Salt contamination was performed by capillary action only in the first cycle, while in the other cycles samples were wetted by deionized water. After the finalization of the cycles, the detached pieces of mortar and efflorescence were removed from the samples. One of the samples from both groups were then cut in two halves, from which one was used for X-Ray Fluorescence (XRF) and another for Scanning Electron Microscopy with Energy Dispersive X-Ray Analysis (SEM – EDX) characterization. For the XRF analysis samples were divided into four layers, and then crushed and sieved through 0.5 mm sieve before testing. For the SEM-EDX analysis the polished thick cross sections were prepared. The paper presents the results of these two analyses, and discusses the advantages and disadvantages of their application for this purpose. Mineralogical analysis of the samples was performed using XRD analysis. It was shown that XRF analysis shows more precise quantification of the elements within one sample, while SEM-EDX analysis gives possibilities for testing of layers with smaller depth within one cross – section.

DEVELOPING A LIME-BASED INJECTION GROUT WITH NO ADDITIVES FOR VERY THIN DELAMINATION: THE ROLE OF AGGREGATES AND PARTICLE SIZE/MORPHOLOGY

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Keywords: injection grout; thin delamination; injectability; aggregate; particle size

Abstract: A thin grout was designed and tested for the stabilisation of the 16th c. Perez d'Aleccio's wall painting cycle of the Great Siege, in the Grandmaster's Palace in Valletta, Malta. The painting, on a one layer-lime-based plaster applied on Globigerina Limestone, presented delaminated pockets estimated to be ca. 0.5 cm thick, with access points just 1.5 mm wide (cracks) to inject the grout. Particularly in the case of wall paintings, it is not advisable to enlarge access points or to open new ones, unless this is done in areas of existing loss and is strictly necessary. When such areas are not present, existing access points such as cracks should be used not to damage original materials and not to alter the composition of the painting. Larger/new access points could not be created in this case. For this reason, the grout could just be injected through very fine needles, a 18G (1.27 mm outer diameter, 0.84 mm inner diameter) and/or 19G needle (1.07 mm outer diameter, 0.69 mm inner diameter, https://darwin-microfluidics.com/blogs/tools/syringe-needle-gauge-table). In general, the design of site-specific lime-based injection grouts to stabilise thinly delaminated (<5 mm gap) historic plasters and wall paintings is a very challenging task, particularly when the grout needs to be injected through very narrow access points, as mentioned. Beside minimal shrinkage and good adhesion and cohesion, very good injectability and flow are crucial in such cases. These are typically improved with the use of natural additives (Biçer-Şimşir et al. 2009, Pasian et al. 2020), or very commonly and more widely synthetic additives such as plasticisers/superplasticisers (González-Sánchez et al. 2020, Duran et al. 2018), which are low-molecular-weight polymers reducing the water necessary to achieve the desired injectability and flow, or improving injectability and flow at a constant water/binder ratio. While plasticisers/superplasticisers allow water reduction and improve rheological properties, a lower water content can lead to reduced porosity and higher mechanical strength, not desirable in the case of highly porous historic plasters with a relatively low mechanical strength, where a non-structural intervention is needed. In addition, degradation of anionic polymers (such as the group of lignosulphonates, i.e. anionic surfactants) can lead to the formation of soluble salts (Flatt and Girardet 2000). The site-specific grout was designed without the use of additives such as superplasticisers, to avoid the problems mentioned above, and included just binder (slaked lime putty), aggregates, water. Different aggregates were selected and tested in different proportion, the variables for the selection of the aggregates being: particle shape (round aggregates, improving injectability Pachta 2021 and angular ones, helping in the overall packing geometry and cohesion Pasian 2021), particle size and different porosity (both having an influence on rheological properties and shrinkage, Pasian et al. 2020). Site testing of the grouts included: injectability, flow on plastered tile, expansion and bleeding, shrinkage and adhesion in Globigerina Limestone cups, cohesion. A very thin grout, passing through a needle 0.7 mm wide, was obtained, having appropriate injectability, flow, cohesion and shrinkage. This was achieved without the use of additives such as superplasticisers, but just relying on the role of aggregates and their particle size.

ENHANCEMENT OF LATENT HEAT STORAGE CAPACITY OF LIME RENDERING MORTARS

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Keywords: Air lime mortars; Phase Change Materials (PCM); Thermal energy storage materials; thermal efficiency, renders

Abstract: Microencapsulated Phase Change Materials (PCMs) were introduced in air lime rendering mortars in order to improve the thermal comfort of the inhabitants and the energy efficiency of buildings of the Architectural Heritage under the premises of minimum intervention and maximum compatibility. PCMs were directly added during the mixing process to fresh air lime mortars in three different percentages: 5, 10 and 20 wt. %. Some chemical additives were also incorporated to improve the final performance of the renders: a starch derivative as an adhesion booster, metakaolin as pozzolanic addition to shorten the setting time and to increase the final strength; and a polycarboxylate ether as a superplasticizer to adjust the fluidity of the fresh renders avoiding an excess of mixing water. The specific heat Cp, the enthalpy ΔH ascribed to the phase change and the melting temperature of the PCMs were determined by Differential Scanning Calorimetry (DSC). The capacity of the renders to store/release heat was demonstrated at a laboratory scale, proving by thermal conductivity measurements the effectiveness of PCMs for the reduction of gaps between peak and off-peak thermal loads as well as for the delay in the appearance of the peaks. The favourable results proved the effect of these PCMs with respect to the thermal performance of these rendering mortars, offering a promising way of enhancement of the thermal efficiency of building materials of the Cultural Heritage.

OBTAINING OF REPAIR LIME RENDERS WITH PHASE CHANGE MATERIALS: INFLUENCE OF THE SUBSTRATES, MECHANICAL AND DURABILITY STUDIES

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Keywords: Air lime mortars; Phase Change Materials (PCM); durability; compressive strength; shrinkage; adhesion; Architectural Heritage; Restoration

Abstract: Different batches of repair lime rendering mortars were designed by mixing microencapsulated Phase Change Materials (PCMs) and other additives. The final aim of these renders is to improve the thermal efficiency of the envelope of the Built Heritage, while allowing the practitioners to apply a render with positive final performance. The combinations of the PCMs in different weight percentages, a superplasticiser (to increase the fluidity of the render keeping constant the mixing water), an adhesion improver and a pozzolanic additive were studied. The adhesion of these renders onto bricks and limestone specimens and the shrinkage and cracking of the mortars were studied in detail. X-ray diffraction technique was used to study the composition and evolution of the carbonation process. Compressive strength measurements were studied in hardened specimens. In addition, the porous structure of the rendering mortars was studied by mercury intrusion porosimetry to assess the effect of the PCMs' addition. Samples underwent accelerated climatic ageing to study their durability and the preservation of the thermal efficiency. Results have shown that these thermally enhanced mortars are feasible materials for real-life application in the context of architectural heritage restoration and conservation.

TIME-DEPENDENT DEFORMATIONS OF LIME-BASED MORTARS AND MASONRY SPECIMENS PREPARED WITH THEM

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Keywords: lime-based mortars, drying shrinkage, creep, deformation, masonry samples, thick joints

Abstract: Lime-based mortars are used for repair interventions of Historic Masonries (HS) which are the bearing elements of old constructions.In historic castles and towers and particularly in cases of thick mortar joints long term deformations are of great interest for the structural stability of the repaired monuments. The exposure of lime-based mortars to drying and sustained loading influences both phenomena of shrinkage and creep. In this experimental work the behaviour of different composition mortars (based on hydrated lime, lime-pozzolan, hydraulic lime and lime+pozzolan+cement) have been studied under sustained load by using spring loaded creep frames.The same type of mortars were also used for the construction of masonry specimens with traditional roman type bricks in successive layers. All specimens, mortar prisms (4x4x16) cm and masonry were placed in moisture controlled room of RH 55-65% and 20o C temperature.Bricks' and mortars' compressive strength has been separately estimating by crushing proper samples. Deformations were recorded for more than 6 months because of drying or/and sustained loading. It seems that strain measured is much higher than in the case of cement based mortars/ concretes. Furthermore, for thick joints the quality of mortar expressed in compressive strength play a crucial role in the total deformation measured.

ADHESIVE STRENGTH ASSESSMENT OF LIME INJECTION GROUT USING STANDARDISED AND MODIFIED TEST METHOD

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Keywords: lime-based grout, pull-off strength, modified test method, sandwich panel, sandwich disc

Abstract: The adhesive strength of non-structural lime-based grouts used to stabilise sensitive detached decorative plasters is an important mechanical property. However, it is difficult to determine it due to the lack of suitable standard test methods. The existing standard procedures are mainly aimed at testing the properties of hydraulic binders and are not suitable for injection grouts or mortar specimens based on lime binder. In the present study, the focus is on the comparison of the pull-off results between the standardised method (EN 1015-12) performed on pre-drilled specimens on sandwich panels (PMS) and the modified method using sandwich discs (DSS). It was found that the modified method with sandwich discs (DSS) achieved up to 58% higher adhesive strength than the standard method with sandwich panels. In the sandwich panel specimens, fracture occurred in the grout since pre-drilling reduced the cohesive strength of the grout. For the sandwich discs (DSS), fractures occurred predominantly in the interface between mortar and grout.

INFLUENCE OF METHYL CELLULOSE IN INJECTION GROUT ON MOULD GROWTH ON MURAL PAINTINGS – PRELIMINARY RESULTS

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Keywords: mural painting, casein binder, methyl cellulose, injection grout, mould

Abstract: Commercially non-structural injection grouts often contain cellulose ether as an additive, mainly to modify the viscosity and stability of the grout. Nevertheless, in our previous field studies we observed mould growth after injection of commercial grout that contained methyl cellulose (MC) as an additive. Therefore, our objective was to determine the effect of MC on mould development after grouting of painted plaster layers. For this purpose, a painted panel sandwich model, simulating delaminated plaster layers, was inoculated with fungal strains isolated from various cultural heritage sites. After incubation (27 days), mould growth was assessed using Calcofluor white fluorescent staining. Our preliminary results show that during the incubation the moisture content on the surface of the dry part of the model increased steadily due to the high humidity in the chamber and the absorption capabilities of the porous plaster. Moreover, grouting increased the moisture content on the surface of the paint layer by ~10%. As a result, fungal stains EXF-15333 and EXF-15047 grew exclusively on the dry injected part of the surface (growth of 30 %) and no growth was observed on the dry non-injected part. Alarmingly, when the mortar was removed, it was revealed that the injected grout in the air pockets had not cured after 27 days.

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