CultTech

Master of Science in
Cultural Heritage Materials & Technologies

Department of History, Archaeology
& Cultural Resources Management
University of the Peloponnese

UNIVERSITY OF THE PELOPONNESE

Elisavet Mantzana

(R.N. 1012201602010)

DIPLOMA THESIS:

“Reactivity and performance characteristics of mosaic lime mortars with different types of ceramic pozzolans”

SUPERVISING COMMITTEE: Dr. Ioannis Karatasios

EXAMINATION COMMITTEE: Dr. Ioannis Karatasios

Dr. Vassilis Kilikoglou

Prof. Nikos Zacharias

KALAMATA, FEBROUARY 2018

I. Acknowledgements

Present thesis constitutes the final project within *CultTech* program, Master in Science in Cultural Heritage Materials and Technologies by the Department of History, Archaeology and Cultural Resources Management, Faculty of Humanities and Culture Studies, University of the Peloponnese. The work described in this thesis has been carried out on laboratory of Institute of Nanoscience and Nanotechnology of the National Centre for Scientific Research “Demokritos”.

First of all, I would like to thank my supervisor Dr Ioannis Karatasios for the patient guidance and knowledge he has provided throughout the whole process. Also I would like to express my gratitude to Prof. Nikos Zacharias and Dr. Vassilis Kilikoglou for their interest and their useful advices. Special thanks go to two *CultTech* program members Dr. Eleni Palamara and Vasiliki Valandou for their encouragement and advice they have offered throughout the last year.

Finally, I must express my very profound gratitude to Popi, Eleni, Ilias and Konstantinos for providing me with unfailing support, continuous encouragement and real help. This accomplishment would not have been possible without them. Thank you.

II. Table of Contents

I. Acknowledgements 1
II. Table of contents 2
III. Table of tables, diagrams and maps 4
IV. Abstract 9
V. Introduction 10
VI. Main text
1. Ancient mosaic pavements. 11
1.1. Description and Terminology 11
1.2. Mosaic pavements origins 15
1.3. Mosaics and architectural context 19
2. Construction technology of ancient mosaic pavements 21
2.1. Stratigraphy of mosaic pavement structure 21
2.1.1. Stratigraphy investigation of mosaics in Greece 23
2.2. Mosaic construction materials 30
2.2.1. Tesserae materials 30
2.2.2. Historical substrate mosaic mortars 32
2.2.3. Pozzolans 33
2.2.4. Ceramic materials as artificial pozzolans in lime mortars. The Cocciopesto mortars 35
3. Gymnasium mosaic floors in Chalkis in Euboea 37
4. The conservation of mosaic pavements 41
5. Literature review 45
6. Aims of thesis research 49
7. Methodology of research 50
7.1. Ceramic materials and mortars preparation 50
7.1.1. Selection, preparation and firing of ceramics 50
7.1.2. Preparation of air lime mortars with ceramic and clay admixtures 51
7.2. Thesis research analytical methods 52
7.3. Analytical techniques 54
7.3.1. Stereomicroscopy 54
7.3.2. X-ray diffraction (XRD) 54
7.3.3. Scanning Electron Microscopy coupled with X-ray detector EDX 55
7.3.4. Differential Thermal Analysis 55
7.4. Physical and Mechanical strength tests 57
7.4.1. Porosity 57
7.4.2. Compressive Strength Test 58
7.4.3. 3 Point Bending Test 59
***8.* Results**
8.1. Stereomicroscopy 61

8.1.1. Laboratory prepared mortar samples with ceramic and clay admixtures 61
8.1.2. Historic mosaic mortar substrate sample from Chalkis 62
8.2. Scanning Electron Microscopy / EDX 64
8.3. X-ray diffraction (XRD) 66
8.4. Porosity 67
8.5. Mechanical strength performance 71
8.5.1. Compressive Strength Test 72
8.5.2. 3 Point Bending Test 76
8.5.3. Historic mosaic mortar sample from Chalkis mechanical properties 78
9. Discussion 79

VII. Bibliography 82
VIII. Appendix A – Compressive strength results 87
IX. Appendix B – 3 point bending strength results 101

III. Table of figures, tables, graphs and diagrams

Figures **Page**

1. Two of the most famous emblemata works of Dioscorides of Samos (www.commons.wikimedia.org/wiki). 14
2. Banquet leftovers, or *Unswept Floor*, mosaic. Vatican museum. (www.commons.wikimedia) 14
3. Walls made of terracotta cones from Uruk, Mesopotamia Staatliche Museum in Berlin. 3,000 B.C. (www.icom.museum/resources) 15
4. Nereid seated on a seahorse. Pebble mosaic of andron in the 'House of the Mosaics" at Eretria. Mid 4th century BC. (Swiss School of Archaeology in Greece) 16
5. Lion hunt. Pebble mosaic floor from Pella Museum. Late 4th century BC. (commons.wikimedia.org) 17
6. Subterranean room in the House of Amphitrite, Bulla Regia, Tunisia. Courtesy of the Getty Conservation Institute. Photo by Scott S. Warren (www.getty.edu/art/exhibitions/roman_mosaics) 20
7. A graphic reproduction of floor mosaic stratigraphy as it is described by Vitruvius in *"The Ten Books of Architecture"*. (The Getty Conservation Institute) 23
8. 'House of the Mosaics' in Eretria (early 4thcentury B.C). Pebble mosaic pavement from the *Andron*. (Ducrey P.,1993, p.93) 26
9. Different periods mosaic pavements stratigraphy from various Hellenic archaeological sites (Papayianni I.,2008 p.440) 26
10. Mosaic samples from Palace of Aegae (Starinieri V.2009 p.95 & 98) 27
11. Schematic graphic reproduction of the stratigraphy of the mosaic of the *Augusteum*, Roman city of Dion (Starinieri V.2009 p.37) 27
12. Ancient city of Dion. Left: The mosaic of the Polygon. Right: The mosaic of the bathhouse of Villa Dyonisos (Starinieri V.2009 p.52 & p.58) 27
13. Ancient city of Dion. The mosaic from the west atrium of the House of Epigenes. Right: The mosaic from the atrium of the House of Eubulus. (Starinieri V.2009 p.44 & p.48) 28

14. Ancient city of Dion, the west atrium of the House of Epigenes and the mosaic from atrium of the House of Eubulus. (Starinieri V.2009 p.44 & p.48) 28
15. South side of mosaic pavement B. Archaeological site of Roman gymnasium in Chalkis, Late 3rd century A.D. (Mantzana E.) 28
16. An overview of the mosaic pavements in Roman gymnasium in the city of Chalkis. (Mantzana E.) 29
17. South side of mosaic floor A. Mosaic substrate with one mortar layer on top of big ashlar (Mantzana E.) 29
18. East side of mosaic floor A. Mosaic substrate mortar layers on top of big ashlars. (Mantzana E.) 29
19. East side of mosaic floor B. Mosaic substrate with two mortar layers (Mantzana E.) 29
20. Lion hunt detail. Pebble mosaic floor from Pella Museum. Late 4th century BC. (www.global-geography.org) 30
21. Geographical map of ancient stone quarries and Roman roads (Fiorentini I. 2002, p.206) 31
22. Pozzolanic Lime Cycle (Rogers S. 2011 p.20) 34
23. Cocciopesto mortar example from the Roman gymnasium in the city of Chalkis. (Mantzana E.) 36
24. Cocciopesto mortar cross section sample in stereomicroscope. Detection of reaction rims on brick – lime interface (Mantzana E.) 36
25. Aerial photography of Chalkis (Mantzana E.) 37
26. The top view of the mosaic pavements of the archaeological site of the Roman gymnasium in Chalkis (Mantzana E.) 37
27. Roman gymnasium in Chalkis. Mosaic floor, south central scene, wrestlers in action. (Mantzana E.) 38
28. Roman gymnasium in Chalks. Mosaic floor, west central scene. A pair of boxers at the end of their competition. (Mantzana E.) 38
29. Mosaic floor remains in Atalanti (www.helenmilesmosaics.org) 41
30. Deterioration phenomena in mosaic pavements (Mantzana E. / The Getty Conservation Institute 2003) 42

31. Detached tesserae in mosaic floor in Ostia of Italy. (The Getty Conservation Institute 2003www.blog.travelmarx.com/2010/11/mosaic-and-marble-floors-of-ostia.html) 42
32. Proposed framework of requirements (Van Balen K. et al.,2005 p.782) . 44
33. Mosaic of Tragic Mas from the House of the Faun in Pompeii. Archaeological Museum of Naples (www.gettyimages.com) 49
34. Thermal analysis results for Thrapsano and Agios Syllas clays 50
35. Mortar sample from the mosaic pavement of roman gymnasium in Chalkis and fragments from the Tessellatum layer in storage (Mantzana E.) 53
36. Authentic mosaic mortar rectangular prisms and samples, before mechanical properties tests. (Mantzana E.) 53
37. Measuring ranges of different methods for determination of porosity and pore structure parameters and radii ranges of relevance for different transport phenomena (Meng B. 1996 p. 196) 58
38. Schematic representation of uniaxial compressive strength test (Γιαννακόπουλος K. 2011 p.14) 58
39. Rectangular sample under a load in a three-point bending set up (en.wikipedia.org/wiki/Flexural_strength#/media/File:Beam_3pt.png) 59
40. Laboratory prepared lime mortar samples. Images from stereomicroscope 61
41. Reference mortar sample with Metakaolin admixtures 61
42. Stereomicroscopy images from historic mosaic mortar samples from Chalkis. 62
43. Stereomicroscopy and Scanning Electron Microscopy images with EDX results of laboratory prepared lime mortars 64
44. The comparison of SEM images of lime mortar specimens 65
45. X – Ray Diffraction results of laboratory prepared lime mortar samples with ceramic admixtures Thrapsano and Agios Syllas........ 66
46. Laboratory lime mortar specimens with ceramic admixtures, ancient mosaic mortar sample, after the completion of mechanical properties tests. The INSTRON machine of “NCSR DEMOKRITOS” during compressive strength test........ 71
47. Specimen of LAS 580 of 6 months mature compressive strength 72

48. Laboratory prepared lime mortars with ceramic admixtures during 3pb strength test. 76

Tables

1. Results of mortars analysis from the study of IA Ephorate Prehistoric and Classic Antiquities in Euboea. (Mantzana E. et al. 2014. ΔK1 &ΔK2 mosaic mortar analysis . Appendix A) 40
2. Functional and technical requirements according Van Balen and others (2005) 44
3. Published researches analyzing old mortars with coarse ceramic fragments (Matias G. 2014 p.6 &17) 46
4. Published works as far as concern mosaics stratigraphy and analysis of substrate mortars (Mantzana E.) 47
5. An overview of research analytical techniques.................................... 60
6. The percentage porosity measurements of laboratory prepared specimens and ancient mosaic mortar sample 68
7. Water absorption of laboratory prepared mortar specimens 69
8. The percentage relative increase of compressive strength among 28 days and 6 months performance... 73

Diagrams

1. Grain size distributions of aggregates from mortars ΔK1 and ΔK2 (Mantzana E. et al. 2014 . Appendix A) 40
2. Graphical representation of mortar specimens water absorption 70
3. Thermal Analysis results for laboratory prepared mortar samples. 74

Graphs

1. Percentage porosity results for laboratory prepared lime mortars with Metakaolin, ceramic admixtures (Thrapsano & Agios Syllas) and ancient mosaic mortar sample 67

2. Total results of compressive and 3pb tests for the laboratory prepared specimens and ancient mosaic mortar sample 71
3. Compressive strength results for laboratory prepared and authentic mortar specimens. 72
4. The diagram of lab-prepared mortar samples with ceramic admixtures of Thrapsano and Agios Syllas.. 75
5. The total results of 3 point bending strength 76
6. Mechanical properties of mosaic mortar sample from Chalkis 78
7. Compressive strength results for laboratory prepared mortar samples with ceramic and clay admixtures 80
8. Water absorption results 81

IV. Abstract

The purpose of the present research is the analysis of lime mortars as far as their ceramic pozzolans admixtures are concerned and has been mainly inspired by the technology of mosaic floors and cocciopesto mortars. The attention is focused on the reactivity and performance characteristics of ceramic materials once they are added into a lime mortar. The first part is composed by a brief presentation of mosaic floors, their construction materials and technology. Consequently, in situ mosaic conservation and new repair mortars requirements are discussed, in order to determine the context of that type of interventions. Finally, the theoretical part is completed with a literature review of previous research works related to the subject.

The part of experimental methodology is based into two types of clays, Metakaolin as reference material and an authentic mosaic mortar substrate sample. The chosen clays, a calcareous Agios Syllas and a non-calcareous Thrapsano come from areas of Crete. Ceramic substances were created by firing those clays in two different temperatures. Subsequently, seven lime mortar mixtures containing these ceramics in very fine particles were prepared and left to mature (LMtk, LTHRaw, LTH550, LTH700, LASRaw, LAS550, LAS700). The specific specimens, as well as the ancient sample, were tested for their pozzolanic reaction and their mechanical properties after 28 days and then again after 6 months of maturation. The analysis was carried out with Thermal analysis, XRD, SEM/EDS, water absorption, compressive strength and 3 point bending test.

The results indicate differences between the calcareous and non-calcareous ceramic admixtures concerning their pozzolanic reactivity and that is also reflected on their mechanical properties. Furthermore, useful conclusions were derived from their firing process, since there are differences between ceramics fired in 700^{o} C and 550-580^{o} C.

V. Introduction

Mosaics are a significant form of art. Due to their durability characteristic important information has survived not only concerning artistic values but technological as well. Motivated by mosaics' sophisticated construction techniques and materials, the present research is focused on mosaic floors technology. More precise, the subject of interest is the substrate lime mortars with ceramic admixtures known also as *cocciopesto*. This study is aiming to determine the role of ceramic admixtures in lime mortars but also to detect any pattern of preference in the use of specific types of ceramics, as mortar admixtures. To fulfill these purposes, mortar specimens were analyzed. Laboratory prepared lime mortars with ceramic and clay admixtures but also an authentic substrate mosaic mortar were the research samples. The whole effort ultimate goal is to offer more information as far as concern potential raw materials for new repair mortars. Especially for the in situ mosaic floors structures that face many challenges in order to be preserved.

VI. Main text

1. Ancient mosaic pavements.

1.1. Description and Terminology

To the present day, the word *mosaic* defines with sufficient precision the creation of a particular type of artifact that is produced by using a certain type of techniques and materials, under specific conditions. More precisely, a mosaic is the result of an artistic technique that generates mostly flat surfaces, with geometric or figurative patterns[1]. This process consists of fitting together side by side small pieces of various materials, that can be artificially or naturally shaped. Throughout the ages, the materials that have been mainly used are pebbles, marble and coloured stones, enamel glass, ceramics, ivory shells and semiprecious stones. The shape of these pieces can be cubic, squared, irregular or even rounded in the case of pebble mosaics. All these different pieces, known as *tesserae,* that constitute the mosaic surfaces are held in place by mortar and are separated by visible interstices.

For more than one thousand years, from the late Classical period to the late Antique, there has been a significant evolution and flourishing of the pictorial, figurative and ornamental aspects of the mosaic technique, as well as its elements of composition, that transformed the production of mosaics into a significant form of art in its own right. Furthermore, mosaics of a more artisan nature have been serving practical functions and they were a part of everyday life in houses or public buildings. One of the reasons behind that

[1] Their appearance, however, could vary enormously, ranging from plain monochrome floors into simple designs in two colors, usually black and white to the most elaborate of polychrome geometric patterns, to floral and vegetal motifs, but also figured scenes. These in turn could range from simple designs using isolated figures to highly ambitious narrative compositions. Mosaics could also serve as the support for written texts, ranging from single words to quite lengthy verses. (Dunbabin p.1)

was the high durability of the materials used and the most significant characteristics are their resistance to wear and water, but also their inalterability of colour (Farneti M. 2001 p.23). The double role of mosaics - artisan and works of art- seems to be the reason for their establishment and widespread application in domestic contexts, as well as in monumental decorations.

It is very difficult to define exactly the precise origin of the word *mosaic*, as even the ancient writers were not exact or in agreement concerning its starting point. Actually, various terms have been used to describe the same thing. However, the most ancient manuscripts help us by defining *Mosibum* as something having a root compatible with another ancient term, *De Musivo*. An epigraph discovered in Tunis reads *Opere Museo*. Also in one of Emperor Constantine's laws, mosaicists - the mosaic manufactures - were named as *Musivarius*. There is also a question for the derivation and the ethnic roots of the word mosaic, if it is Hebrew or Greek. Finally, the most dominant theory supports that the term *mosaic*, or the Italian *mosaic*, derives from the Latin *mosaicus* and ultimately from the Greek *mouseios*, meaning *belonging to the Muses*. Moreover, the term 'opus' is the Latin for 'work' and refers on the way in which the pieces are cut and placed (Fiorentini 2002 p.9).

During the Roman period the mosaic art flourishes and the various styles and techniques acquire their own individual names that are used even today. The most known are:

i. Opus Alexandrinum: A technique that uses cubic tesserae from tough materials, such as stones and it is similar to the opus sectile. It is named by the emperor Alessandro Severo (222-235 A.D.) whose palace was covered with this kind of mosaic (Fiorentini 2002 p.9).
ii. Opus Tesselatum: The mosaics that are made with small cubic tesserae with dimensions of 0,5 to 2cm. The materials in this case are calcareous rocks and medium hardness marbles.
iii. Opus Vermiculatum: The term refers on the multicolored mosaic floors with very small tesserae size, often not bigger than 3 mm and with even 63 tesserae per cm^2. This technique could be found in mosaic

icons, in Greek and Alexandrian mosaic panels, but also in the finest parts of Roman mosaics as well.

iv. Opus Signinum: An ancient technique for the creation of pavements, in which black or white tesserae are placed on a layer of lime mortar with ceramic dust and fragments. The tesserae are forming geometric patterns without filling the whole surface.

v. Opus Sectile: Distinct mosaics technique in which pieces of stone (often marble) are formed and placed on the surface in order to create geometric and figurative themes.

vi. Opus Segmetatum: A technique identical to the Opus Sectile as far as the size and shape are concerned, but not the thickness of the slabs, which is smaller.

vii. Opus Musivum or Musaeum: These terms are used to describe the wall and vaults mosaics that are made with glass, enamels and marble tesserae.

viii. Emblema: Mosaics with central representations in squared, rectangle or rounded shape. The Emblemata were made of opus vermiculatum by expert mosaicists and the most capable workshops (fig.1). This type of mosaics was surrounded by two or three zones of geometric motifs, for which opus tessellatum or opus sectile were used. Usually the richest marbles and colored glass were used for the tesserae. These types of mosaic were embedded either in special earthenware containers or on marble slabs. They could be transferred and placed in the floors or in walls of important houses and public buildings. The famous Greek mosaicist Sosus of Pergamon is considered as the father of this specific technique (2nd century B.C.) (Χαραλάμπους Ε. 2012 p.128) (fig.2).

ix. Crustae: This technique is used in floor mosaics and uses various colors, irregular pieces of marble in combination with tesserae in black mortar supporting layer.

x. Opus Barbaricum: Floor mosaics in which the tesserae never have squared shape and there is no specific order or design on the final result.

Figure 1. Two of the most famous eblema Left: A scene from a play by the comic playwright Menander. Right: Theatre scene, two women making a call on a witch (the three of them wear theatre masks). Roman mosaics from the *Villa del Cicerone* in Pompeii, now in the Museo Archeologico Nazionale (Naples). Works of Dioscorides of Samos (www.commons.wikimedia.org/wiki/File:Pompeii_Villa_del_Cicerone)

Figure 2. Banquet leftovers, or *Unswept Floor*, mosaic. Inspired by Sosus of Pergamon, Museum Gregoriano Profano, Vatican. 4.05 x 0.41 m. (www.commons.wikimedia.orgwikiFileRestes_du_banquet,_mosa%C3%AFque.jpg)

Mosaics are distinguished into two main categories, the floor mosaics and the wall and vault mosaics. Their distinction of course is based on the different architectural features on which they are located. In both cases most of the materials of tesserae and substratum mortars are the same. Alterations have been found on the stratigraphy and ingredients of their supporting mortars. Elm root, linseed, tufaceous material and glues of any kind have been added in ancient wall mosaics mortars in order to modify their properties. A characteristic example are the mosaics found in areas under the eastern Byzantine influence, where lime was mixed with vegetable fibres in order to make the mixture lighter (Fiorentini 2002 p.133).

1.2. Mosaic pavements origin and evolution

The origin of the mosaic technique is a subject that always divides the opinion of scholars. The different theories argue that the mosaic art comes either from the East, namely Mesopotamia, or Crete in Greece (Χαραλάμπους E. 2012 p.126). In the case of Mesopotamia, archaeological finds in the Uruk temple of Chaldea give evidence that the Sumerians, in the 4th millennium BC, used colored cones of terracotta as “tesserae” to decorate walls with geometric patterns (fig.3) (Farneti M. 2001 p.25). On the other hand, pavements with plain or colored pebbles into clay or plaster have been revealed in Crete, dating back to the early Neolithic period and then used by both the Minoan and Mycenaean civilizations. Nowadays, the second theory is regarded as the most acceptable.

Figure 3. Walls made of terracotta cones from Uruk, Mesopotamia (Iraq) now in Staatliche Museum in Berlin. 3,000 B.C.(www.icom.museum/resources)

Most scholars support that the mosaic technique as it has developed in the Classical and Hellenistic period, could not have originated from the early example of Mesopotamia. Such a faraway derivation has long been discarded and the mosaic technique is rather being seen as an indigenous development in Greece (Dunbabin M.D.K.,1999, p.5). Consequently, the earliest decorated mosaics are dated in the late 5^{th} century BC, with the largest group consisting of the pebble mosaic floors of Olynthos (432 century BC). Such early examples are also the pebble mosaics from Corinth, Sikyon and Eretria in Euboea (fig. 4). This group that has been found mostly in private houses belongs to the late Classical period, from the early fourth century down to 340 BC. These pavements are considered to be evidence of luxury and especially in the case of the pebble mosaic floors from the House of Mosaics in Eretria, an initial effort for naturalism, representation of space and third dimensional effect. These precursors introduce the pebble mosaics of the Hellenistic period (last third of the 4^{th} century BC) from Pella in Macedonia. This specific group consists of outstanding examples that seem to imitate or compete the achievements of painting through the pebble mosaics' technique (Dunbabin M.D.K.,1999, p.10) (fig.5).

Figure 4. Nereid (female sea spirit) seated on a seahorse, Arimaspians confronting griffins, panthers and lions hunting deer. Pebble mosaic of andron in the 'House of the Mosaics" at Eretria. Mid 4^{th} century BC. (Swiss School of Archaeology in Greece).

Figure 5. Lion hunt. Pebble mosaic floor from Pella Museum. Late 4th century BC. (commons.wikimedia.org/wiki/File:Lion_hunt_mosaic_from_Pella.jpg)

The transition from pebble to tesserae was gradual. Focusing on the 3rd century BC it would seem that it was a period of experiments and attempts to combine different mosaic techniques. In these experimental examples the pebble mosaics have been enriched with irregular tesserae such as cut pieces or stone chips, but also cubic tesserae[2]. Pebble mosaics haven't disappeared completely. The technique was still in use afterwards but only sporadically, in areas close to riverbeds and seashores, where raw materials where available (Ασημακοπούλου – Ατζακά Π. 2003, p.23). Concerning the change of materials, Dunbabin (1999 p.18) argues: "There is no direct and uniform passage from pebble mosaics to tessellated, with intermediate techniques transitional between them". The mosaics of that period, even though they are characterized as heterogeneous in technique and style, they also clearly indicate that alteration of materials. The use of cut stones offered to mosaicists an enriched color palette, due to the multitude of hues of natural

[2]A characteristic example is a pavement in Rodos island from the 3rd century BC, in which the central theme is made with cubic black and white tesserae but the rest of the surface is a pebble mosaic (Χαραλάμπους Ε.2012 p.127). Another example, even in its present poor condition, is the mosaic from the pronaos of the Zeus Temple in Olympia (after the mid-third century BC). Also in that case most of the surface is covered with pebbles but small pieces of red, yellow and white stones have been used in details of the figures (Dunbabin M.D.K.1999 p.5).

stones, but also flat and even surfaces. The elevated aesthetic effect of this new technique advocates to its future success and widespread use in the subsequent periods. Consequently, after the 3rd century BC, the mosaics obtain a prominent place among the arts and are capable from now on to give unique artifacts with interesting aesthetic perspective, but can also testify the social position of their owner. The technique of artificially shaped tesserae was established in the second half of the 2nd century BC in the broad Mediterranean area and continues until the late antiquity (Ασημακοπούλου – Ατζακά Π. 2003,p.21). On the other hand, the squared tesserae mosaics manage to be very popular since the Hellenistic period (1st century B.C.). Their highest achievements are the emblemata, that are characterized as paintings in stone and are distinguished for their polychromy and their effects of light and shade, that indicate volume and perspective.

Even though the mosaic art originated in Greece, it has flourished and been imposed to the known world during the Roman period. Mosaics in the 1st century BC were one of the most popular forms of art and many important production centers can be mentioned all over the Roman Empire. After the Romans conquered Greece, they came into contact and embraced various types of art, including the mosaic art, so by adopting the Greek patterns and decorative motifs they firmly established a new stage in the historical evolution of this artistic technique. Some specific parameters played a significant role in that transition. First of all, the fact that in roman times a vast variety of materials such as marble and other stones from all over the Mediterranean was available. This easy access was determinant for architects but also mosaic artists that had made a particular use of it (Fiorentini 2002 p.36). Furthermore, the enormous urban expansion that began in the Imperial Age increased the demand for mosaic pavements and the middle classes were the new purchasers that motivated the growth of mosaic constructions. The third factor was the improvement in brick building methods that led to the erection of huge structures. Buildings like baths and basilicas, with extended floor surfaces, required not only to be covered, but also to be decorated with new mosaic compositions. Mosaics in roman period had begun as “luxury items” with limited use but developed into a popular and common form of floor covering. Also remarkable is their expansion over the provinces of the Empire, so that the same themes and mosaic techniques can be found as far apart as Ostia and North Africa, Antioch and Gaul (Farneti M. 2001, p.35).

Afterwards, during the Late Antiquity (3rd to 8th century AD) and like other figurative forms of art of that period, the mosaics gradually abandoned the Hellenistic pictorial naturalism. Figures weren't defined by gradual shading effects but in vibrant colors and clear outlines. Stylization instead of plasticity was produced by two-dimensional themes, in compositions separated into isolated elements placed in any spatial setting. These changes point out the final stage of classic Roman period and the sequential Christian wall mosaics. Mosaic art, mainly in the Byzantine period (5^{th} century and onwards) managed to reach its zenith especially in wall and vault mosaics. The economic development and the political stability were the main factors that assisted that flourishing. Byzantine mosaics had the purpose to instruct by providing figures and scenes that were meant to address the worshipper directly. Mosaics like other forms of art, has passed from the classical phase to a hieratic mode that would last for more than a thousand years (Ling R.1998 p.112).

1.3. Mosaics and architectural context

Viewing and observing mosaic floors as museum exhibits - usually on wall panels - or as illustrations in a book, can be in many ways misleading. Valuable information can be determined by their location inside the building or the style of decoration and certain design types can lead to conclusions about the economical status of the owners or the usage of specific rooms. But all these details are possible to be extracted only if the mosaics are preserved in their original site and its broader architectural context. Floors covered with mosaics are at the same time architectural surfaces and important units of a building and therefore they cannot be considered as individual pictures, but as inseparable parts of the buildings and the people that use them.

Mosaics as architectural surfaces are built with materials and techniques that applied on these types of structures. The combination of inorganic materials and subsequent bending mortar layers has resulted in very durable constructions with an extremely sophisticated methodology.

Figure 6. Subterranean room in the House of Amphitrite, Bulla Regia, Tunisia. Courtesy of the Getty Conservation Institute. Photo by Scott S. Warren (www.getty.edu/art/exhibitions/roman_mosaics)

2. Construction technology of ancient mosaic pavements

In her book «*Mosaics of the Greek and Roman World»* Katherine Dunbabin contends that, "Mosaics are among the most durable forms of decorative art to have survived from antiquity". This specific statement underlays the fact that mosaics, compared to other archaeological finds, have proven to be greatly resistant to wear. Their durability is without a doubt superior in relation to other ancient decorative features such as paintings and wall paintings and the determining parameters to that achievement are the structural technology and the nature of the chosen manufacturing materials used.

2.1. Stratigraphy of ancient mosaic pavements

The way that the mosaic floors were made and the materials that were being used are known to us through the surviving sources of ancient literature, but mainly through the observation of archaeological finds. In the case of ancient written sources, there are several documents that refer to the technology of mortars and how they were manufactured for a variety of structures. Writers like Aristotle (384-322 BC), Theophrastos (372-287/5 BC), Stravon (63/64 BC – 23AD), Pliny (23-79 AD) Dioskouridis (40-90AD) and mainly Vitruvius (authorship 27-23 BC) make mention of the technological issues concerning constructing mortars and their binders, such as lime and pozzolan (PachtaV.et.al. 2014,p.846).

The Roman architect Vitruvius provides the most important ancient written source, concerning the technology of mosaic pavements and their structural materials. His description of the multilayer substrate of mosaic floors (Vitruvius 1914 p.202), included in his work *The ten books of Architecture - Book VII,* is regarded, even today, as an essential bibliographic reference for the description of that technique, according to its frequency of occurrence in studies and scientific articles (Moropoulou A. 2005a p.295; Pachta V. 2014 p.846; Papayianni I. 2008 p.437; Kramar S.2011 p1043).

Vitruvius distinguishes three foundation layers for the construction of a mosaic pavement. These layers are described in detail and concern pavements that are built on ground level. According to the Latin author, the first layer or *statumen*, was made by large rubble stones *“not smaller than can fill the hand”* that were placed on compact and flattened ground. The *statumen* thickness was no less than 23cm (three quarters of a foot). The second layer was called *rudus* and it was a lime mortar with stone aggregates in proportion one to three, which was spread over the *statumen* and was well rammed with wooden beetles*.* Afterwards the third layer or *nucleus* was constructed. The *nucleus* had the thickness of 15cm (six inches) and contained lime and aggregate of crushed terracotta (tiles) in proportion of one to three. Above the *nucleus,* a rich in lime fine mortar was applied, called the *bedding layer,* into which the tesserae or the marble slabs had been pressed. Due to the fact that laying a mosaic is a time consuming process, this lime mortar was prepared fresh and placed in stages for every day’s work, just like it happens in fresco painting (Ling R. 1998 p.11). The *bedding* and *tessellatum layer* were smoothed and rubbed down when the creation of the mosaic was finished. When the surface was completely even and polished, marble powder and a layer of lime and sand were applied. At the end of the whole procedure, the *tessellatum* layer is a composition of tesserae and fine lime mortar that is filling the interstices between them (Starinieri V.2009 p.5) (fig.7).

In general, the above methodology of mosaics’ substrate with the use of multilayer mortars has remained constant throughout the centuries. On the other hand, major changes have been identified on the tesserae manufactured materials and their pictorial results. Consequently, these constitute a major deposit of evidence for the development of mosaic art from Classic period to the Late Antique (Dunbabin K.1999.p.1). Even though this long-term construction technique has remained faithful to its baselines, some alterations can also be mentioned. The most significant is the fact that although Vitruvius’ model is very precise, it doesn’t always match with the archaeological findings, as the surviving mosaic pavements might often reveal differences on the number and thickness of the substratum layers. Nowadays and after a systematic examination of the mosaics’ substrates, it has been derived that the Vitruvius' stratigraphy isn't always present and that many differences can be identified, both in the substratum layers, as well as in the raw materials used for the mortars.

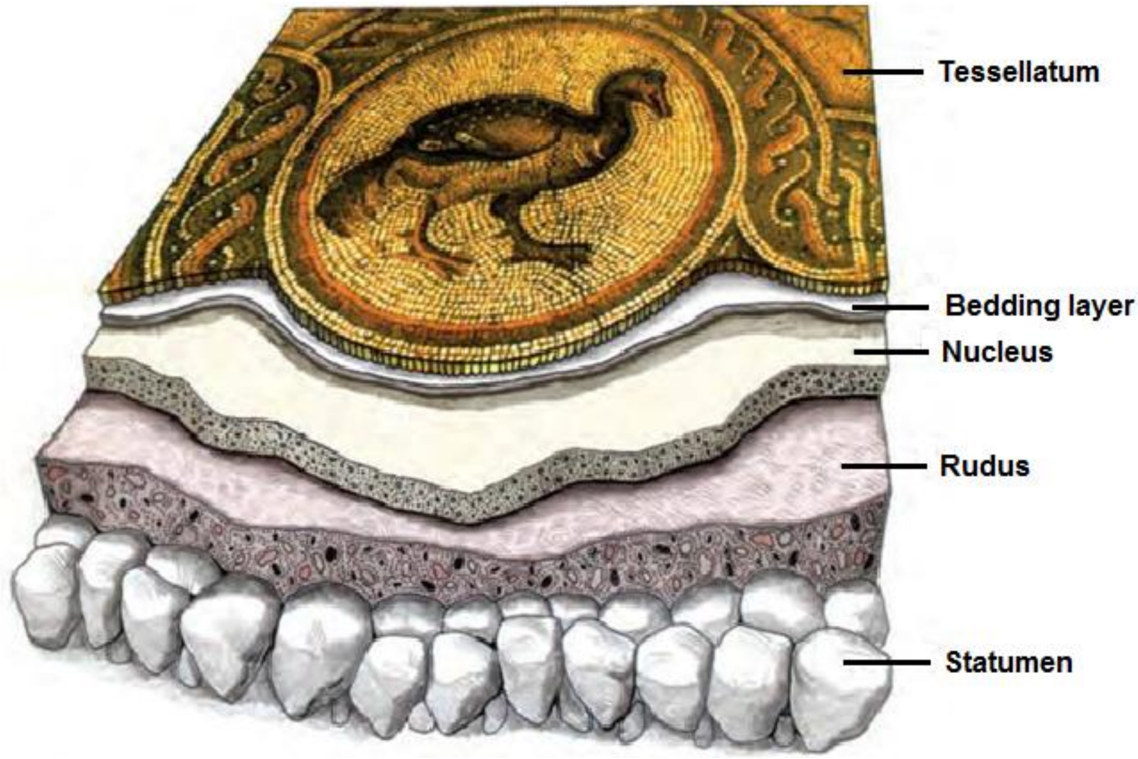


Figure 7. A graphic reproduction of floor mosaic stratigraphy as it is described by Vitruvius in *"The Ten Books of Architecture"*. (The Getty Conservation Institute, 2003 p.17)

2.1.1. Stratigraphy investigation of mosaics in Greece.

In Greece, the research of the mosaics' substratum is neither extensive nor systematic and it cannot provide an integrated database. Nevertheless, there are two studies focused on mosaic stratigraphy from various archaeological sites (Papayianni I. 2008 & Starinieri V. 2009), the results of which are quite informative. In their methodology, the mosaic substrate mortars are analyzed according to their chemical and mineralogical composition, grain size distribution and porosity and the results are directly compared to each stratigraphy formation, thus providing a complete documentation. According to that information and the conclusions drawn, it has become apparent that the construction of mosaic substrates clearly does not follow the Vitruvius model and the most prominent differences are indicated, regarding the chronology, the type of foundation ground and the use of the specific pavements.

Regarding the chronological sequence, Papayianni (2008) in her study claims that the substrates from Classic and Hellenistic period mosaics (cases from Maronia and Pella) are more technical and composed by four layers. This characteristic is also confirmed by the stratigraphy of late Classic period pebble mosaics from Eretria of Euboea. On "*Maison aux mosaïques*" pavements, the archaeological research observed four substratum layers that are constructed with diligence and are comparable with the case of Pella (fig.8) (Ducrey P.1993 p.93). Later on, the variations of substrate structures are reduced and gradually, from four during the Classic times, only two are observed in the Roman and Early Byzantine period (fig.9) (Papayianni I., 2008 p.440). Starinieri (2009) also analyzed mortar layers from the Hellenistic pavements of the Palace of Aegae in Vergina (fig.10 &11) and the Roman city of Dion (fig.12-14). His findings agreed with the previous case as far the general characteristics of well constructed stratigraphy are concerned, but the number of layers is similar only in one pavement from Aegae (fig.11 left). According to his observations it is mentioned that on the same pavement there are differences on the substrate layers (fig.11) (Starinieri V.2008 p.31). The alterations mentioned above, that are also met in Roman period findings, help the researcher in concluding that the morphology of the mosaic substrates is not connected to the chronological periods. On the contrary, it would seem that the structures vary according to the type of building surface, the initial use of the room where the mosaic is located and probably the funding parameters as well.

The existence of a variable number of layers as substrates on the same mosaic pavement is also confirmed by the example of Chalkis (fig. 15-19) (see also Chapter 3), in which, during the implementation of conservation and the enhancement project on the specific archaeological site, the conservators were able to study and document the substrates of two pavements[3]. The results of the *in situ* analysis and observation came to confirm the theory that the mosaics' stratigraphy is depended on the type of surface upon which the pavements are built, as they concluded that both of the mosaic floor substructures were based on top of previous structures and natural leveled ground as well. These older structures are visible in several areas around the mosaics (fig.15) and in some cases consist of big ashlars. These architectural remains are responsible for the construction of multiform mosaic substrates and it seems that each pavement has been ideally adjusted to any underlying distortion and the presence of earlier remains. As a result, it is possible to observe substrates consisting of various numbers of mortar layers in the same pavement. In the example of the mosaics of Chalkis, two different substrates are located over a line of ashlars on the same pavement, either with only one layer (*Tessellatum*) (fig.17) or with three in other areas (fig.18 & 19). On the contrary, wherever the base was naturally leveled ground, the mosaic stratigraphy seemed to be similar with the Vitruvius model (fig.15). Furthermore, in these cases, a *Statumen* layer is distinguished that consists of stones and mainly pieces of ceramic *hypocausts*; probably recycled materials from the surrounding structures. This specific paradigm of mosaic substratum can be characterized as quite complicated but also as very effective. Even nowadays, their stability and state of maintenance are optimal, even though they are exposed to the deteriorating factors of the urban environment since the beginning of the 20th century (Ανδρειωμένου Α. 1961 p.312).

---

[3]The details are presented on the study of 11th Ephorate of Antiquities in Euboea region: Μαντζάνα Ε., Γεωργοπούλου Β., Θεοδωροπούλου Κ., Τσίντζου Α. (2014) Μελέτη Συντήρησης Ψηφιδωτών Δαπέδων Ρωμαϊκής Παλαίστρας στη Χαλκίδα. ΙΑΕΠΚΑΕΣΠΑ 2007-2013 (αρ.πρωτ.1613/20-5-13) Έγκριση ΚΑΣ του ΥΠΠΟΑ: 24/30-7-2013/Αρ.Πρωτ.: ΥΠΠΟΑ/ΣΥΝΤ/Φ25/4301/92 ΑΔΑ:ΒΙ6ΖΓ-Ζ1Φ

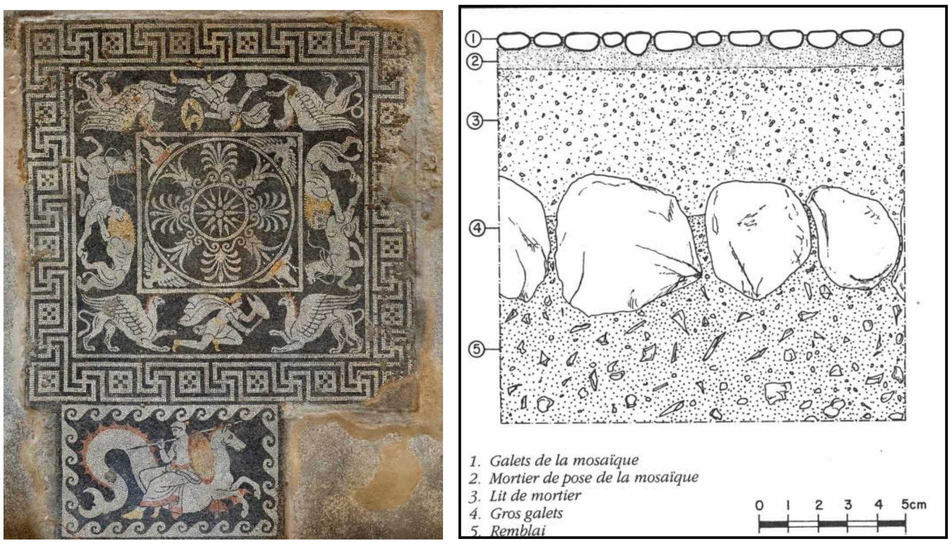


Figure 8. Left: 'House of the Mosaics' in Eretria (early 4thcentury B.C). Pebble mosaic pavement from the *Andron*. Right: Mosaic floor substrate stratigraphy in five layers (Ducrey P.,1993, p.93)

SAMPLE	STRATIGRAPHY	STEREOSCOPIC PHOTOS
1 **Classic** Maronia 4thcent. B.C.	1o 2o 3o 4o pebble	1st 2nd Interaction of tesserae-1st & 2nd layer
6 **Hellenistic** Pella House of Helen's abduction 3rd cent. B.C.	1o 2o 3o pebble	1st 2nd 3rd Interaction of 1st, 2nd & 3rd layer
9 **Roman** Galerius. Palace W.1 corridor 3rdcent. A.C.	1o 2o	1st 2nd Interaction of 1st & 2nd layer
12 **Early Christian** Basilica of Thiva	1o 2o	Tesserae's print in the 1st layer

Figure 9. Different periods mosaic pavements stratigraphy from various Hellenic archaeological sites. The reduction in mortar layers is obvious after Roman period (Papayianni I.,2008 p.440)

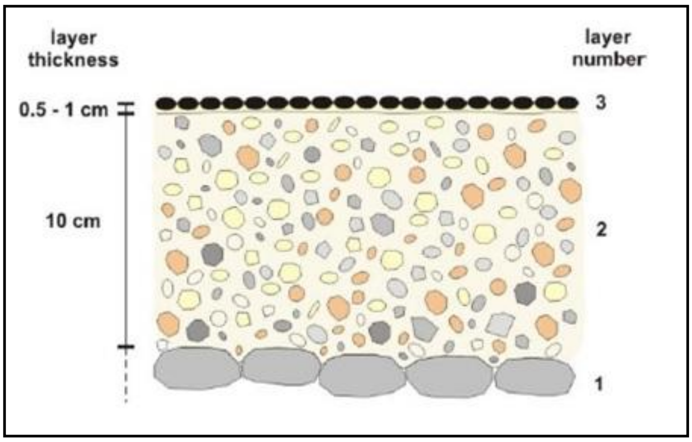


Figure 10. Mosaic samples from Palace of Aegae. Schematic graphic reproduction of mosaic stratigraphy of three substrate layers (Starinieri V.2009 p.95)

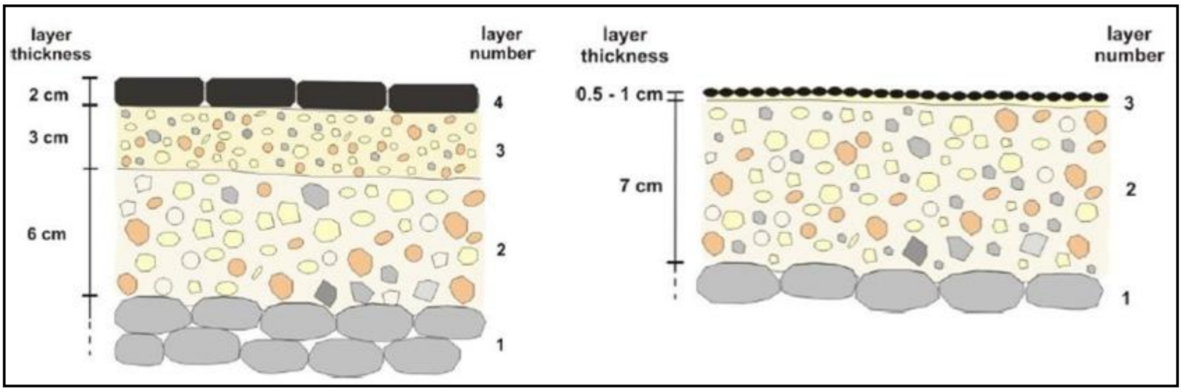


Figure 11. Mosaic samples from Palace of Aegae. Left: Schematic graphic reproduction of the stratigraphy of the mosaic in the inner area. Right: The schematic graphic reproduction of the stratigraphy of the mosaic in the outer frame (Starinieri V.2009 p.98)

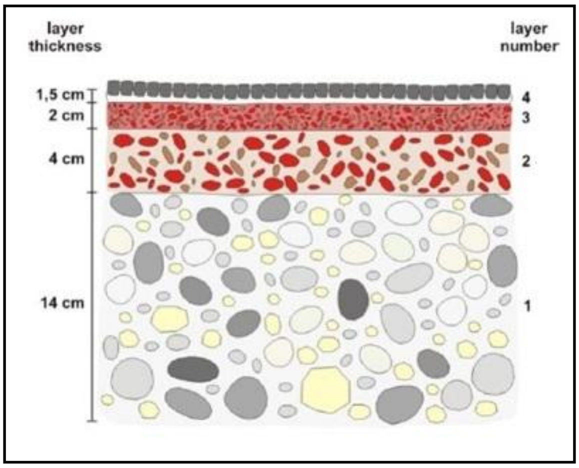


Figure 12. Schematic graphic reproduction of the stratigraphy of the mosaic of the *Augusteum*, Roman city of Dion (Starinieri V.2009 p.37)

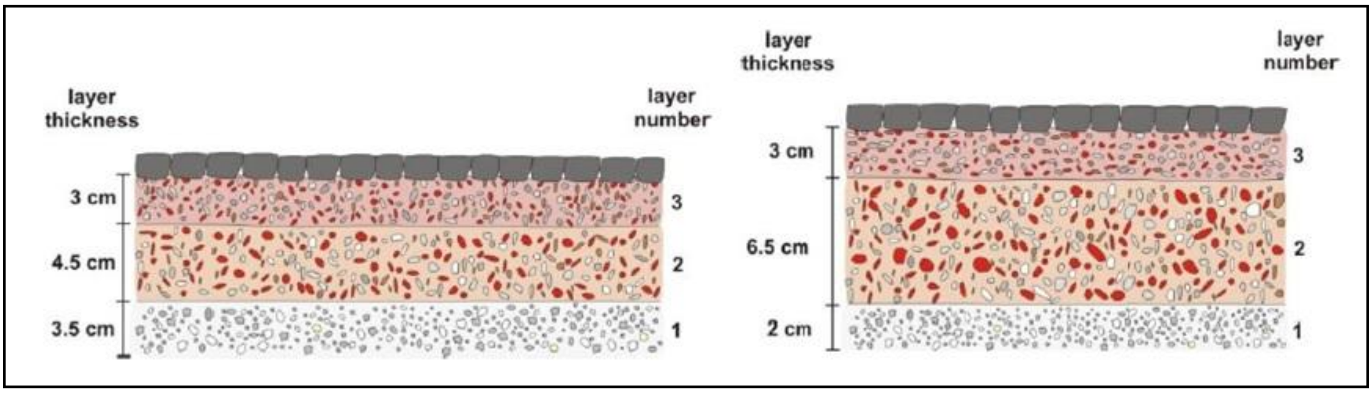


Figure 13. Ancient city of Dion. Schematic graphic reproductions of the stratigraphy of Roman mosaics. Left: The mosaic of the Polygon. Right: The mosaic of the bathhouse of Villa Dyonisos (Starinieri V.2009 p.52 & p.58).

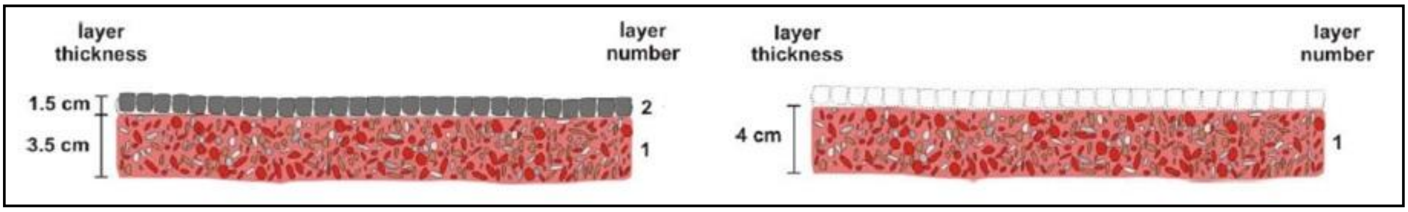


Figure 14. Ancient city of Dion, schematic graphic reproductions of the stratigraphy of two mosaics. Left: The mosaic from the west atrium of the House of Epigenes. Right: The mosaic from the atrium of the House of Eubulus. (Starinieri V.2009 p.44 & p.48)

Figure 15 . Left: South side of mosaic pavement B. Earlier structures underneath mosaic pavements that had been used as base for the substratum layers. Right: East side of substrate mortar layers in pavement A. Archaeological site of Roman gymnasium in Chalkis, Late 3rd century A.D. (Mantzana E.)

Figure 16. An overview of the mosaic pavements in Roman gymnasium in the city of Chalkis. With numbers and lines are distinguished the areas where the substrate layers were examined during conservation project 2011-2013. (Mantzana E.)

Figure 17. South side of mosaic floor A. In figure : Red line (h) area. Mosaic substrate with one mortar layer on top of big ashlar (Mantzana E.)

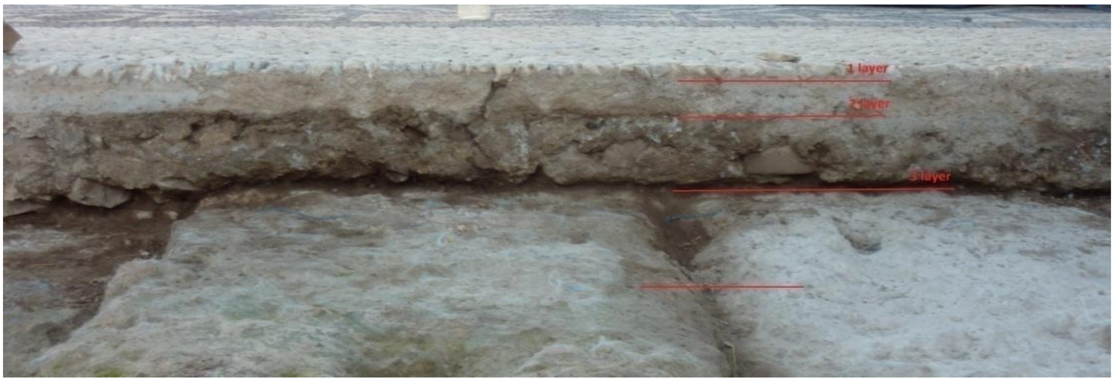


Figure 18. East side of mosaic floor A. In figure: Red line (a) area. Mosaic substrate mortar layers on top of big ashlars. (Mantzana E.)

Figure 19. East side of mosaic floor B. In figure : Yellow line (a) area. Mosaic substrate with two mortar layers (Mantzana E.)

2.2. Mosaic construction materials

Mosaics are composite structures consisting of inorganic materials that are separated into two main groups: Materials that are used as tesserae on the surfaces and mortars that are applied as substrate layers forming the already presented stratigraphy.

2.2.1. Tesserae materials

The materials that have been used as tesserae in mosaic production are limited. Naturally shaped stone pebbles were the first that have been employed during the Classical period and even though they offered a limited color pallet, those first mosaicists managed to achieve remarkable effects of plasticity and realism. The late Classical period mosaics of Pella are fine examples of high-quality results of that category. In these cases, the incorporation of lead and ceramic strips has helped to create details (fig.20). In the middle of the 2nd century B.C., the passage from pebbles to cut stone tesserae is the only and most significant evolution in mosaics construction technology (Ασημακοπούλου – Ατζακά Π. 2003,p.21).

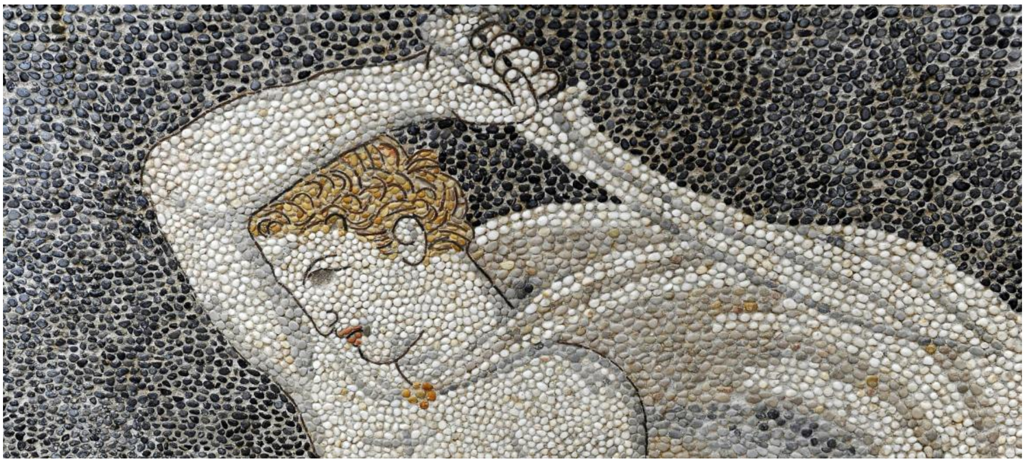


Figure 20. Lion hunt detail. Pebble mosaic floor from Pella Museum. Late 4th century BC. (www.global-geography.org)

The use of shaped stones as tesserae lead to a flourishing of the mosaic art, as marbles, other limestones, but also igneous rocks provided a vast variety of colors. All the known natural sources of stones seem to have been utilized in the production of ancient mosaics, especially during the imperial Roman period, in which case, due to the power of Rome and the well organized transportation by sea and land, the mosaic artists had at their disposal an extended diversity of stones from many Mediterranean countries (fig.21) (Fiorentini I. 2002, p.36). Therefore, apart from their elevated artistic result, the mosaics of that period can be considered as very interesting enigmas concerning their origin. But other cases are also present where the mosaic production was based only on local stone sources. Cypriot mosaics are an excellent example, because it is proven that they were using mainly types of stone that are found on the island’s geological formations (Χαραλάμπους Ε. 2012, p.24).

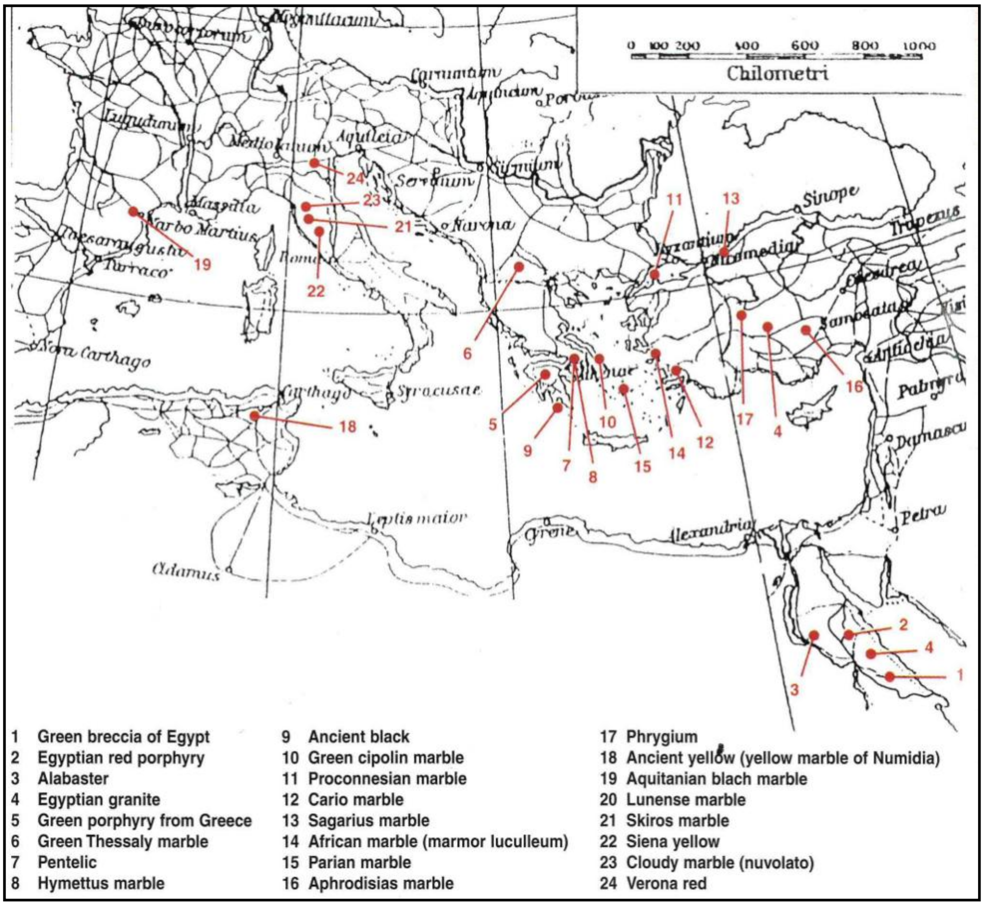


Figure 21. Geographical map of ancient stone quarries and Roman roads (Fiorentini 2002 p.206)

2.2.2. Historical substrate mosaic mortars

Mortars are essential elements of the building process and have a significant role in this procedure. They are cultural products whose characteristics and properties depend on raw materials and technological knowledge (Crisci G.M. et al 2004 p.260). Their use can be traced back to the Neolithic period and is constant until the present. With some exceptions, such as classical period's Greek temples, mankind is using them in order to create structures of any type. Historical is a term that is used for all types of mortars before the 19^{th} century, when the Portland cement first appeared (Moropoulou A. et al 2003 p.891). Mosaic floors are characteristic examples of structures where extended application of mortars has taken place. In that case, subsequent mortar layers are present (Chapter 2.1) following distinct methodology and including specific components in order to create even and water-resistant surfaces.

According to the type of their binder but also their use, mortars are characterized and categorized. Consequently, there are two main types, the air-hardened and the hydraulic mortars, but also three different categories as far as their function is concerned:

- Bedding mortars. Used to connect and join elements (stones, bricks etc.) on masonries and other building structures, or to support the layers on pavements, floor and wall mosaics, marble inlays, etc.
- Pointing mortars. Used to fill the external gaps on the joints of a - vertical or horizontal – structure and secure the mass of the inner bedding mortars.
- Plasters. Used in one or more layers in order to cover wall, dome and ceiling surfaces. They can be placed in areas either inside or outside (renders) of a building. Plasters can also be the preparatory layers of wall paintings.

Mortars are composite materials mainly comprising of inorganic binders and aggregates, but also additives and admixtures can be detected.

According to the type of the binder mortars are distinguished in air-hardened and hydraulic ones. The aggregates are segments of stones, naturally or artificially transformed in a variety of sizes. Additives and admixtures can be passive or active, to react with the binding material and be modified during their setting by hardening and ageing (Moropoulou A. 2000 p.164).Into the last category are included the natural and artificial pozzolans, materials that can give mortars hydraulic properties (Starinieri V. 2009 p15). Brick, tile and other ceramic fragments are a particular type of artificial pozzolans. These materials have a constant presence in lime mortars of floor mosaics substrates. Of course water is the last element added in these raw materials, in order to activate the joining process.

2.2.3. Pozzolans

The term of *pozzolana* comes from the Pozzuoli area near Naples and the mount of Vesuvius. As Vitruvius pointed out, that was the main extraction point of volcanic ash materials (Cowper A.D.,1927 p.2). By definition, pozzolanic are materials that contain siliceous or alumino-siliceous constituents. These materials have little or no cementitious value but when are combined with hydrate lime at ordinary temperatures and in the presence of moisture can form stable insoluble compounds of binding properties (Boffey G., 1999 p.37). The production of pozzolanic lime mortars is presented in a cycle formation in figure 22.

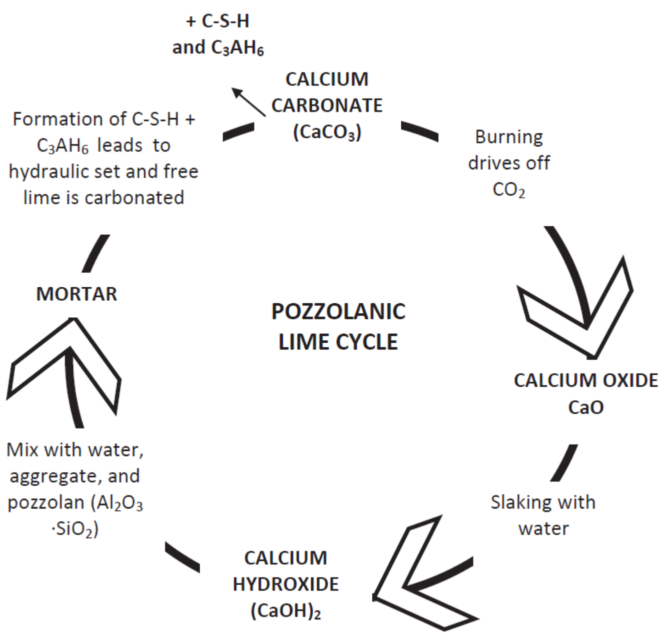


Figure 22. Pozzolanic Lime Cycle (Rogers S. 2011 p.20)

An accurate classification of pozzolans isn't easy since many types of materials show an identical behavior when are mixed with lime and water. For that reason pozzolans are distinguished in two categories of natural and artificial. Natural pozzolans as already mentioned are mainly volcanic materials that don't need any special treatment before their use. Artificial pozzolans on the other hand are the result of chemical and structural alterations of materials that initially had no or weak pozzolanic characteristics (Baronio G. 1997a p.41). The crushed ceramics in forms of powder and fragments belong to the second category. These amorphous materials contain silica and alumina components that react with lime (Calcium hydroxide) and form an alkaline interfacial surface of cementitious compounds. On this chemical reaction (2.2.3.i), calcium – silicate – hydrate (CSH) and calcium – aluminum – silicate – hydrate (CASH) are formed on the brick – lime interface in reaction rims (fig.24) and provide lime mortars with hydraulic properties and increased mechanical strength (Nezerka V. 2015 p.16).

$$Ca(OH)_2 + AS + H_2O \rightarrow CSH + CAH \quad (2.2.3.i)$$

The abbreviations on the reaction are: C – Calcium oxide (CaO), A – Aluminum oxide (Al_2O_3), S – Silicon dioxide, silica (SiO_2) and H – Water (H_2O)

2.2.4. Ceramic materials as artificial pozzolans in lime mortars. The Opus Signinum or Cocciopesto mortars

During the firing process of clay-based ceramics, partial melting of the clay occurs. These materials are capable to react with lime and show some pozzolanic activity. That process is much slower than in the case of natural pozzolans but can show impressive mechanical resistance. A necessary condition is the long permanency of materials in an increased moisture environment. The traditional *cocciopesto* (literally, “crushed shard”) mortar is composed of lime paste, finely ground crushed ceramics and larger fragments of the same material. Pozzolanic activity shows only the fine fraction and the shards acting only as low-porosity aggregates (Torraca G. 2009 p.57).

The incorporation of milled ceramic products into lime mortars was practiced since ancient times (Vitruvius 1914 p.202). In constructions from Babylon (300 B.C.) hydrated lime pastes with clayish additions were found (Moropoulou A. 2005 p.295) but also the Phoenicians (1200 to 800B.C.) seem to have had the knowledge of those types of mortars (Baronio G. et al. 1997 p.34). Later on, the use of pozzolanic ceramic materials as admixtures is detected in Greece (Island of Delos 2nd century B.C.). Although the addition of ceramics in lime mortars had occurred earlier, during the Roman period the technique predominated on architectural structures and changed the way of building. The names with which these lime mortars were and still are known, *opus testaceum,opus signinum* especially for pavements and *cocciopesto* (Moropoulou A. 2005 p.296; Velosa A.L. 2007 p.1208).

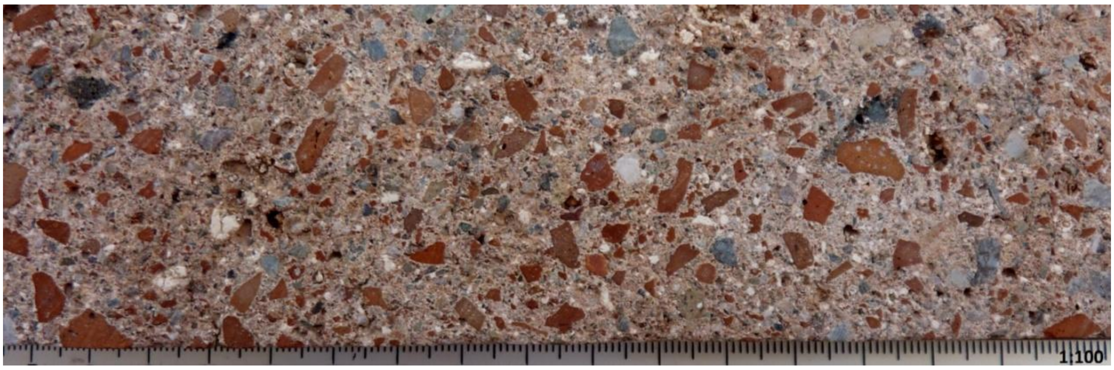


Figure 23. Cocciopesto mortar example. Mosaic mortar substrate from the Roman gymnasium in the city of Chalkis. Late 3rd century AD. (Mantzana E.)

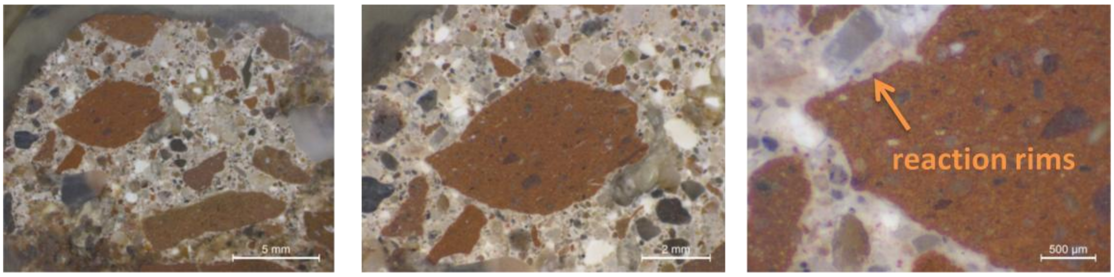


Figure 24. Mosaic mortar substrate from the Roman gymnasium in the city of Chalkis. Late 3rd century AD. Cocciopesto mortar cross section sample in stereomicroscope. Detection of reaction rims on brick – lime interface (Mantzana E.)

Cocciopesto are mixtures of lime mortar with hydraulic properties due to the addition of ceramic materials that are acting as artificial pozzolans (Biscontin G., et al. 2002 p.31). These hydraulic mortars were applied extensively as renders and plasters but also as bending layers, in structures of baths, water conduits, foundations, cisterns but also in the foundations of mosaic floors. All these structures were in environments of extended rise of moisture (Nezerka V. 2015 p.4) and consequently demanded water resistant materials. Furthermore, the characteristics of major importance of this type of lime mortars are their high consistency and strength. It seems to have been known since the antiquity that the addition of ceramic fragments and dust in air lime mixtures has, as a result, the manufacture of materials with resistance to mechanical stresses (Baronio G. et al. 1997 p.33). Quite impressive examples of substrate mortar samples with compressive strength above 10 MPa have been detected in Sicily (Torraca G. 2009 p.57).

3. Roman gymnasium mosaic pavements in Chalkis of Euboea

Two mosaic pavements are located on the archaeological site of the Roman gymnasium in the city of Chalkis (fig.25). The finds are known since the beginning of the 20^{th} century but the systematic archaeological research was completed in 1952. Based on the mosaics' decorative elements and characteristics the excavator has dated them on the late roman period between the 3^{rd} and 4^{th} century AD (Ανδρειωμένου Α. 1961 p.312). With a total coverage of 94 cm^2 and 96 cm^2 the mosaic floors are constructed next to each other on the southwest of a bathhouse complex (fig.26). Their most significant decorative features are the representations of wrestlers and boxers at the center of the first mosaic floor (fig.27 & 28).

Figure 25. Aerial photography of Chalkis and the exact location of the Roman gymnasium archaeological site. Right: The location in more detail. (Mantzana E.)

Figure 26. Left: The top view of the mosaic pavements of the archaeological site of the Roman gymnasium in Chalkis. Right: Southeast area of mosaic pavement A. In the red circle, the sample area (Mantzana E.)

Figure 27. Roman gymnasium in Chalkis. Mosaic floor, south central scene, wrestlers in action. (Mantzana E.)

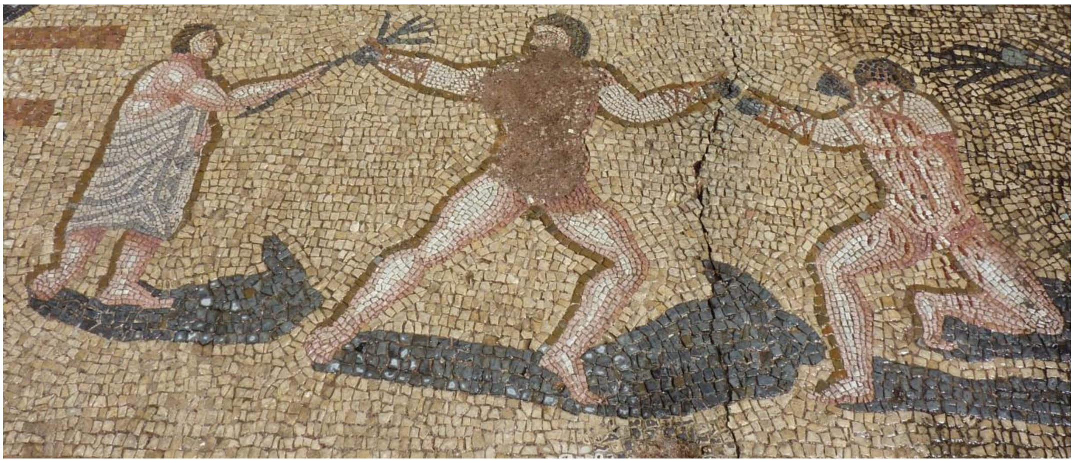


Figure 28. Roman gymnasium in Chalks. Mosaic floor, west central scene. A pair of boxers at the end of their competition. (Mantzana E.)

During the period between 2011 and 2013, a multidisciplinary team from the Ephorate of Antiquities in Euboea manages to complete the conservation and enhancement project for the specific archaeological site. As far as the mosaic remains are concerned, the macroscopic *in situ* examination was focused on their surface, stratigraphy and the base ground features. Furthermore, a granulometry analysis of the substrate mortars was executed in order to design compatible repair mortars. The observations of the study concluded that the specific mosaic pavements have been made with sufficient constructing diligence and with high technical characteristics.

The *Tessellatum* layer consists of tesserae made by different types of stone and according to the surface observation, most tesserae were made by limestones of various color hues. With the exception of marble, that has been used exclusively on the external zone of the mosaic, the tesserae palette is composed by white, black-grey, brown, yellow and red-pinkish limestones. In some cases, a very fine white-coloured layer is located in the interstices, probably of pure lime. The substratum layers of these mosaic floors are not uniform and as it is presented on chapter 2.1.1, the stratigraphy varies and is determined mainly by the base ground morphology and the underlying architectural remains.

In situ examination and laboratory analysis of the substrate mortars were carried out in the beginning of the project, in order to learn their microstructural and compositional characteristics. The main aim was to design proper compatible new repair mortars for mosaics' conservation implementations such as re-laid of fragments and ending repair supports. Mortar samples from the second substrate layer were collected and their analysis proved that in both of the mosaics were used very similar mortars, the characteristics of which date them back to the Roman period. The mortar samples ΔK1 and ΔK2 have been selected from the mosaic floors A and B respectively and both of them are lime mortars with the addition of a great amount of crushed ceramics in various grain sizes, that are responsible for their reddish color, as well as their hydraulic characteristics. Samples were rich in lime with a binder to aggregate ratio of almost 1:3. Lime lumps through the mortar mass and dark-coloured rounded aggregates with pretty good distribution could be also observed. These two substrate mortars also had a similar apparent specific gravity of 1.7 and 1.8 gr/cm^2 respectively and a bulk density of 15-16% (Μαντζάνα Ε. et al. 2014).

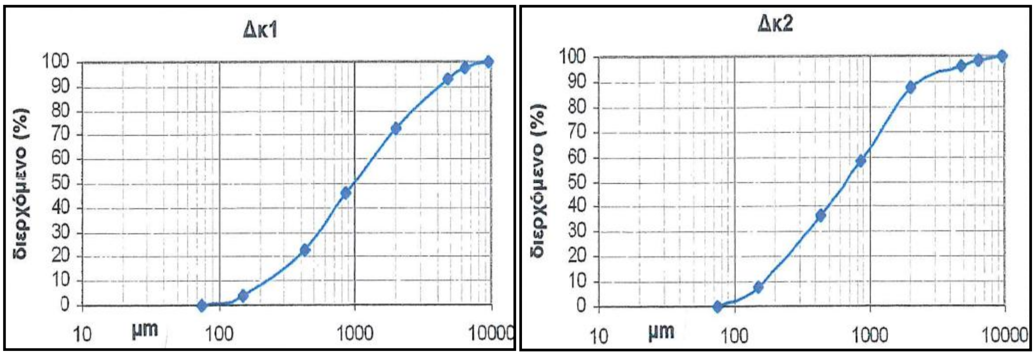


Diagram 1 a&b. Grain size distributions of aggregates from mortars ΔK1 and ΔK2 of the mosaic pavements in Chalkis. (Mantzana E. et al. 2014 . Appendix A)

Code	Description	Origin	Aggregate grain average (mm)	Binder/ Aggregate Ratio	Apparent specific gravity (gr/cm^2)	Water absorption by mass
ΔK1	Reddish color lime mortar with several ceramic fragments	Substrate 2nd mortar layer from mosaic floor 1	1	1:3	1.74	16.4
ΔK2	Reddish color lime mortar with several ceramic fragments	Substrate 2nd mortar layer from mosaic floor 2	0.65	1:3	1.86	15.2

Table 1. Results of mortars analysis from the study of IA Ephorate Prehistoric and Classic Antiquities in Euboea. (Mantzana E. et al. 2014. ΔK1 &ΔK2 mosaic mortar analysis . Appendix A)

The mosaic pavements of the Roman gymnasium from the ancient city of Chalkis are remarkable examples of archaeological architectural remains that easily may inspire further research. The longevity and resistance to deterioration of the structures is notable, even though these mosaic floors remained exposed and unattended in an urban environment for more than one hundred years. These conditions could have been more than enough to result in their total deterioration, but in this case that did not occur. The durability of these pavements seems to be great and their condition survey is almost at the highest level. Cracks and mechanically detached areas are present on their surface, but the areas where the deterioration of the *Nucleus* layer has lead to the loss of *Tessellatum* layer are limited.

4. The conservation of mosaic floors and design of new repair mortars

In the past, the preservation of mosaics into their architectural context wasn't considered a priority. The mosaic surfaces were detached from their initial position and usually the support layers were sacrificed and destroyed. It was common for mosaic surfaces to be treated separately from their architectural surroundings, like images created only by a fine layer of tesserae.

During the last decades, a number of efforts are in progress, supported mainly by the International Committee for the Conservation of Mosaics (ICCM) and the ICCROM organization, with the main aim to save *in situ* as many as possible mosaics in archaeological sites. This campaign gradually manages to alter the tactic of unreasonable detachments, as the interest and the attention shifted from the concept of the mosaics as separate components and single objects, to the wider picture, the context, represented by the room, the building and finally the whole of the archaeological site (Nardi R. 2003 p188). Consequently, the *in situ* conservation of mosaics has become nowadays a priority and the detachment of mosaic surfaces is implemented only in extraordinary circumstances, such as in the Zeugma Project (Cassio A.2005 p.155; Nardi R. 2005 p.331) or in cases like the mosaic pavements of Atalanti (fig.29).

Figure 29. Mosaic floor remains in Atalanti (www.helenmilesmosaics.org)

The conservation implementations practiced on mosaic floors must often deal with many problems and challenges. The most frequent phenomena of deterioration are the *lacunas* or *Tessellatum* layer missing areas or cracks, including detached tesserae, cavities of support layers and fragmentation (fig.30 & 31) (Papayianni I.2010 p.1368). In all these cases, the main implementation materials required are new repair mortars, in order for the gaps to be filled and the mosaic fragments to be supported properly.

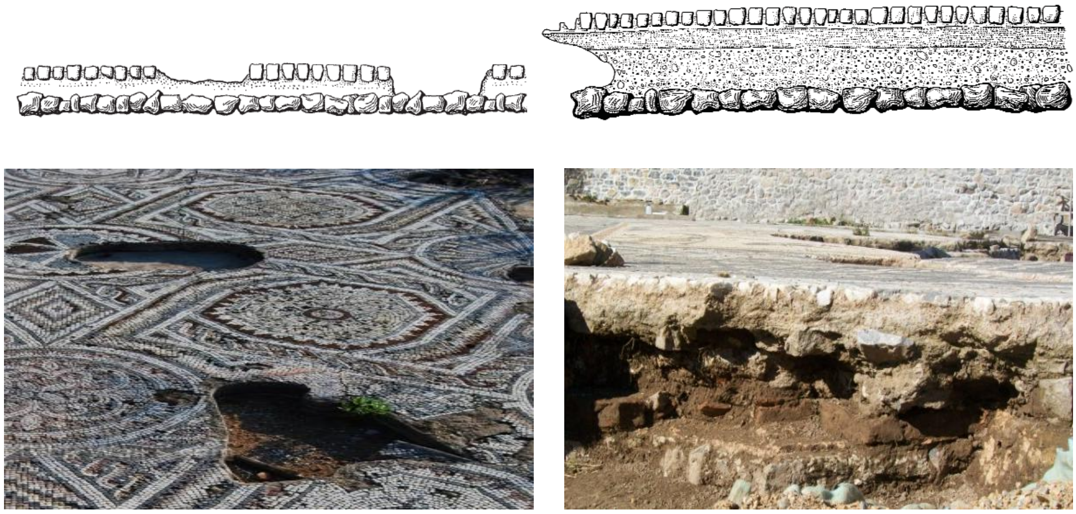


Figure 30. Deterioration phenomena in mosaic pavements. Left: Examples of lacunas. Right : Cavities and subsurface losses (Mantzana E. / The Getty Conservation Institute 2003)

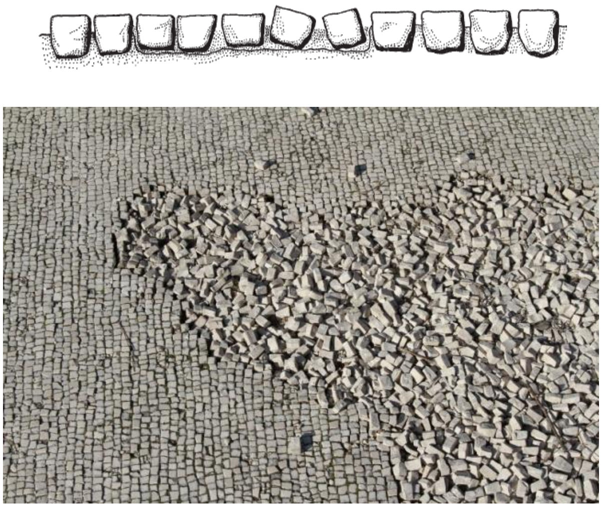


Figure 31. Detached tesserae in mosaic floor in Ostia of Italy. (The Getty Conservation Institute 2003 (www.blog.travelmarx.com/2010/11/mosaic-and-marble-floors-of-ostia.html)

The design of new materials and techniques has a crucial role in the planning of successful and ethically correct interventions. Concerning the scientific field of conservation and preservation of the architectural heritage, specific requirements have been defined for the design of new mortars. The first step is the characterization of the authentic mortars and materials according to their broader historical context; a process that serves multiple objectives such as documentation and damage analysis of the ancient materials, but also provides useful information for the decision making process of future interventions. Usually the study of archaeological and historical mortars is focused on their quality and performance characteristics and for that reason the parameters that should be analyzed are the type and quantity of binder, the binder to aggregate ratio, the water to binder ratio, the granular distribution of aggregates, the shape and type of aggregates and the type of admixtures or additives that might be present (Karatasios I. et.al. 2014 p.271).

The production of new materials must first of all be respectful to the authenticity of the original structures and the basic ethical values regarding heritage and must always have as guides the three fundamental conservation principles of compatibility, retreatability and reversibility (Van Balen K. et al.2005 p.782). From these three principles, the insurance of compatibility[4] between the new repair mortars and the ancient or historical structures is regarded as the most important and realistic approach (Papayianni I. 2004 p.625).

As it is defined in the Van Balen K. and others (2005) document, the functional and technical requirements for the design of new repair mortars have many parameters (fig.32). Briefly, the technical requirements contain all the characteristics and properties that the new materials should fulfill in order to be compatible with the authentic ones. Regarding the functional requirements, these can be both technical and aesthetical and determine the

[4]By definition compatible are the materials that have no negative consequences or help deterioration phenomena on the authentic materials. Also, retreatability is the capability of new repair materials to allow further treatments in the future (Van Balen K. et al.2005 p.782).

performance characteristics of compatible repair mortars. This type of requirements derives from the role of mortars in the masonry element, but also from the role of masonry elements in the building (Table 2).

Mosaic floors belong to a particular category of architectural remains with specific characteristics and functional requirements, that have to be thoroughly examined and determined in order for new mortars to be designed for their proper conservation.

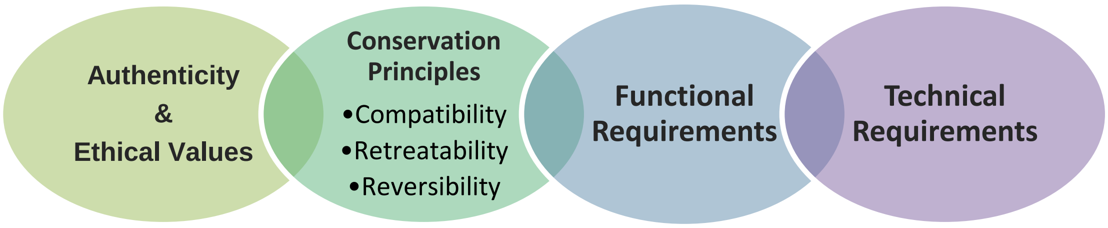


Figure 32. Proposed framework of requirements (Van Balen K. et al.,2005 p.782)

Technical Requirements
• Surface features • Composition (type of binder, type of aggregates, grain size distribution) • Strength (compressive and tensile) • Elasticity (modulus of elasticity) • Coefficient of thermal dilation • Technical recommendations for raw materials and implementation techniques • Porosity properties (total porosity, app. Specific gravity, pore size distribution, water absorption by capillarity and vapour transport) • Technical recommendations: Workability - Curing conditions - Compaction - Monitoring
Functional Requirements
• Efficient load bearing capacity • Prevention of water penetration • Resistance in environmental influences • Diagnosis of degradation mechanisms • Contribution of aesthetic appearance • Contribution of durability of structure

Table 2. Functional and technical requirements according Van Balen and others (2005).

5. Literature review

Throughout the last decades, the use of ceramic materials as artificial pozzolans, their presence as admixtures in historical and ancient lime mortars and their exact role have been one of the main interests and a popular subject of the archaeometric research. To the present day, a number of studies have been carried out so as to understand and characterize this type of mortars and in order to accomplish their objectives these works have focused on the analysis of materials, the definition of the mortars' proportions and the study of ancient implementation techniques. Furthermore, the need for new compatible mortars for modern conservation interventions constitutes a further motivation for these studies. A group of related publications is presented by Gina Matias and others on their review article (Matias G. 2014 p.6,17). Table 3 contains summarized studies, focused on the analysis of ancient lime mortars with ceramic inclusions. Among the different types of monuments from which mortar samples were selected, mosaic pavements are the most limited category.

The systematic study of mortars from the mosaic multilayer substrates has started timidly since the middle of the nineties. Puertas F. and others in 1994 carried out a chemical, mineralogical, physical and mechanical characterization of mortars coming from roman mosaic pavements of the archaeological site of Italica in Spain. The main aim of the authors was the determination of deterioration phenomena that occurred in the authentic but also in the modern cementitious repair mortars of previous interventions (Puertas F. et al.1994,p.124). Studies dealing with the materials used in the construction of mosaic pavements have been published mainly in the ICCM (International Committee Conservation of Mosaics) conference proceedings and are summarized in Table 4. From this specific group, the research of Karatasios I. and others (2005), as well as the work of Kramar S. and others (2011) can be distinguished for their focus in the analysis of the ceramic fragments as components of the lime mortars. In the first case (Karatasios I. et al. 2005 p.214), the technological and compositional characteristics of the ceramic aggregates of the mortars have been analyzed. In the same study, the formation of hydraulic phases between lime and ceramic surfaces within the mortars' matrix was examined by Scanning Electron Microcopy (SEM) coupled with energy dispersive X-ray analyser (EDX). In the second study (Kramar S. et al. 2011 p.1050) SEM / EDS examinations were carried out and detected reaction rims around brick particles that indicate pozzolanic reactivity.

Researchers, Year	Significant findings
Moropoulou et al., 1995 [18]	Mortars designated "crushed brick mortars" in which reaction products were detected at the brick fragment-lime interface (were classified as "pozzolanic mortars")
Maravelali-Kalaitzaqui et al., 2003 [32]	Mortars that contained coarse aggregate from crushed brick with clear hydraulic properties
Moropoulou et al., 2000, 2003 and 2005 [2,30,31]	Ceramic residues used in ancient mortars that also worked as an aggregate substitute, providing mortars some lightness and waterproofing capacity (mentioning the example of Hagia Sophia mortars)
Santos-Silva et al., 2006 [11]	Mortars with brick fragments whose grain sizes reached 5 mm, with reaction products in the microstructure that suggested pozzolanic reactions
Santos-Silva et al., 2006 [12]	Mortars that contained high amounts of crushed ceramics, in dust and coarser forms, with high amounts of pozzolanic reaction products, both in the binder-ceramic interface and, indeed, all over the binder and dissolved into the lime
Böke et al., 2006 [8]	Larger particles from brick milling in mortars with clear signs of pozzolanic reaction
Velosa et al., 2007 [13]	Mortars with brick fragments whose particle sizes were similar to those of aggregates
Ugurlu and Böke, 2009 [17]	Mortars in which aggregates with particle sizes larger than 1.18 mm were the main aggregate fraction
Borsoi et al., 2010 [9]	Mortars with ceramic and brick residues in a granular form and with the occurrence of rims around brick fragments, arising from pozzolanic reactions with the binder
Cardoso et al., 2013 [34]	Ceramic fragment mortars with different grain sizes whose sample with larger ceramic fragments exhibited a higher hydraulicity factor

Table 3. Published researches analyzing old mortars with coarse ceramic fragments (Matias G. 2014 p.6 &17)

Researchers, Year	Significant findings
Puertas F. et al., 1994	Characterization of 2nd century A.D. mosaic floor substrate mortars from Spain. Chemical, physical, mineralogical and mechanical analysis of the mortar layers.
Chlouveraki S.N., PolitisK.D., 2003	Early Byzantine nave mosaic floor from the basilica of Agios Lot in Jordan. Mosaic stratigraphy determination and characterization of constructing materials
Karatasios I., et al., 2005	Archaeological area of Thebes, Greece. Microstructural and compositional characterization of floor mosaic mortars. Observations on the ceramic inclusions
Clouveraki S.N. et al., 2008	Early Byzantine mosaic floors from the basilica of Agios Lot in Jordan. Mosaic stratigraphy determination and characterization of constructing materials and their contribution to the archaeological study
Papayianni I., Pachta V., 2008	20 mortar samples of mosaics substrate from different historic periods in Greece. Physico - chemical, mineralogical and mechanical analysis of mortars and distinction of their stratigraphy
Starinieri V., 2009	Hellenistic and Roman period mosaic floors from archaeological sites in Greece and Italy. Characterization of substrate mortars and distinction of their stratigraphy
Akyol A.A., Kadioglu Y.K., 2011	18 mortar samples from different support layers from the Amazons Villa in Turkey. Elemental analysis (PED-XRF), determination of aggregate/binder ratio, aggregate granulometry, optical microscopy of fine section were carried out
Camaiti M., et al 2010	1st-2nd century B.C. floor mosaic in Castiglione dellaPescaia, Italy. Examination of original setting bed mortar with optical microscopy and evaluation of composition and binder/aggregate ratio.
Kurtosi B.M.,2011	3rd century A.D. mosaic pavement in Hungary. Microscopic, chemical and X-ray diffraction analysis on mosaic fragments in order to be examined the structure and the technology of the support mortar layers.
Kramar S., et al. 2011	Characterization of mortars from the bath complex of Roman villa rustica in Slovenia. Mosaic floors mortar examination by means of optical microscopy, X-ray powder diffraction FTIR spectroscopy for their mineralogical and petrographical determination. Analysis of aggregate – binder interfaces by the use of SEM – EDS and the observation of various types of reaction rims
Charalambous E.,2012	Hellenistic Roman Early Christian and Byzantine period mosaic floor analysis from Cyprus. Examination of 28 mortar samples from different substratum mosaic layers for their composition and technological characteristics. Use of Scanning Electron Microcopy (SEM) coupled with energy dispersive X-ray analyser (EDX). Determination of mortars' average porosity connected with their original position in the mosaic substrate.

Table 4. Published works as far as concern mosaics stratigraphy and analysis of substrate mortars.

On the other hand, there is a more extensive number of published research works dealing with the pozzolanicity of natural and industrial clays. A separation into subcategories is distinguished. In general, the relative studies are focused on the characterization of chemical and mineralogical composition of different fired clayish materials. These analyses have given conclusions concerning the ideal conditions and parameters for the production of ceramics with pozzolanic properties. These pozzolanic materials have been observed after their addition in cementitious mortars (He C. et al. 1995 p.1692; Lavat A.E. et al. 2009 p.1667) but also with their incorporation into lime mortar mixtures. The pozzolanic reactivity of the ceramics and the hydraulicity of the mortars are determined mainly by thermal analysis (DTA/TG) and Scanning Electron Microcopy (SEM) examination. In some cases, the measurement of mechanical properties completes the characterization of lime mortars as far as their strength and durability are concerned (Teutonico et al.1994 p.34; Charola A.E. et al. 2005 p.112; Moropoulou A. et al. 2005b p.290; Bakolas A. et al. 2008 p.345; Budak M.et al. 2010 p.414). Furthermore, another group of studies have tested lime mortar mixtures with ceramic aggregates and their effort is focused on detecting the reactions at the binder – ceramic surface, as well as on investigating their mechanical properties (Baronio G. et al.1997 p.39; Moropoulou A. et al. 2005b p.291). Apart from the incorporation of ceramics in hydrated lime, other studies have detected pozzolanic reaction of ceramic powder by measuring its conductivity in saturated calcium hydroxide solution $Ca(OH)_2$ (Baronio G. and Binda L. 1997 p.42, Karatasios I. et al. 2014 p.272). The aims of that group of researchers are to understand the properties of clays and their potentials for their use as raw materials on new repair mortars.

6. Aims of thesis research

The present research is motivated by the sophisticated construction technology of the ancient mosaic pavements and is focused on the study of lime-based mortars containing ceramic admixtures. The study is based on the same clay materials that Karatasios and others (2014) have tested regarding their pozzolanic reactivity, while the forthcoming analysis is accomplished through laboratory prepared mortars and a representative historical mortar sample, of roman period. The main aim of this undertaking is to contribute further to the knowledge about the artificial pozzolanic materials and the hydraulic mortar mixtures, as well as their evaluation as proper modern materials for conservation implementations. To achieve these objectives, the thesis targets are divided into the following sub-categories:

- Characterization and investigation of mechanical properties of authentic mortar samples from the substrate layer of the Roman mosaic floor from the city of Chalkis.
- Identification of pozzolanic activity on different laboratory prepared ceramic types, while they are used as admixtures in modern air lime mortar mixtures.
- Investigation of mechanical properties of modern laboratory air lime mortar mixtures with ceramic admixtures.
- The study and evaluation of ceramic pozzolans as new raw materials for the design of compatible repair mortars that can be used in conservation interventions on mosaic floors.

Figure 33. Mosaic of Tragic Mas from the House of the Faun in Pompeii. Archaeological Museum of Naples (www.gettyimages.com)

7. Methodology of the research

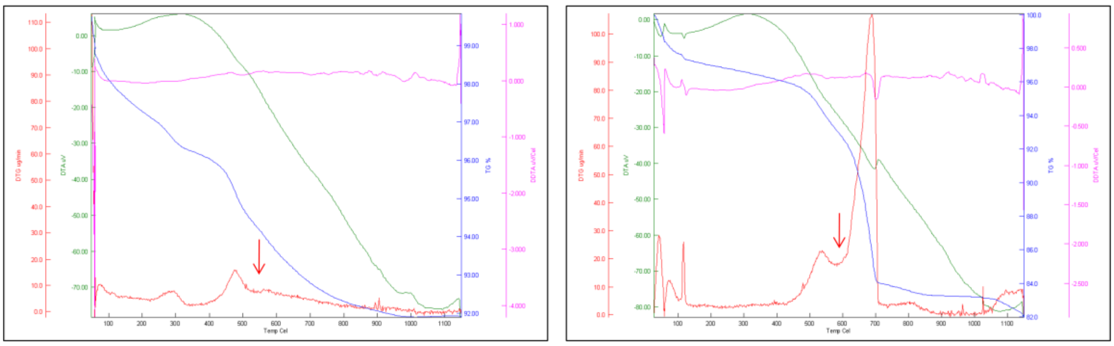
7.1. Ceramic materials and mortars preparation

7.1.1. Selection, preparation and firing of ceramics

For the present experimental work Metakaolin and two types of clays have been chosen. The clay samples are natural deposits of Thrapsano (TH) and Agios Syllas (AS) from island of Crete in Greece (Hein A. et al. 2004a, 2004b). Preparation of the samples has been started with a total amount of 1kg from each clay. Thrapsano is a non calcareous clay with CaO concentrations below 1% (Hein A. et al. 2004a p.248) and Agios Syllas is a calcareous clay with 12% of CaO (Hein A. et al. 2004b p.364). The same clayish materials had been used on the research work of Kartasios I. et al.(2014).

These amounts of clays were divided into three equal parts. One third from each clay had remained raw, while the rest were fired in two different temperatures for two hours. The firing temperatures for the non calcareous clay Thrapsano are 550°C and 700°C and for the calcareous Agios Syllas 580°C and 700°C respectively. The firing temperatures were selected according thermal analysis results. The dehydroxylation temperatures of clay minerals are determined by thermal analysis on non calcareous clay Thrapsano at 550 °C and calcareous Agios Syllas 580°C degrees (fig.34)

THRaw Clay (Non – Calcareous) | ASRaw Clay (Calcareous)



550°C | 580°C

Figure 34. Thermal analysis results for Thrapsano and Agios Syllas clays. With read arrows are point out the dehydroxylation temperatures.

After the firing process, all the ceramic and clay materials, including the Metakaolin (Mtk), were crushed into finer particles on porcelain mortar, sieved and the powder with grain size below 63μm was collected[5]. Therefore, Thrapsano samples took the names, THRaw, TH550 and TH700 and Agios Syllas, ASRaw, AS580 and AS700. Finally, these ceramic and clay materials were added in mortar mixtures as admixtures and a small amount of that fine powder was analyzed with differential thermal analysis (DTA/TG) and the X-ray diffraction (XRD) test.

7.1.2. Preparation of air lime mortars with ceramic and clay admixtures

Seven different air lime pastes had been mixed and casted into prismatic molds with dimensions of 40x40x160mm. All these mortar mixtures have the same binder to aggregate ratio of 1:3. The amount of the binder is separated 50% to hydrated lime powder[6] and 50% clay or ceramic laboratory prepared fine powder. More precisely each mortar paste contain 1350gr of standard quartz sand, 225gr hydrated lime powder and 225gr of fine grain size (under 63μm) of ceramic or clay admixtures. Mortar specimens were left to mature and after seven days were removed from their molds. From each lime mortar with ceramic admixtures, three prismatic specimens with 40x40x160mm dimensions were formed and left to mature under standard temperatures $20\pm1^{o}C$ and humidification support conditions. The mechanical properties of the specimens were tested in two different periods, on 28 days and six months. These mortar specimens are named: LMtk, LTHRaw, LTH550, LTH700, LASRaw, LAS580 and LAS700.

[5] The small particles of pozzolanic materials provide bigger surface per volume and consequently increased hydraulic reactivity (Nezerka V. 2015 p.16).
[6] Lime powder compared with lime putty has higher and quasi stable percentage of $Ca(OH)_2$ content (Moroloulou A. et al. 2005 p.290).

7.2. Historic mosaic mortar samples from Chalkis

The ancient mortar samples come from the substratum layers of the mosaic pavement from the archaeological site of the Roman gymnasium in the city of Chalkis. These mosaic pavements, according to their decorative characteristics are dated back to the 3rd and 4th century AD (ΑνδρειωμένουΑ. 1961 p.312). During the conservation and reconstruction processes that took place from 2011 until 2013, an original mortar fragment with dimensions of 10x30x30cm (fig.35) was collected from the southeast area of mosaic pavement A (fig.26). The specific sample was identified as a part of the second mosaic substrate layer and its original position wasn't clear. Consequently, it was decided not to be placed back on the floor and to remain stored as reference archaeological material, available for future research. Furthermore, many smaller fragments from the *Tessellatum* layer were collected from the perimeter of the mosaic after the cleaning process. Many of these fragments were placed in their original position, but some were also kept in storage (fig.35).

In 2011, the freelancing conservation laboratory of Lithou Sintirisis performed the analysis of two mortar samples, in order to design the proper repair mortars for the conservation of mosaics. Mortar samples from both the mosaic pavements were studied for their granular distribution of aggregates, the type and quantity of binder, the binder to aggregate ratio, the shape and type of aggregates and the type of admixtures or additives that might be included. The observations of that study concluded that the specific mosaic mortars are similar, contain respectable amounts of ceramic fragments and are representative examples of roman technology. The results are summarized in Table 1 & Diagram 1(ΜαντζάναΕ. et al. 2014).

The specific mortar samples are very compact and durable and these properties are also characteristic of the *in situ* mosaic structures. In the present research the examination of the mosaic substrate mortars will continue in order to complete the characterization of its components. The type of ceramic fragments, admixtures on the specific mortar, as well as their pozzolanic reactivity are the main issues. The analytical techniques that will be used are stereomicroscopy, X-ray diffraction (XRD), thermal analysis, Scanning Electron Microscopy (SEM/EDS) and mechanical strength tests (3 point bending and compressive strength).

Figure 35. Left: Mortar sample from the mosaic pavement of roman gymnasium in Chalis. Right: Fragments from the Tessellatum layer in storage (Mantzana E.)

Figure 36. Authentic mosaic mortar rectangular prisms and samples, before mechanical properties tests. (Mantzana E.)

7.3. Thesis research analytical methods

7.3.1. Analytical techniques

7.3.1. Stereomicroscopy

The stereomicroscopy is very useful in surface analysis in order to understand its characteristics specially colour alterations and topography. Often it consists the first step in mortars examination and might indicate the direction of further investigations (Szczepanowska H.M. 2013. P. 69)

7.3.2. *X-ray diffraction (XRD)*

X-ray diffraction is a method in analytical chemist capable to provide qualitative and quantitative information on the presence of phases (e.g., compounds) in an unknown mixture. X-Ray powder diffractometry involves characterization of materials by use of data that are dependent on the atomic arrangement in the crystal lattice (Jenkins R. 2001 p.899). It is very helpful technique for the determination of the crystalline, mineralogical components in a mortar. XRD provide bulk analysis with the identification and differentiation of binders and aggregates within a mortar since they are in crystalline form. It cannot disclose information as far as concern texture and spatial distribution of the mortars components and this is the reason why is used in combination with other chemical and textural analysis techniques (Hughes J.J. 2003 p.34). In the present research powered samples (below 63μm) of clays raw materials of Thrapsano and Agios Syllas, archaeological sample and the new laboratory prepared mortars (in 28 days and 6 months of age) were analyzed by powdered X – ray diffractometry.

7.3.3. Scanning Electron Microscopy coupled with X-ray detector EDX

Scanning Electron Microscopy coupled with the energy dispersive x-ray detector (SEM/EDX) has a revolutionary role on materials study and specifically in characterization of mortars. The application of the technique in mortars provides both qualitative and quantitative analysis for their components but also information for their texture. The high resolution images of SEM (down to 10's or 100's of nanometers) enable the access to microstructural and morphological properties of mortars structure to be imaged directly. In that case small rough fractured pieces of mortar samples are required. On polished two-dimensional surfaces of mortar samples, compositional variations, and chemical elements analysis can be detected and mapped across the surface, over a large area or in a spot (Hughes J.J. 2003 p.39). Furthermore the technique allows elemental analysis (EDX) of samples and is used for characterisation of morphologies and textural and compositional interrelationships of mortar binders and additives as well as degradation products. SEM analysis is important for the characterisation of hydraulic mortars. The hydrated hydraulic phases in hydraulic lime mortars are mostly too free to identify by other techniques such as microscopy and XRD since most of these phases are less crystalline or amorphous. The examination in high magnifications with SEM permits the identification of the microstructure of such hydrated hydraulic phases (needle shaped calcium silicate-hydrates C-S-H) and with the EDX analysis the chemical composition of the phases can be determined (Middendorf B. et al.2005 p.765).

7.3.4. Differential Thermal Analysis

The *Differential Thermal Analysis* (DTA) is a technique in which the temperature difference between a substance and a reference material is measured as a function of temperature while the substance and an inert standard are heated at the same rate and at the same time with a controlled program. The plot is called a DTA curve; the temperature difference ΔT should be plotted on the ordinate, with the endotherm processes shown downward and the exotherm processes in the opposite direction, and the temperature or time on the abscissa, increasing from left to right. This technique is often applied quantitatively when the area of the peaks can be made proportional to the quantity of the material decomposing or to the enthalpy of the process. The endothermic or exothermic transitions are characteristic of particular minerals, which can be identified and quantified using DTA. *Thermogravimetry* (TG) measure the weight loss in a sample while it is heated to a controlled temperature program. The record on the thermogravimetric, or TG, curve is the mass plotted against the temperature (T) or time (t) if the variation of temperature with time can be indicated as well on the same graph. In solid-state decomposition reactions, the reactant material degrades, often to be replaced by the solid product. During heating the weight loss is related to specific physical decompositions in the materials that are due to the effects of increasing temperature (Dollimore D. 2001 p.594, Middendorf B. et al.2005 p.766).

Differential Thermal Analysis (DTA) and Thermogravimetry (TG) are used to identify binders, aggregates and admixtures and require a very small amount of sample. For the present study samples from clay raw materials TH, AS and Metakaolin, but also from mortar specimens LMtk, LTHRaw, LTH550, LTH700, LASRaw, LAS580 and LAS700 were tested with Differential Thermal Analysis and Thermogravimetry (DTA/TG). Their fraction was smaller than 63μm in order to constitute the binding materials in the case of mortars. With the same analytical technique were tested samples from the ancient mosaic mortar and its ceramic particles. Thermal analysis was carried out with a Perkin-Elmer Diamond TG/DTA unit, using 20-25 mg of the solid fraction. Measurements were performed in air with a heating rate of 108C/min in the range 30-1000^{o}C. The pozzolan - lime mortar specimens were analyzed in 28 days and 6 months of mature.

7.4. Physical and Mechanical strength tests

As already mentioned in conservation of architectural heritage, the replacement of deteriorate authentic mortars, generates the necessity to design compatible new repair mortars. A crucial step for that attempt is the determination of physical and mechanical properties for both categories of mortars. Physical tests refer to pores structure characteristics such as porosity, capillarity, permeability, water absorption and others. On the other hand, mechanical testing of mortars usually includes measurements of strength characteristics and the modulus of elasticity. Compared with the physical properties investigation, the mechanical strength tests especially in authentic mortars are not frequently examined since they demand bigger amount of samples.

7.4.1. Porosity

The porosity and the pore structure of mortars are inseparably linked with the amount of water of a lime mortar mixture and the way that water evaporates in time during the setting process. The water content of a mortar is also connected with the workability of the paste, which also to an extent is influence the quality of compaction of the material. The level of the compaction is capable to affect the pores of the mortar mass. Moreover the setting process of a mortar mixture is crucial stage because the pore structure formed during moisture evaporation. The pore structure is a major parameter that influences the permeability and other characteristics of mortars (Hughes J.J. 2003 p.52). For building porous materials the processes of weathering and moisture transportation are connected with the pores that are accessible from outside - the open pore volume - and the size of that capillary system (fig.). In mortars and other porous materials that volume of pore fraction is measured through water absorption. There are also other methods and each one of them is able to measure only a part of the total range of pore size spectrum (fig.37) (Meng B.1996 p.196).

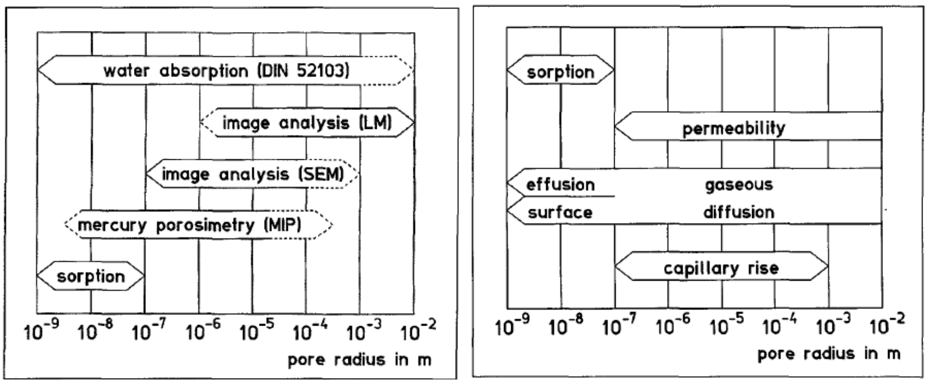
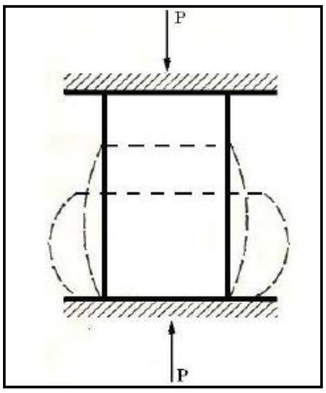


Figure 37. Left: Measuring ranges of different methods for determination of porosity and pore structure parameters. Right: Radii ranges of relevance for different transport phenomena (Meng B. 1996 p. 196)

7.4.2. Compressive Strength Test

Compressive strength is the capacity of a material or structure to withstand loads that tending to reduce their size. The compressive strength of any material is defined as the resistance to failure under the action of compressive forces (fig.38)(Γιαννακόπουλος Κ. 2011 p.14). Materials resistance to compression is calculated with compressive strength test and the equation (7.4.2.a). Especially for mortars such as concrete or lime based, compressive strength is an important parameter to determine the performance of the material during service conditions (Κορωναίος Α. 2006 p.14).

$$\sigma_D = \text{max}\ \sigma_D = \text{max}\ P / F \text{ in (MPa)} \quad (7.4.2.a)$$



max σ_D : the maximum in (MPα), max P : maximum load in Newton (N) and F : specimen's surface in mm^2

Figure 38. Schematic representation of uniaxial compressive strength test (Γιαννακόπουλος Κ. 2011 p.14)

7.4.3. 3 Point Bending Test

The three point bending or flexural test provides values for the flexural stress of a rectangle prismatic specimen. Flexural strength is the strength of the material specimens when are tested to bending stress with the load acting perpendicular to the shaft and given by the equation:

$$\sigma_f = 3FL / 2bd^2 \text{ in MPa } (7.4.3.a)$$

F: load at a given point on the load deflection curve (N)

L : Support span (mm)

b : Width of test beam (mm)

d : Depth or thickness of tested beam (mm)

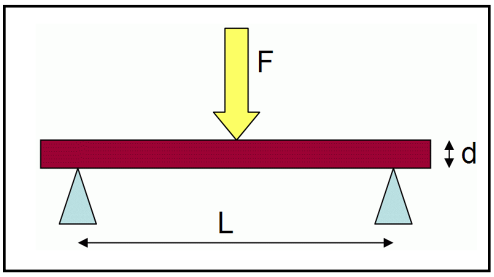


Figure 39. Rectangular sample under a load in a three-point bending set up (en.wikipedia.org/wiki/Flexural_strength#/media/File:Beam_3pt.png)

Methods	Materials Investigation	Properties and Analysis	Type of Samples
Stereomicroscopy	Mortar surfaces	Mortar Microstructure Characterization of aggregates and admixtures	Mortars cross sections and fragments
X-ray diffraction (XRD)	Binders and crystalline materials (aggregates & admixtures)	Mineralogical Analysis Identification and Differentiation	Powder with fraction below 63μm
Scanning Electron Microscopy / EDX	Mortar surfaces	Characterization of mortars Qualitative and Quantitative analysis	Mortars cross sections and fragments
Differential Thermal Analysis (DTA)	Admixtures and additives	Identification of mineral phases and hydraulic components in mortars	Powder with fraction below 63μm
Porosimetry	Mortars	Porosity, Pore Size Distribution	Laboratory and Ancient Mortars in rectangle prisms with base: 40x40cm
Compressive Strength Test	Mortars	Mechanical Properties Compressive Strength	Laboratory and Ancient Mortars in rectangle prisms: 40x40x40mm
3Point Bending Test	Mortars	Mechanical Properties Flexural Strength	Laboratory and Ancient Mortars in rectangle prisms: 40x40x160mm

Table 5. An overview of research analytical techniques

8. Results

8.1. Stereomicroscopy

8.1.1. Laboratory prepared mortar samples with clay and ceramic admixtures

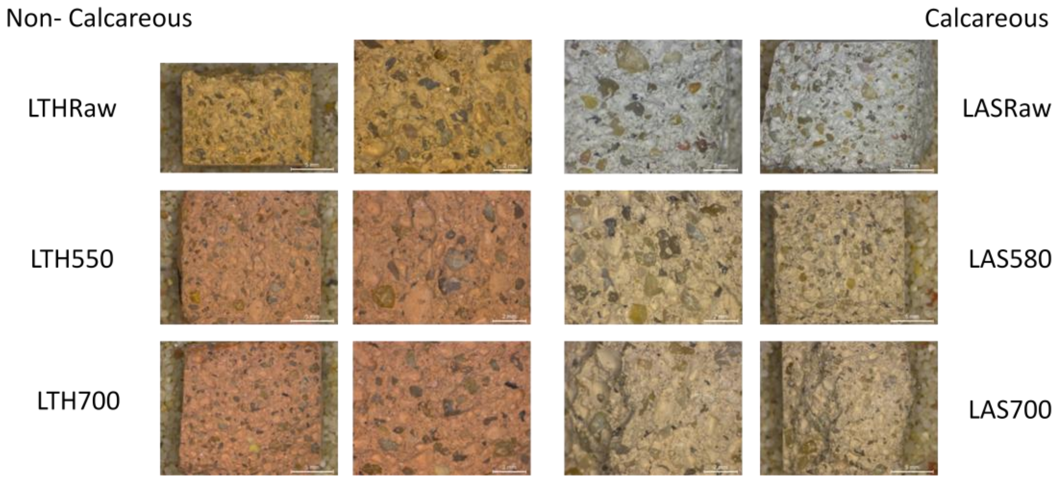


Figure 40. Laboratory prepared lime mortar samples. Images from stereomicroscope. Samples are divided into two categories the non-calcareous Thrapsano group and the calcareous Agios Syllas according the chemical composition of their ceramic admixtures.

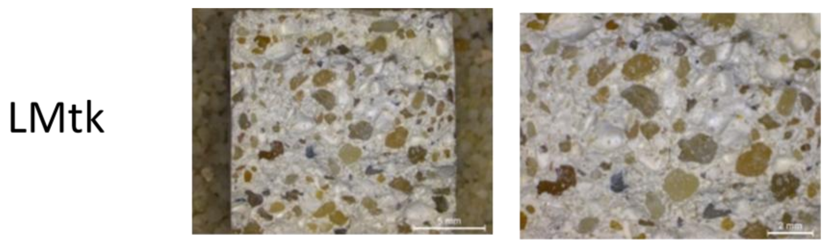


Figure 41. Reference mortar sample with Metakaolin admixtures

The stereomicroscopic analysis provides information as far as concern the physical appearance and microstructure of mortar samples. Laboratory prepared lime mortars contain very fine clay and ceramic particles with grain size below 63 μm. Consequently the binder on these mortars can be described as homogeneous and compact. Thrapsano (non-calcareous) and Agios Syllas (calcareous) have completely different colors as clays. These differences are obvious between these two groups. Color alterations are distinguished among samples with raw clays and ceramic admixtures from the same category. Samples that contain ceramics fired in 700^{o}C have brighter color hue compared to these with ceramic admixtures fired at lower temperatures. As far as concern aggregates, yellow, grey and brown rounded particles are distinguished, with uniform distribution on the mortar bulk.

8.1.2. Ancient mosaic mortar substrate sample from Chalkis

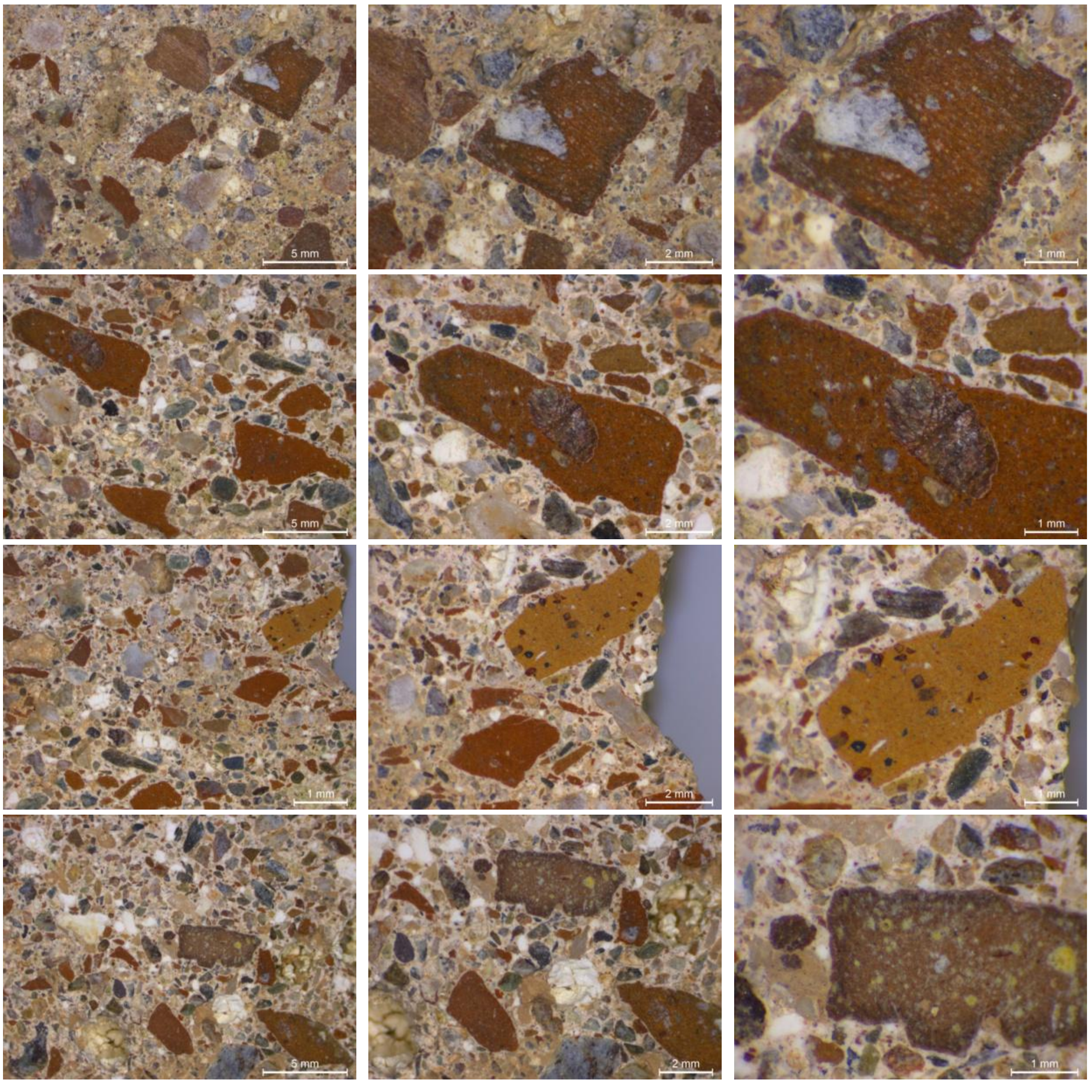


Figure 42. Historic mosaic mortar samples from Chalkis. Stereomicroscopy images gallery with focus on different ceramic inclusions morphological characteristics

Observing the bulk of authentic mosaic mortars some interesting characteristics can be noticed. First of all there is a considerable variation in colors and sizes of aggregates. Their shapes are mostly rounded, indicating that the materials come from natural sources. Further information comes from the detection of medium and large lime lumps inclusions that are located several times. Their presence indicates that mortar was mixed with poorly slaked lime putty that contains relict material. As far as concern ceramic fragments' inclusions, there are distinguished at least five different types of ceramics according their bulk colors. Remarkable is also the variation on ceramics inclusions. Finally are mentioned color alterations on the interface of ceramic and binder of lime.

8.2. Scanning Electron Microscopy coupled with EDX

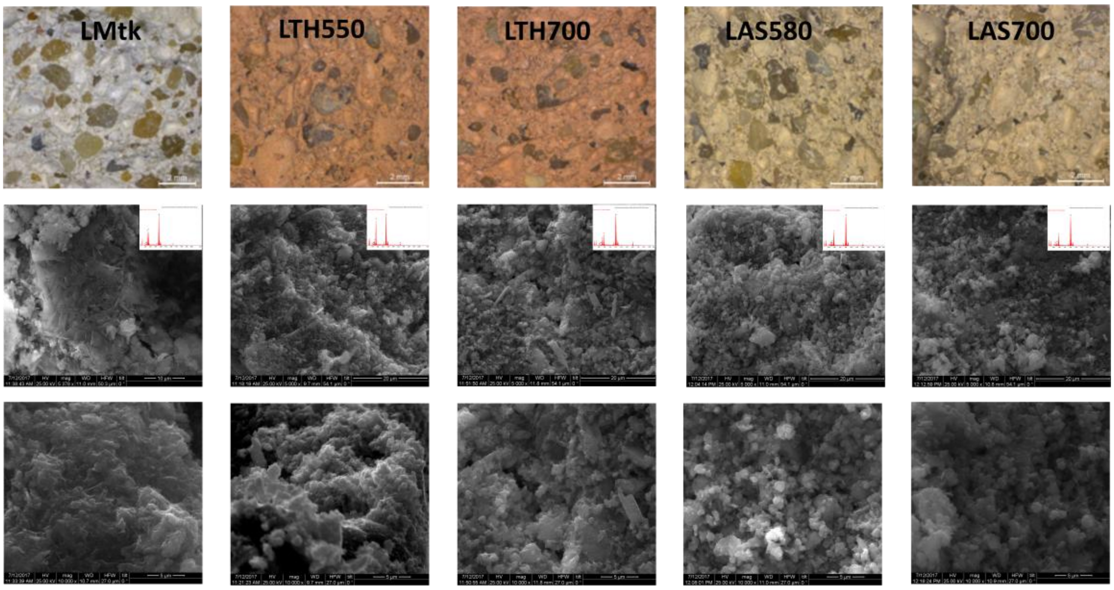


Figure 43. Stereomicroscopy and Scanning Electron Microscopy images with EDX results of laboratory prepared lime mortars with ceramic admixtures specimens after 28 days of mature

All the samples of laboratory prepared lime mortars with ceramic admixtures and reference sample with Metakaolin, on 28 days of mature were examined with Scanning Electron Microscopy. The microstructure characteristics of mortars and qualitative determination of chemical elements of samples' components were investigated. The mentionable observations are:

- LMtk : Solid binder material with few fiber formations of calcium silicate hydrates (CSH). Clearly, hydraulic reactions have taken place on the present sample.
- LTH550 : It is a porous material where small fiber formation are distinguished but they are in an early stage.
- LTH700 : Distinction of fiber formations of calcium silicate hydrates (CSH). Compared with LMtk it is less solid and more porous than LMtk. Hydraulic reactions are present.
- LAS580 : Detection of hexagons particles of calcium hydroxides (portlandite).

- LAS700 : Like LAS580 there are visible hexagons lime products on the bulk of the samples. No hydraulic reactions seem to be present.

On Figure 44, SEM images are presented in comparison. The sample LTH700 present differences in microstructure with fiber formation of calcium silicate hydrates to be distinguished on the bulk. Moreover, in mortar sample LTH550 are visible formations of fibres but clearly on an initial stage.

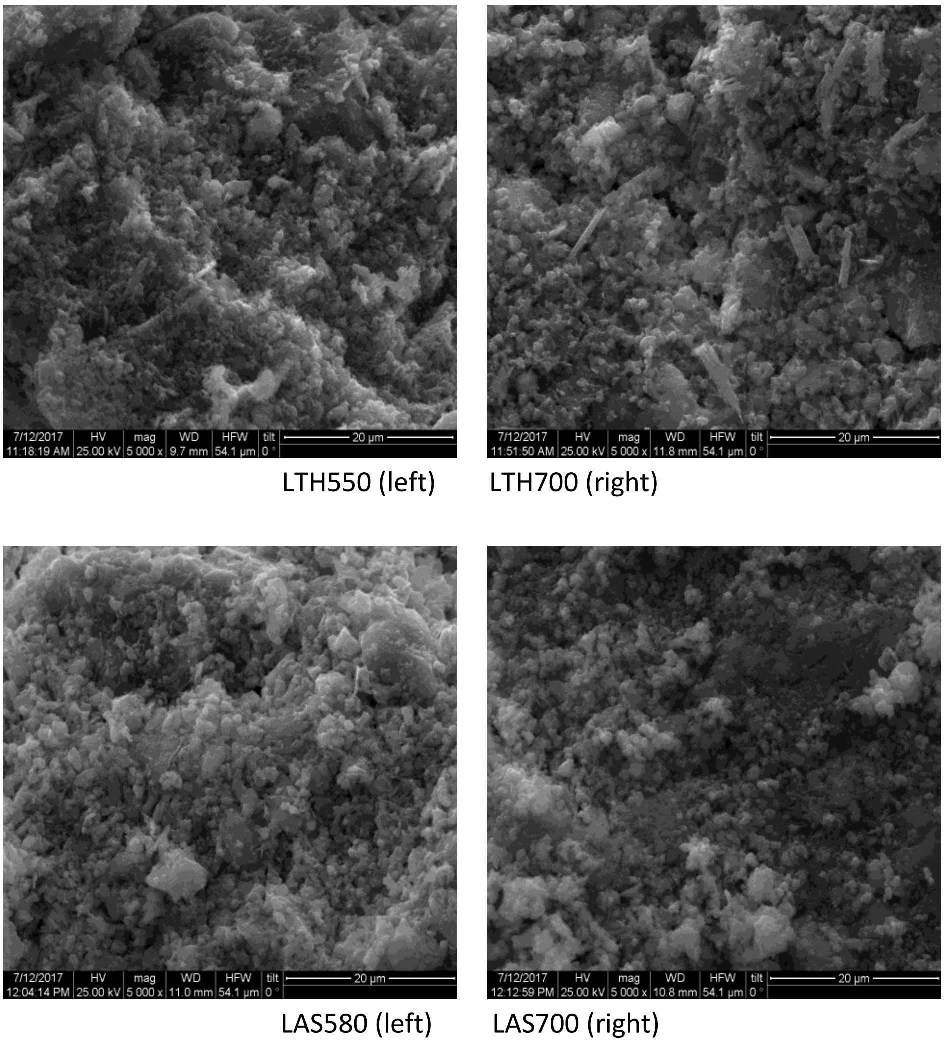


Figure 44. In comparison images from SEM of lime mortar with ceramic admixtures in 28 days of mature

8.3. X-ray diffraction (XRD)

The mineralogical analysis through XRD was carried out on the same samples that presented on SEM results. The aim of that analysis is to verified hydraulic phases thru the identification of mineral components. Indeed on LTH700 diagram the presence of calcium and aluminum hydrates are clearly increased.

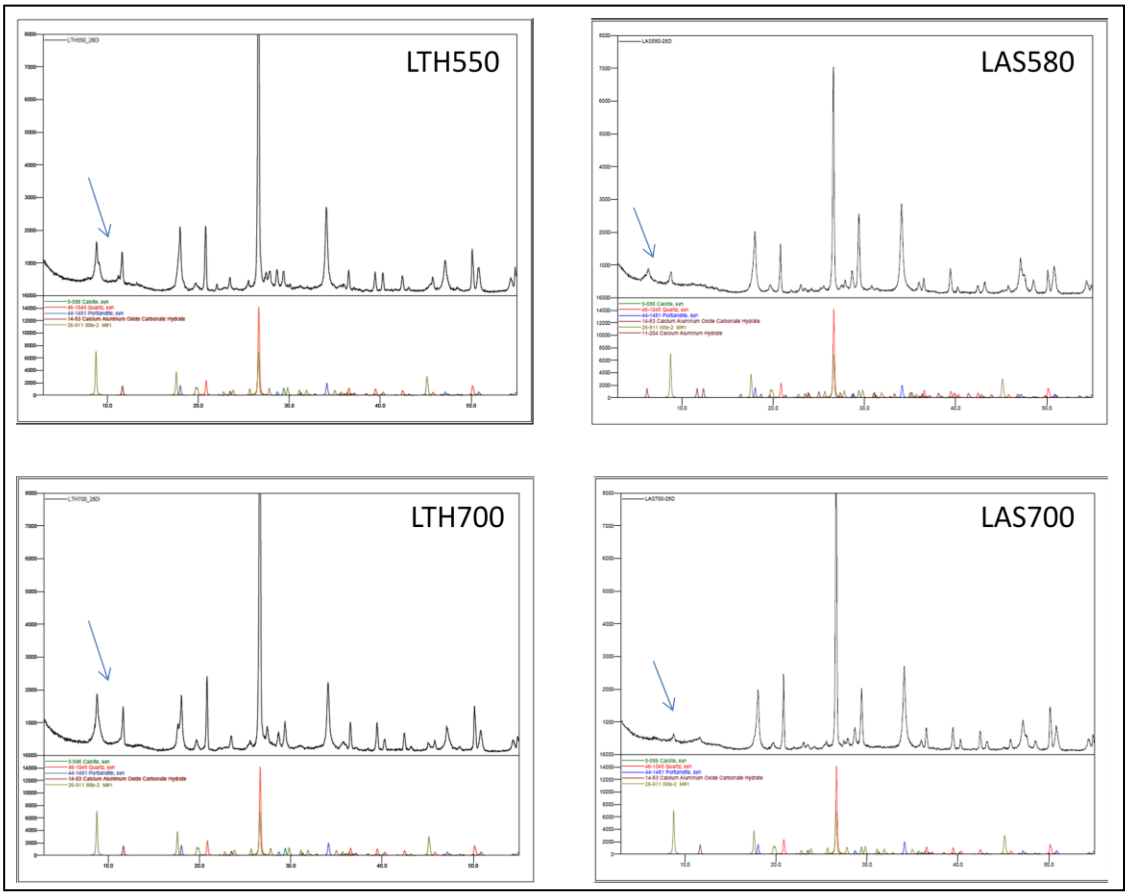
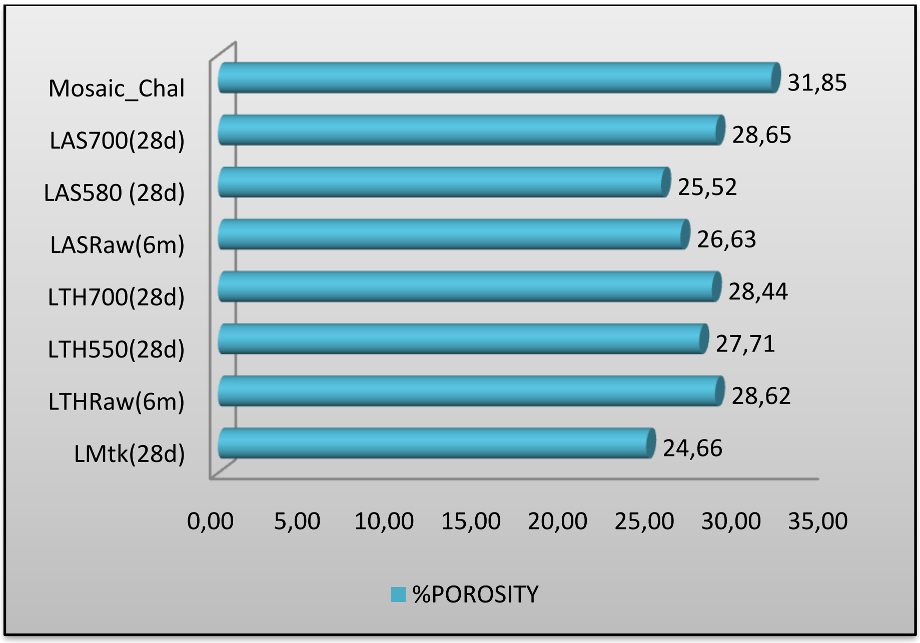


Figure 45. The X – Ray Diffraction results of laboratory prepared lime mortar samples with ceramic admixtures Thrapsano (left) and gios Syllas (right)

8.4. Porosity

Porosity was measured in the total of samples (Table 6). Among laboratory prepared lime mortars with ceramic admixtures, their percentage porosity didn't present specific differences and varies from 25,52 % to 28,65 %. Two exceptions can be mentioned, the lime mortar of Metakaolin that presents the lower value at 24,66%, but also the ancient sample which has the higher value between specimens with porosity 31,85%. On Diagram 2 the uniformity among laboratory prepared specimens is clear. Open porosity measured through water absorption test and the results are presented on Table 7. Furthermore, Diagram 3 displays the water absorption for the total of the laboratory prepared samples compared with the authentic mortar and the reference material with Metakaolin.



Graph 1. Percentage porosity results for laboratory prepared lime mortars with Metakaolin, ceramic admixtures (Thrapsano & Agios Syllas) and ancient mosaic mortar sample

Specimen	**M1** dry weight (g)	**M2** hydrostatic weight (g)	**M3** water saturated (g)	**Vp (M3-M1)** pore volume (cm^3)	**Va (M3-M2)** apparent volume (cm3)	**Vr (M1-M2)** real volume (cm3)	**ρ_r** real density	**ρ_a** apparent density	**%POROSITY**
LMtk(28d)	211.96	122.00	241.41	29.45	119.41	89.96	2356.16	1775.06	24.66
LTHRaw(6m)	217.12	131.82	251.32	34.20	119.50	85.30	2545.37	1816.90	28.62
LTH550(28d)	214.06	128.40	246.89	32.83	118.49	85.66	2498.95	1806.57	27.71
LTH700(28da)	229.10	137,90	265.34	36.24	127.44	91.20	2512.06	1797.71	28.44
LASRaw(6m)	214.70	126.99	246.54	31.84	119.55	87.71	2447.84	1795.90	26.63
LAS580 (28d)	220.19	132.00	250.40	30.21	118.40	88.19	2496.77	1859.71	25.52
LAS700(28d)	222.82	133.00	258.89	36.07	125.89	89.82	2480.74	1769.96	28.65
Mosaic_Chal	258.04	151.95	307.62	49.58	155.67	106.09	2432.27	1657.61	31.85

Table 6. The percentage porosity measurements of laboratory prepared specimens and ancient mosaic mortar sample

$t^{1/2}$ (sec)	Water Absorption [m=Mw/S (g/m^2)]							
	Pal_Chalkis_Mosaic	**LMtk**(28days)	**LASRaw**(6months)	**LAS580 (28days)**	**LAS700**(28days)	**LTHRaw**(6m)	**LTH550**(28days)	**LTH700**(28days)
0	0	0	0	0	0	0	0	0
7,746	2237.50	956.25	1756.25	2000.00	2562.50	1718.75	2100.00	2131.25
1333,4164	3306.25	1825.00	3425.00	3506.25	4343.75	3125.00	3643.75	3706.25
17,3205	4075.00	2487.50	4668.75	4600.00	5662.50	4150.00	4781.25	4881.25
24,4949	5100.00	3556.25	6493.75	6281.25	7725.00	5737.50	6531.25	6706.25
30	5912.50	4331.25	7943.75	7600.00	9350.00	7068.75	7906.25	8168.75
34,641	6568.75	4931.25	9162.50	8743.75	10775.00	8168.75	9100.00	9418.75
423,4264	7468.75	5743.75	10968.75	10506.25	12956.25	9812.50	10887.50	11356.25
51,9615	8587.50	6718.75	13100.00	12593.75	15550.00	11725.00	13006.25	13643.75
60	9506.25	7456.25	14918.75	14343.75	17693.75	13312.50	14731.25	15512.50
73,4847	10987.50	8606.25	17431.25	17150.00	21100.00	15518.75	17437.50	18462.50
84,8528	12256.25	9550.00	18900.00	18331.25	22062.50	17293.75	19450.00	20793.75
103,923	14243.75	11025.00	19000.00	18443.75	22131.25	19681.25	20175.00	22206.25
120	16193.75	12150.00	19037.50	18425.00	22125.00	20318.75	20187.50	22243.75
134,1641	17675.00	13218.75	19118.75	18468.75	22156.25	20425.00	20218.75	22275.00

Table 7. Water absorption of the total of laboratory prepared mortar specimens.

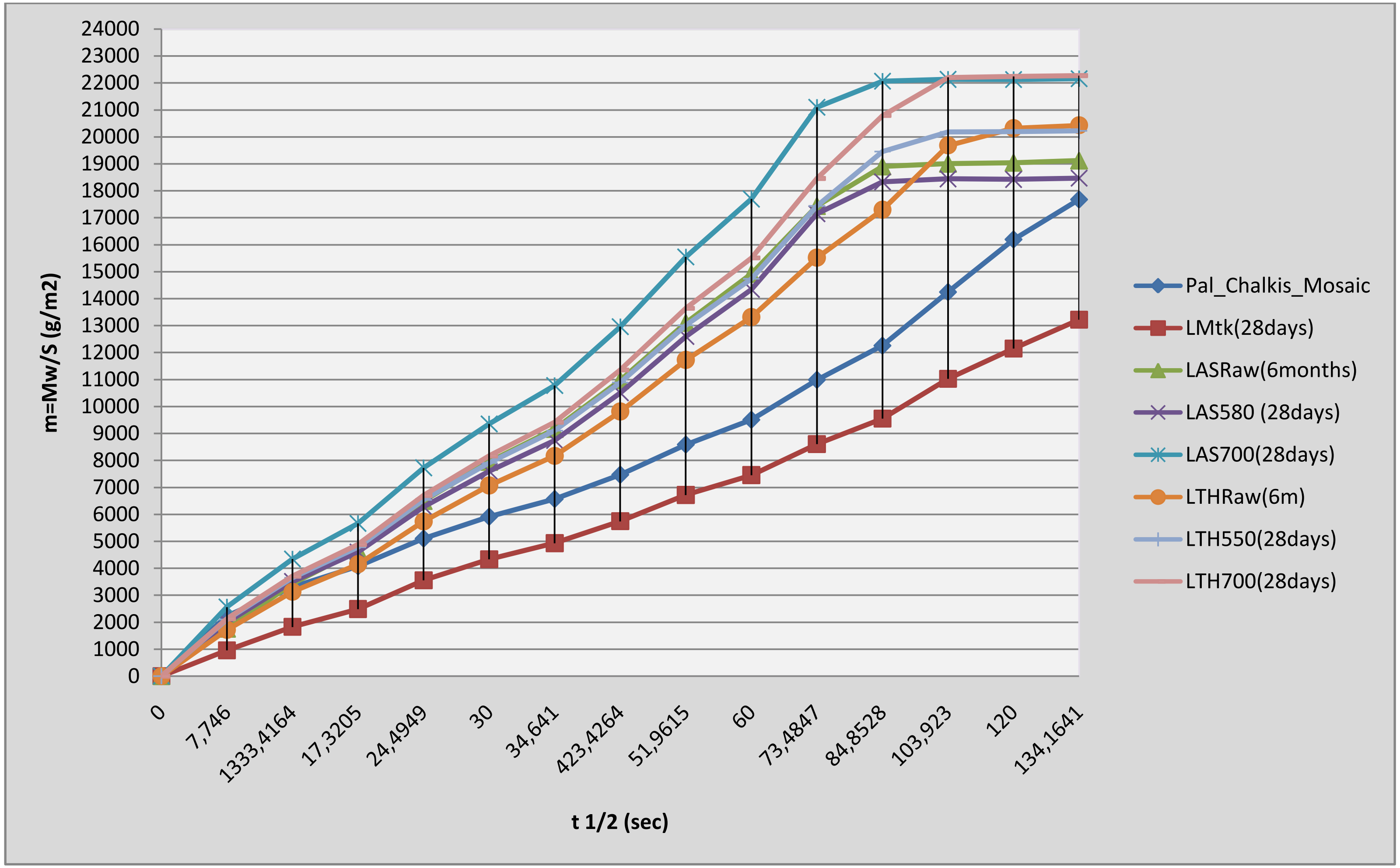
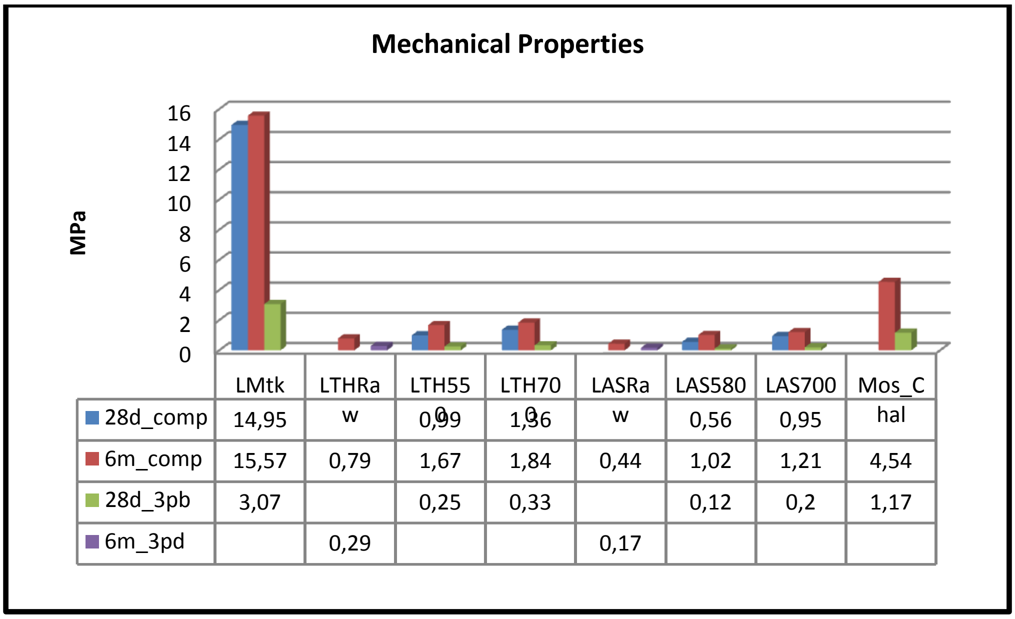


Diagram 2. Graphical representation of mortar specimens water absorption

8.5. Mechanical strength performance

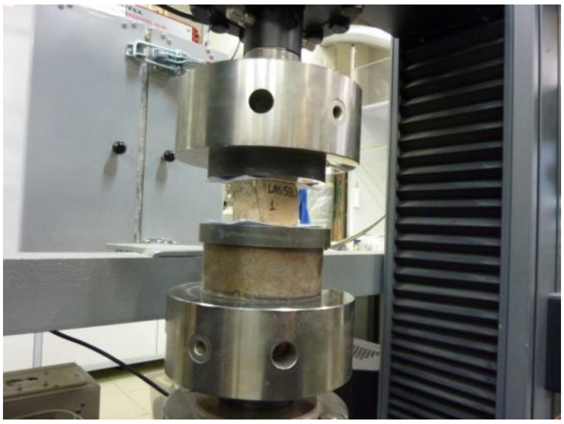
Mechanical strength performance has been examined with two analytical techniques. Compressive strength and 3 point bending tests were carried out with an INSTRON machine. The laboratory prepared specimens of lime mortars analyzed on the 28th day and the 6th month of mature.

Figure 46. Left: The laboratory lime mortar specimens with ceramic admixtures (Thrapsano & Agios Syllas) and ancient mosaic mortar sample, after the completion of mechanical properties tests. Right: The INSTRON machine of "NCSR DEMOKRITOS" during compressive strength test.



Graph 2. Total results of compressive and 3pb tests for the laboratory prepared specimens and ancient mosaic mortar sample

8.5.1. Compressive strength results



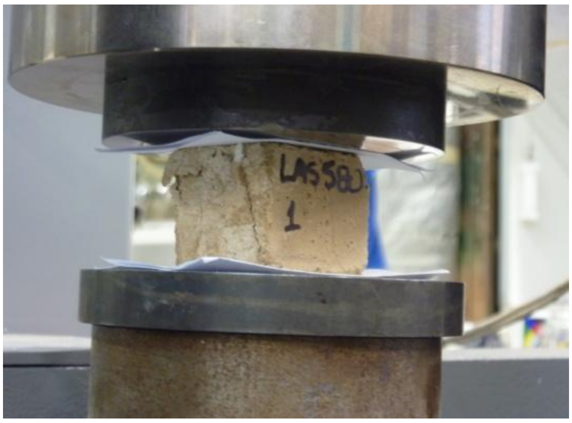
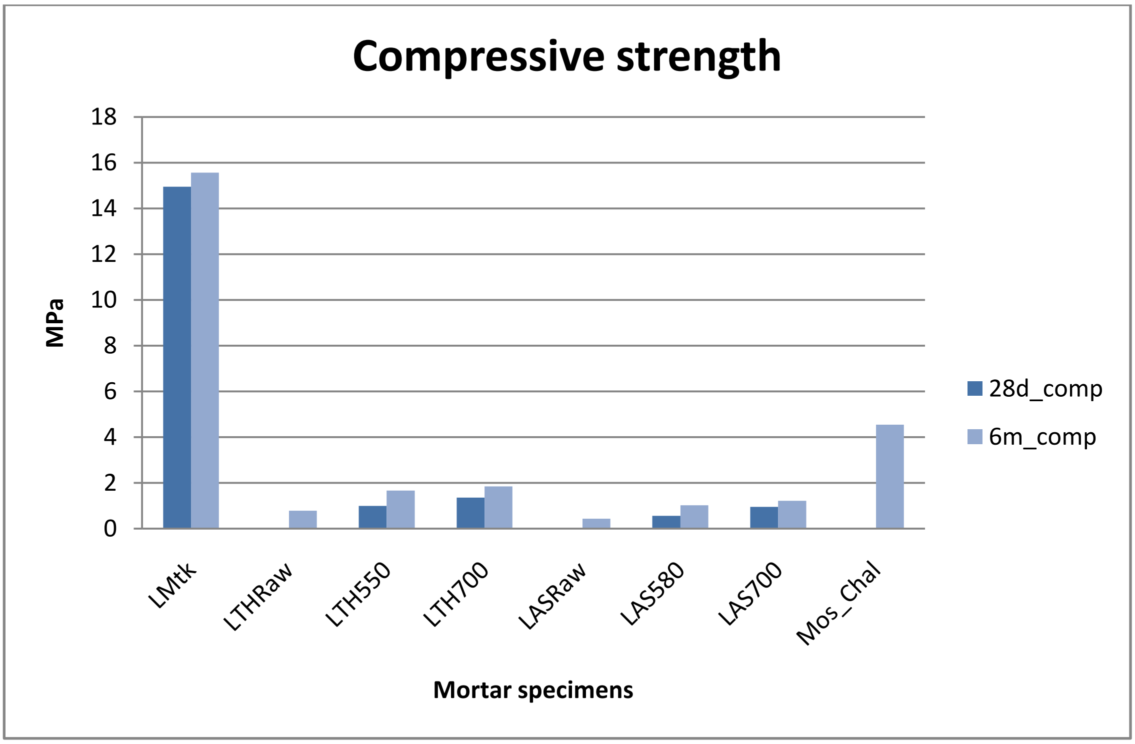


Figure 47. Left: Specimen of LAS 580 of 6 months of mature under compressive strength test. Right: A close up detail cracks and ready to fall fragments are distinguished



Graph 3. Compressive strength results for laboratory prepared and aunthetic mortar specimens in 28 days and 6 months of mature.

Tests were carried out in cubic prisms of 40x40x40mm dimensions on two different time periods. The results are in agreement with SEM and stereomicroscopy observations. About lime mortar specimens' performance it is observed that:

- Mortars with raw clays LTHRaw and LASRaw weren't solid enough in 28 days of mature and finally were tested only in 6 months.
- The LMtk sample perform by far the higher compressive strength values, 3,3 times greater than ancient sample. Also it has very low percentage (%) relative increase (Table 8) among 28 days and 6 months that indicate fast maturing.
- LTH group of mortars with non-calcareous ceramic admixtures presents higher values compared with LAS mortars that contain calcareous ceramics.
- Mortars with ceramic admixtures fired in 700^{o} C performed higher compressive strength compared to those they contain fired ceramics in temperatures of 550^{o}C (LTH) and 580^{o}C (LAS).
- Mortar sample LTH700 exhibits the higher compressive strength among the laboratory prepared mortars with ceramic admixtures. In comparison it is almost 2,5 times and 8,5 times weaker than ancient mortar (Mos_Chal) and LMtk respectively.
- The group of lime mortars with ceramics fired in 700^{o} C (LTH700 & LAS700) present faster maturing (lower value of % relative increase of compressive strength) compared with the group of lower fired ceramics LTH550 & LAS580 (Table)

Sample	Relative Increase%
LMtk	**4.14%**
LTH550	68.68%
LTH700	**35.29%**
LAS580	82.14%
LAS700	**27.36%**

Table 8. The percentage relative increase of compressive strength among 28 days and 6 months performance. The lower the value the quicker the maturing of mortars

Compressive strength performances are verified by Thermal Analysis results. The percentage amount of hydraulic compounds is higher on Thrapsano samples (Diagram 3). Elevated values suggest dense microstructure, less porous materials and higher mechanical properties.

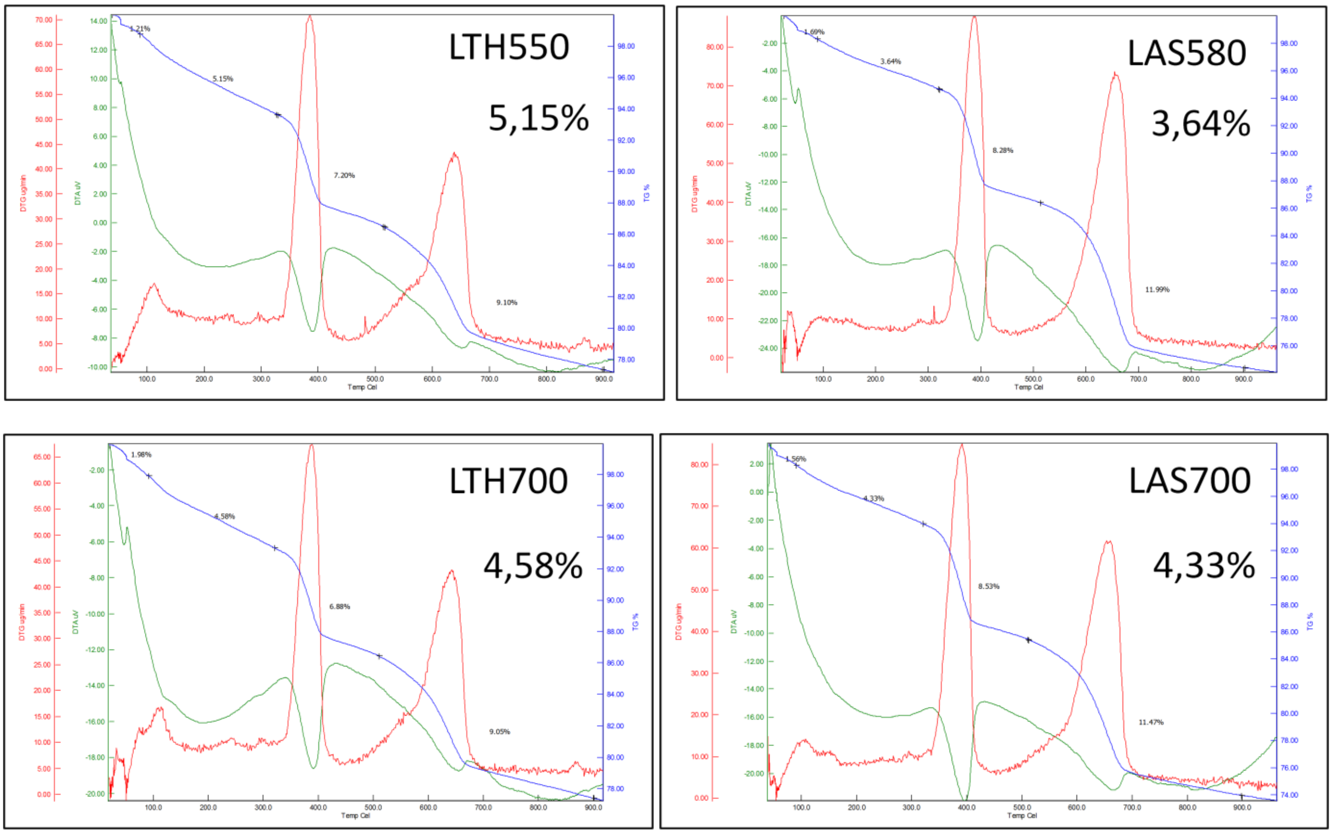
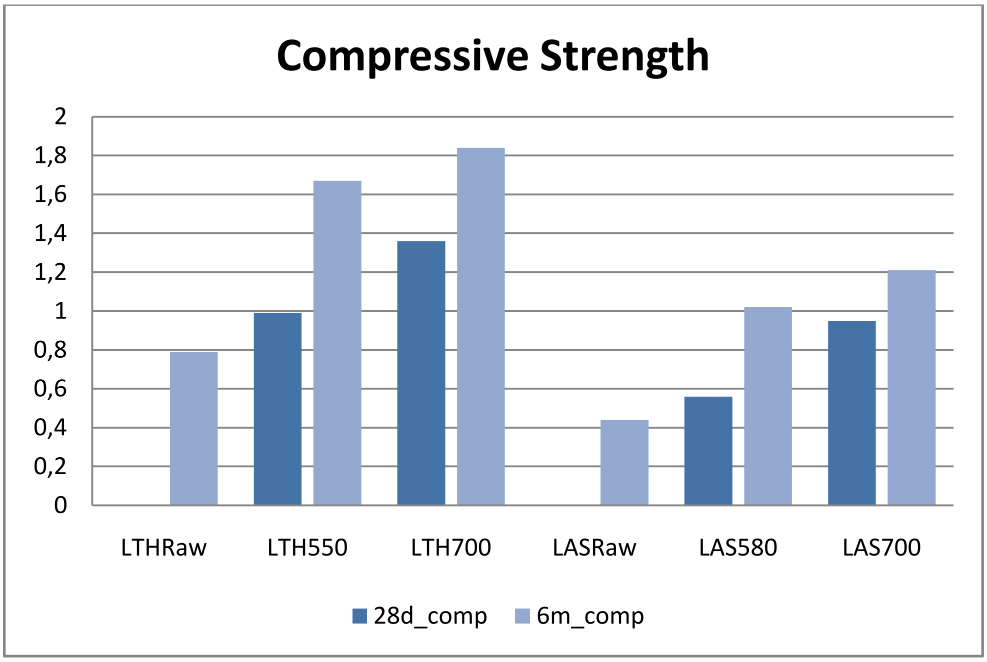


Diagram 3. Thermal Analysis results for laboratory prepared mortar samples. The percentage values present the amount of hydraulic compounds that detected on each sample.



Graph 4. The diagram of lab-prepared mortar samples with ceramic admixtures of Thrapsano and Agios Syllas.

8.5.2. 3 Point bending test results

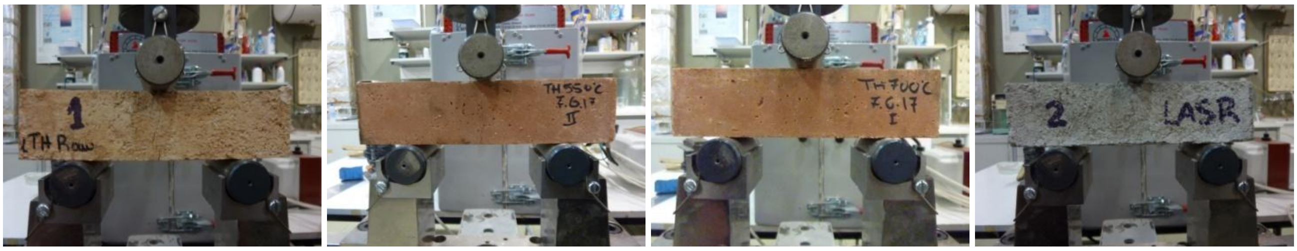
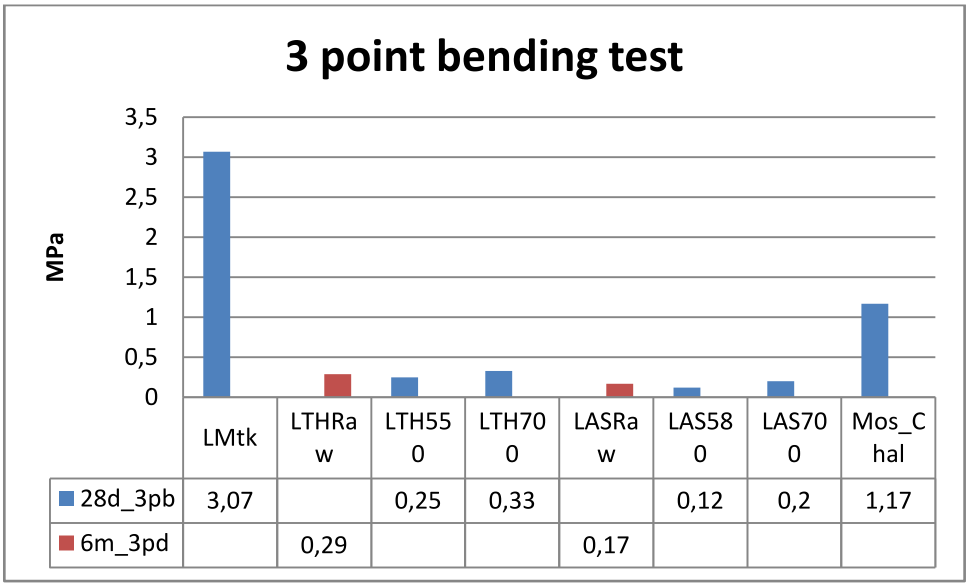


Figure 48. Laboratory prepared lime mortars with ceramic admixtures in rectangular prisms during 3pb strength test.



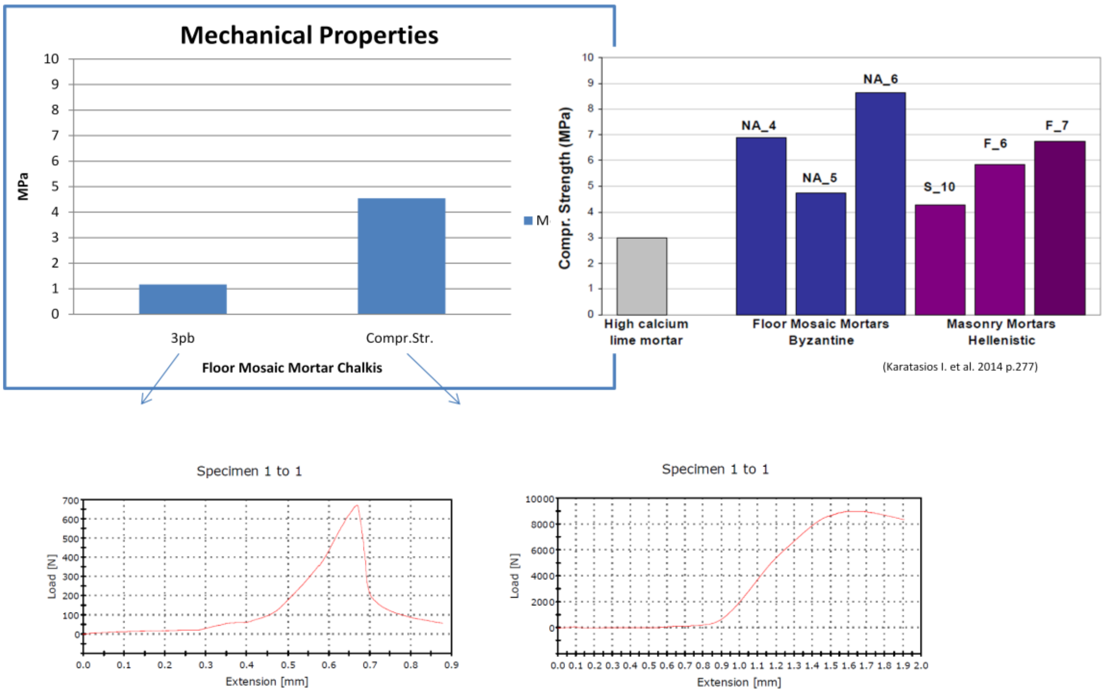
Graph 5. The total results of 3 point bending strength

The specific mechanical test was executed in laboratory prepared mortar rectangular prisms specimens with dimensions 40x40x160mm. All samples were tested on 28 days of mature except mortar specimens that contain the clay admixtures of Thrapsano and Agios Syllas. These mortars as already mentioned in compressive strength results weren't solid enough in 28 days thus they tested on 6 months of mature. According their performance, observations that can be made are:

- LMtk flexural strength is by far the highest among all the laboratory prepared mortar samples. In comparison is 9,3 times greater than 2nd higher value of LTH700 and 2,6 times higher from ancient mortar (Mos_Chal).
- LTH lime mortars with non-calcareous ceramic admixtures have greater values of flexural strength compared with LAS lime mortars with calcareous ceramic admixtures.
- LTH700 specimen has resulted the higher value among laboratory prepared mortar samples with ceramic admixtures. Actually it is 9,3 times and 3,5 times less than LMtk and ancient mosaic mortar respectively.
- Mortars with clays admixtures LTHRaw & LASRaw have present slow maturing. Although in 6months present flexural strength close enough to LTH700 & LAS700 specimens.

8.5.3. Historic mosaic mortar sample from Chalkis mechanical properties

The Roman mosaic mortar sample from Chalkis perform 1,17 MPa in 3pb and 4,54 MPa in compressive strength. In bibliographic references the mechanical properties of those type authentic materials are rare especially for 3 point bending tests. The research of Karatasios and others (2014), presents some examples about compressive strength for comparison. Mosaic mortar from Chalkis compressive strength is close to the lower value of that group of Byzantine floor mosaics (Graph 6). Finally, the 3pb diagram shows a mortar with considerable toughness that doesn't take apart immediately.



Graph 6. Mechanical properties of mosaic mortar sample from Chalkis.

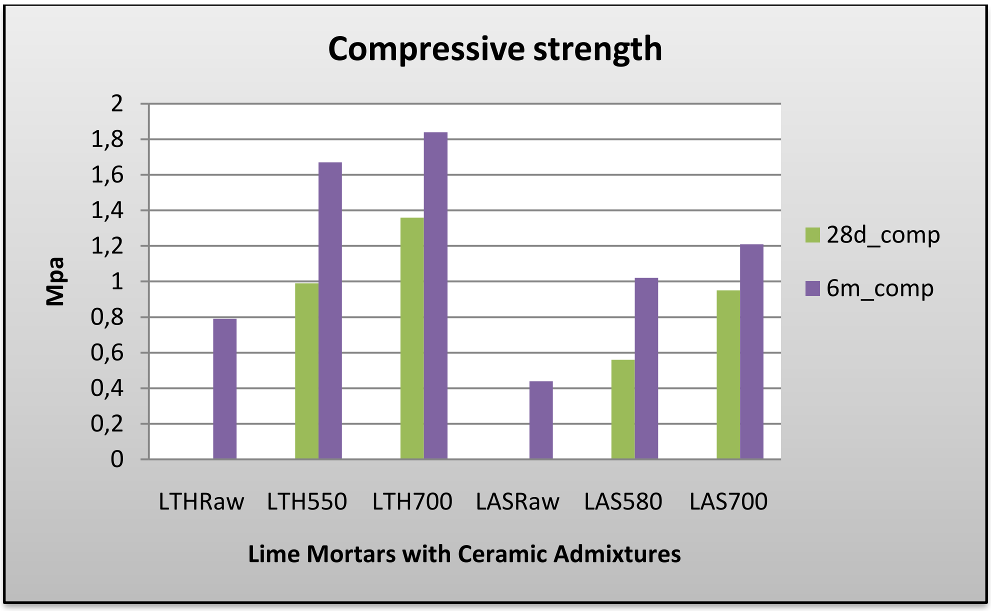
9. Discussion

The present experimental research is focused on the mechanical and physical properties of laboratory prepared lime mortar samples with ceramic admixtures. The performance of the mortars' mechanical properties was compared and confirmed with SEM, XRD and Thermal analysis. The conclusions that emerged after the completion of the process helped to evaluate the role of ceramic particles as pozzolans. In general, significant differences between ceramics created from non-calcareous and calcareous clayswere observed. Also, the level of firing temperatures seems to be an important factor in the pozzolanicity of ceramics.

What should be mentioned first is that lime mortars with non-calcareous ceramic admixtures, the LTH group, have presented better mechanical properties (compressive and flexural strength) than mortar samples with non-calcareous ceramics, the LAS group. This observation is contradicting the results from Karatasios' (2014) study, where it is mentioned that calcareous ceramics of Agios Syllas fired at 700^{o}C were the most active.

As far as the firing temperatures are concerned, it seems that ceramics fired in 700^{o}C have elevated pozzolanic properties compared to ceramics fired in very low (550 and 580^{o}C) or temperatures higher than 700^{o}C[7]. The example of specimen LTH700 verifies these observations, as that mortar sample contains non-calcareous ceramic admixtures fired at 700^{o}C and has demonstrated the higher mechanical properties among the laboratory prepared lime mortars (Graph 7). Based on technological facts, it is known that fired ceramics in 700^{o} C were the functional category used for bricks, tiles and storage containers and it seems that these types of ceramics were used for the ancient cocciopesto mortars, probably in the form of recycled materials. The historical sample from the Roman period presents high mechanical properties. Into the mortar bulk are located different ceramic fragments, with various inclusions according to their color and further analysis of these ceramics could define their exact construction firing temperatures.

[7]That information is already known through bibliography

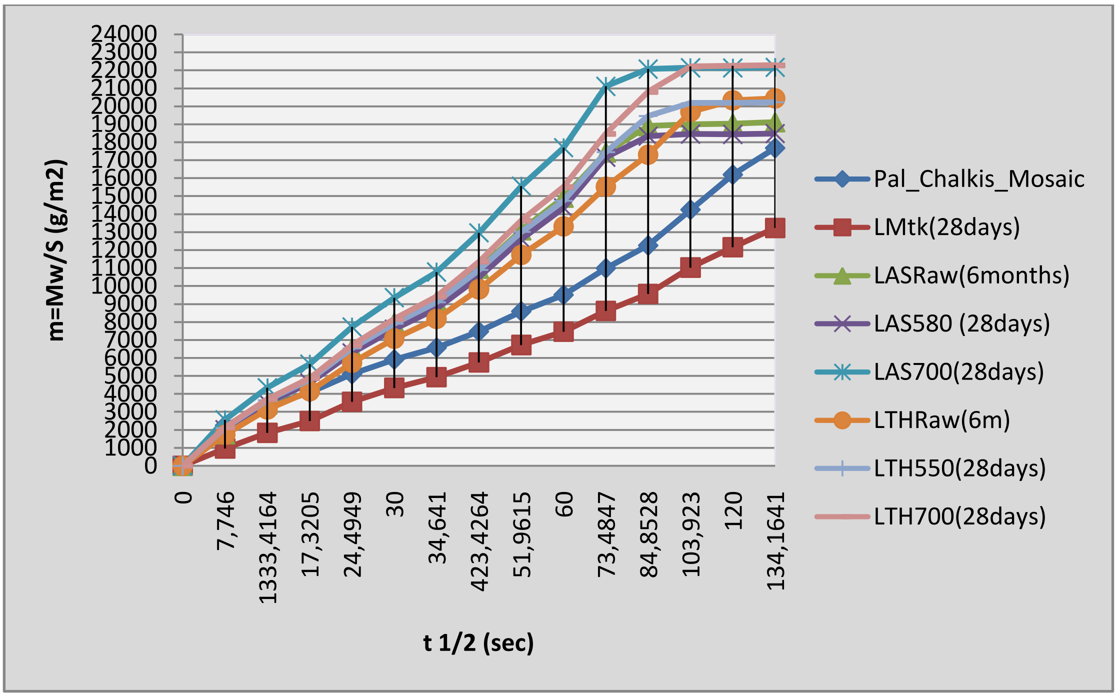


Graph 7. Compressive strength results for laboratory prepared mortar samples with ceramic and clay admixtures

The conclusions that emerged from the research process can provide new information for the design of new repair mortars. To evaluate the analysis results to that direction, the technical and functional requirements - as they are presented in Chapter 4-are under consideration. Furthermore, Hughes J. (2003) presents a well summarized description of properties for new repair mortars, compatible to the methods of conservation of architectural heritage. More precisely, he contends that, “A proper new mortar should have porosity and strength close to the original, be less dense, more permeable than the host construction and at the same time should have sufficient durability” (Hughes J. 2003.p.24). According to this description but also to the technological characteristics concerning the construction of mosaic floors, a lime mortar with non-calcareous admixtures fired at 700^{o}C seems to be a material with potentials. In detail, this mortar has porosity close to the original (Graph 1) but is also more permeable (Graph 8) and less dense. Its differences in mechanical properties can be corrected with proper alterations in aggregates granulometry in order to be closer to the authentic mortar.

On the other hand, lime mortars with raw clays and very low fired ceramic admixtures must be considered as inappropriate material, mainly because of their very slow rate of solidification and maturation. Such a characteristic is not preferred in the conservation implementations of architectural heritage, where the time of setting is a crucial parameter.

Ceramic admixtures in lime mortars can be considered as prospective materials for conservation interventions in mosaic floors. The use of the ancient technique of *cocciopesto* doesn't only ensure authenticity and a compatibility parameter, but also seems to fulfill the prerequisites for proper new mortars. For the field of in situ conservation, such a solution can be considered as a realistic one. Knowledge and scientific analysis still have to bridge some distance with field conservation, but their cooperation is the only way to achieve appropriate mortar mixtures for implementations.



Graph 8. Water absorption results

VII. Bibliography

1. Akyol A.A., Kadioglu Y.K. (2011) Archaeometric studies on the Haleplibahce mosaics in Turkey. Managing Archaeological Sites with Mosaics: From Real Problems to Practical Solutions. The 11th Conference of the International Committee for the Conservation of Mosaics, Menkes 2011. Edited by, Michaelides D., Guimier – Sorbets A.M. p.265-282
2. Ανδρειωμένου Κ.Α. (1961) Ψηφιδωτά εν Χαλκίδι. Αρχαιολογική Εφημερίς 1953-1954. Εις μνήμην Γεώργιου Π. Οικονόμου. Μέρος Τρίτον. σελ.303-313
3. Bakolas A., Aggelakopoulou E., Moropoulou A. (2008) Evaluation of pozzolanic activity and physic – mechanical characteristics in ceramic powder – lime pastes. Journal of Thermal Analysis and Calorimetry, Vol.92, I. p.345-351
4. Baronio G. and Binda L. (1997a) Study of the pozzolanicity of some bricks and clays. Construction and Building Materials, Vol.11, No1. Elsevier Science Ltd. P.41-46
5. Baronio G., Binda L. and Lombardini N. (1997b) The role of brick pebbles and dust in conglomerates based on hydrated lime and crushed bricks. Construction and Building Materials, Vol.11, No1. Elsevier Science Ltd. p.33-41
6. Boffey G., Hirst E. (1999) The use of pozzolans in lime mortars. Journal of Architectural Conservation, 5:3. p.34-42
7. Biscontin G., Birelli M., Zendri E. (2002) Characterization of binders employed in the manufacture of Venetian historical mortars. Journal of Cultural Heritage vol.3. p.31-37
8. Budak M., Akkurt S., Boke H. (2010) Evaluation of heat treated clay for potential use in intervention mortars. Applied Cly Science 49 p. 414-419.
9. Γιαννακόπουλος Ι.Κ. (2011) Σημειώσεις Πειραματικής Αντοχής Υλικών. ΤΕΙ Πειραιώς Σχολή Τεχνολογικών Εφαρμογών Τμήμα Μηχανολογίας Εργαστήριο Μηχανικής
10. Camaiti M., Cantisani E., El Hassani I., Fratini F., Materassi C., Pallecchi P.,(2010) Suitable restoration mortars for the conservation of mosaics in archaeological sites. Managing Archaeological Sites with Mosaics: From Real Problems to Practical Solutions. The 11th Conference of the International Committee for the Conservation of Mosaics, Menkes 2011. Edited by, Michaelides D., Guimier – Sorbets A.M. p.283-290
11. Cassio A., Nardi R., Schneider K. (2005) Zeugma Mosaics Restoration Project. VIIIth Conference of the International Committee for the Conservation of Mosaics (ICCM) Thessaloniki 2002. p.155-168
12. Charalambous E. (2011) Geology and the ue of mortars in the conservation and manufacture of Cypriot floor mosaics. Managing Archaeological Sites with Mosaics: From Real Problems to Practical Solutions. The 11th Conference of the International Committee for the

Conservation of Mosaics, Menkes 2011. Edited by, Michaelides D., Guimier – Sorbets A.M. p.297-311
13. Charola A.E., Rodrigues P.F., McGhie A.R., Henriques F.M.A. (2005) Pozzolanic Components in Lime Mortars: Correlating Behaviour, Composition and Microstructure. Restoration of Buildings and Monuments, Bauinstandsetzen und Baudenkmalpflege Vol.11, No2, p.111-118
14. Chlouveraki S.N., PolitisK.D., (2003) The documentation and conservation of the nave mosaic in the Basilica of Agios Lot at Deir, Ain Abata, Jordan. Mosaics make a Site: The conservation in situ of mosaics on archaeological sites. Proceedings of the VIth International Conference of the International Committee for the Conservation of Mosaics (ICCM) Editor: Michaelides D. p.149-156
15. Chlouveraki, S., Giannakaki, M., Politis K.D. (2008) Observations on the technology of the Early Christian mosaics at the Basilica of Saint Lot, Jordan. 11th Conference of the International Committee for the Conservation of Mosaics (ICCM) was held Palermo (Sicily), October 20-27. 2008
16. Cowper A.D. and Brady F.L. (1927) Pozzolanas. Building Research Bulletin no.2. London: Published under the Authority of his Majesty's stationery office
17. Crisci G.M., Franzini M., Lezzerini M., Mannoni T., Riccardi M. P. (2004) Ancient mortars and their binder. An International Journal of Mineralogy Crystallography Geochemistry, Ore Deposits, Petrology, Volcanology. Per. Minera. 73 p.259-268.
18. Ducrey P., Metzger I.R. Reber M. (1993) ERETRIA Fouilles et recherché VIII. Le Quartier de la Maison aux mosaïques. Ecole suisse d'archéologie en Grèce. Editions Payot Lausanne
19. Dunbabin K.M.D.(1999) Mosaics of the Greek and Roman world. Cambridge University Press
20. Dollimore D. (2001) Thermal Analysis. Encyclopedia of Physical Science and Technology (Third Edition) p.591-612
21. Farneti M. (1993) Technical – Historical Glossary of Mosaic Art. With a Historical Survey of Mosaic Art. Longo Editore Ravenna
22. Fiorentini Roncuzzi I., Fiorentini E.(2002) Mosaic. Materials, Techniques and History.MW E V Editions
23. He C., Osbaeck B., Makovicky E. (1995) Pozzolanic reactions of six principal clay minerals: Activation, Reactivity assessments and technological effects. Cement and Concrete Research 25. p.1691-1702
24. Hein A., Day P.M., Cau Ontiveros M.A., Kilikoglou V. (2004) Red clays from Central and Eastern Crete: geochemical and mineralogical properties in view of provenance studies on ancient ceramics. Applied Clay Science 24 p.245-255

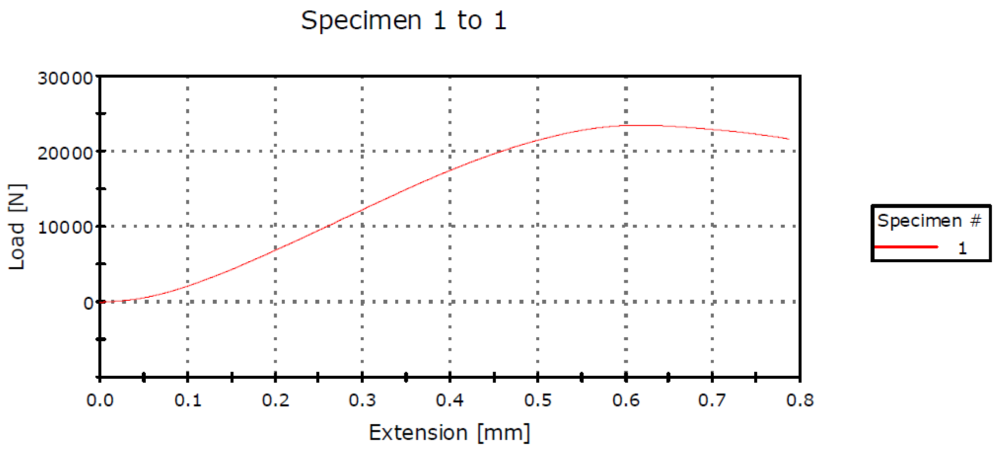
25. Hein A., Day P.M., Quinn P.S., Kilikoglou V. (2005) The geochemical diversity of neogene clay deposits in Crete and its implications for provenance studies of Minoan pottery. Archaeometry 46, 3. P.357-384
26. Hughes J.J., Valek J. (2003) Mortars in Historic Buildings. A review of the conservation, technical and scientific literature. Published by Historic Scotland. Technical Conservation, Research and Education Division. Edinburgh 2003
27. Jenkins R. (2001) X-ray Analysis. Encyclopedia of Physical Science and Technology (Third Edition) p.887-902
28. Karatasios I., Theoulakis P., Colston B., Watt D., Lampropoulos V., Kilikoglou V. (2005) Analytical and microscopic techniques for the study of mortars from the floor mosaics of Thebes, Greece. VIIIth Conference of the International Committee for the Conservation of Mosaics (ICCM) Thessaloniki 2002. p.209-223
29. Karatasios I., Alexiou K., Muller N.S., Day P.M., Kilikoglou V. (2014) The second life of ceramics: a new home in a lime environment. In M Martinon – Torres 9Ed.) Craft and science: International perspectives on archaeological ceramics. Doha, Qatar Foundation. p.271-279
30. Κορωναίος Γ. Α. Πουλάκος Ι.Γ. (2006) Τεχνικά Υλικά Τόμος 1. Εθνικό Μετσόβιο Πολυτεχνείο
31. Kramar S., Zalar V., Urosevic M., Korner W., Mauko A., Mirtic B., Lux J., Mladenovic A. (2011) Mineralogical and microstructural studies of mortars from the bath complex of the Roman villa rustica near Mosnje (Slovenia) Materials Characterization 62 p1042-1057
32. Kurtosi B.M.,(2011) Investigation and conservation of frgment of a Roman mosaic floor from the Governor' s Palace of Aquincum Pannonia), Hungary. Managing Archaeological Sites with Mosaics: From Real Problems to Practical Solutions. The 11th Conference of the International Committee for the Conservation of Mosaics, Menkes 2011. Edited by, Michaelides D., Guimier – Sorbets A.M.
33. Lavat A.E., Trezz M.A., Poggi M. (2009) Characterization of ceramic roof tile wastes as pozzolanic admixture. Waste management 29. p.1666-1674
34. Ling R. (1998) Ancient Mosaics. British Museum Press
35. Μαντζάνα Ε., Γεωργοπούλου Β., Θεοδωροπούλου Κ., Τσίντζου Α. (2014) Μελέτη Συντήρησης Ψηφιδωτών Δαπέδων Ρωμαϊκής Παλαίστρας στη Χαλκίδα. ΙΑ ΕΠΚΑ ΕΣΠΑ 2007-2013 (αρ.πρωτ.1613/20-5-13) Έγκριση ΚΑΣ του ΥΠΠΟΑ: 24/30-7-2013/Αρ.Πρωτ.: ΥΠΠΟΑ/ΣΥΝΤ/Φ25/4301/92 ΑΔΑ:ΒΙ6ΖΓ-Ζ1Φ
36. Matias G., Faria P., Torres I. (2014) Lime mortars with heat treated clays and ceramic waste : A review. Construction and Building Materials 73 p.125-136
37. Meng B. (1996) Determination and interpretation of fractal properties of the sandstone pore system. Materials and Structures Vol.29 p.195-205

38. Moropoulou A.,Athanasiadou A.,Bakolas A., Moundoulas (2000) Desinnd in situ application of repair mortars for the works of 'Restoration and Strengthening of the Markos' Water Mill in Veria, Greece. (Scientific Editors: Moropoulou A., Biscontin G., Delgado Rodrigues J., Erdik M.) Compatible Materials Recommendations for the Preservation of European Cultural Heritage PCT 59.163-176.
39. Moropoulou A., Polikreti K., Bakolas A., Michailidis P. (2003) Correlation of physiochemical and mechanical properties of historical mortrs nd classification by multivariate statistics. Cement and Concretr Research 33 p.891-898.
40. Moropoulou A., Bakolas A., Anagnostopoulou S. (2005a) Composite materials in ancient structures. Cement & Concrete Composites 27. p.295-300
41. Moropoulou A., Bakolas A., Moundoulas P., Aggelakopoulou E., Anagnostopoulou S. (2005b) Strength development and lime reaction in mortars for repairing historic masonries. Cement & Concrete Composites 27 p.289–294
42. Middendorf B., Hughes J.J., Callebaut K., Baronio G., Papayianni I. (2005) Investigative methods for the characterisation of historic mortars – Part 1 : Mineralogical characterisation. RILEM TC 167-COM Materials and Structures 38. p.76-769
43. Nardi R. (2003) The treatment of mosaics in situ. Mosaics make a Site: The conservation in situ of mosaics on archaeological sites. Proceedings of the VIth International Conference of the International Committee for the Conservation of Mosaics (ICCM) Editor, Michaelides D. p.187-202
44. Nardi R. (2005) The conservation of Zeugma. VIIIth Conference of the International Committee for the Conservation of Mosaics (ICCM) Thessaloniki 2002. p.331-346
45. Nežerka V. (2015) Modeling and Design of Modern Cocciopesto Mortars. Czech Technical University in Prague. Faculty of Civil Engineering
46. Pachta V., Stefanidou M., Konopisi S., Papayianni I. (2014) Technological evolution of historic structural mortars. Journal of Civil Engineering and Architecture Vol8 No. 7 (Serial No. 80) pp. 846-854
47. Papayianni I. (2004) Design of compatible repair materials for the restoration of monuments. International Journal for Restoration Vol 10 No 6. p.623-635
48. Papayanni I., Pachta V. (2008) Technology of mortars used for the substratum of mosaics. Proceedings of the 4th Symposium of the Hellenic Society for Archaeometry. National Hellenic Research Foundation 28-31 May 2003. Edited by: Facorellis Y., Zacharias N., Polikreti K., p.437-440
49. Papayianni I. (2010) Performance and repair requirements for flooring mortars. 2nd Historic Mortars Conference HMC2010 and RILEM TC 203-RHM Final Workshop 22-24 September 2010, Prague, Czech Republic.

50. Rogers S.B. (2011) Evaluation and testing of brick dust as a pozzolanic additive to lime mortars for architectural conservation. University of Pennsylvania, Philadelphia ,PA.
51. Starinieri V. (2009) Study of materials and technology of ancient floor mosaics' substrate. Doottorato di ricerca Science for Conservation. Alma Mater Studiorum – Universita d Bologna
52. Stefanidou M., Papayianni I., Pachta V. (2011). Evaluation of Inclusion in Mortars of Different Historical Periods from Greek Monuments. Archaeometry University of Oxford.
53. Szczepanowska H. M. (2013) Conservation of Cultural Heritage. Key Principles and Approaches. Routledge Taylor & Francis Group.
54. Puertas F., Blanco-Varela M.T., Palomo A., Ortega-Calvo J.J., Arino X., Saiz-Jimenez C. (1994) Decay of Roman and repair mortars in mosaics from Italica, Spain. The Science of the Total Environment 153 p.123-131Teutonico J.M., Mc Caig I., Burns C., Ashurst J.(1994) The Smeaton Project – Factors affecting the properties of lime based mortars. A future of the past: A jint Conference of English Heritage and the Cathedrel Architects Association, London p.32-49.
55. The Getty Conservation Institute and the Israel Antiquities Authorities (2003) Mosaics In Situ Project – Illustrated Glossary. The Getty Conservation Institute.
56. Torraca G. (2009) Lectures on Materials Science for Architectural Conservation. The Getty Conservation Institute, Los Angeles. J. Paul Getty Trust.
57. Van Balen K., Papayianni I., Van Hees R., Binda L., Waldum A. (2005) Introduction to requirements for and functions and properties of repair mortars. RILEM TC 167-COM. Materials and Structures 38. p.781-785
58. Vitruvius. The Ten Books on Architecture. Translated by Morris Hicky Morgan. Cambridge Harvard University Press London: Humphrey Milford Oxford University Press 1914
59. Velosa A.L., Coroado J., Veiga M.R., Rocha F., (2007) Characterisation of roman mortars from Conimbriga with respect to their repair. Materials Characterization 58. p.1208-1216.
60. Χαραλάμπους Ε.Ν. (2012) Τεχνολογία κατασκευής των επιδαπέδιων ψηφιδωτών της Κύπρου. Αριστοτέλειο Πανεπιστήμιο Θεσσαλονίκης – Πολυτεχνική Σχολή. Διδακτορική Διατριβή, Λευκωσία 2012

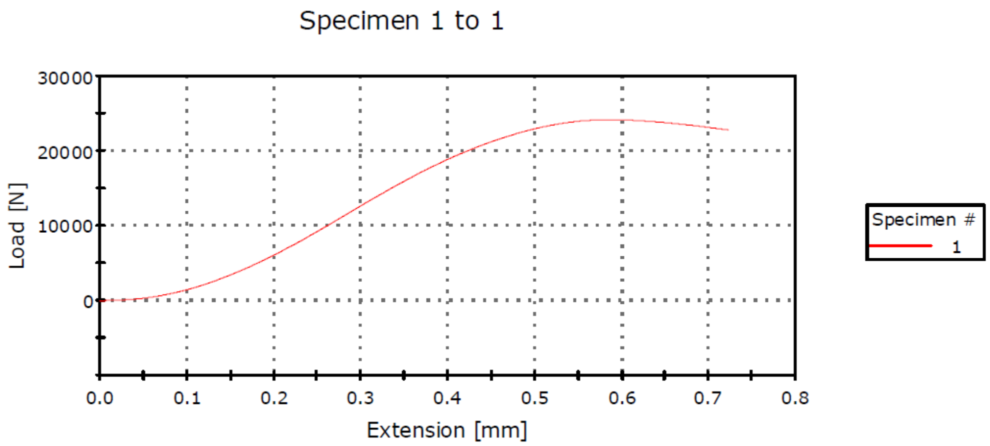
VIII. Appendix A – Compressive strength results

LMtk_28d_compressive_01



	Maximum Load [N]	Extension at Maximum Load [mm]	Specimen note 1	Rate 1 [um/min]
1	23,451.23828	0.61856		150.00000

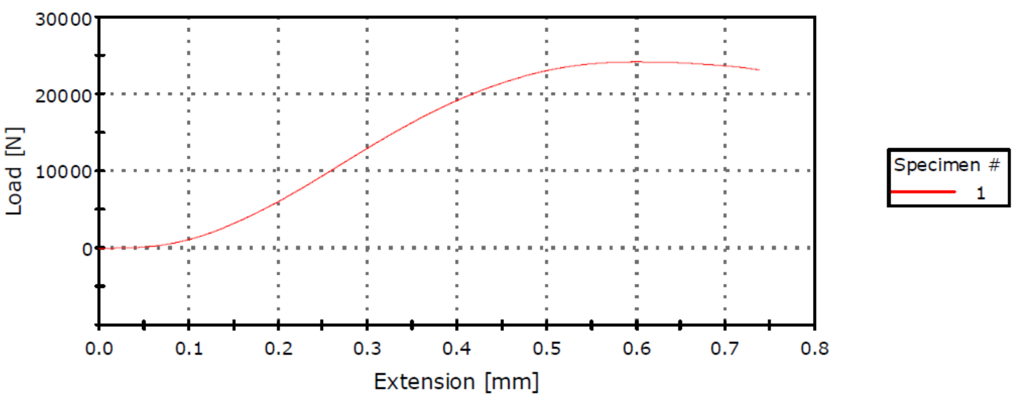
LMtk_28d_compressive_02



	Maximum Load [N]	Extension at Maximum Load [mm]	Specimen note 1	Rate 1 [um/min]
1	24,160.13867	0.58705		150.00000

LMtk_28d_compressive_03

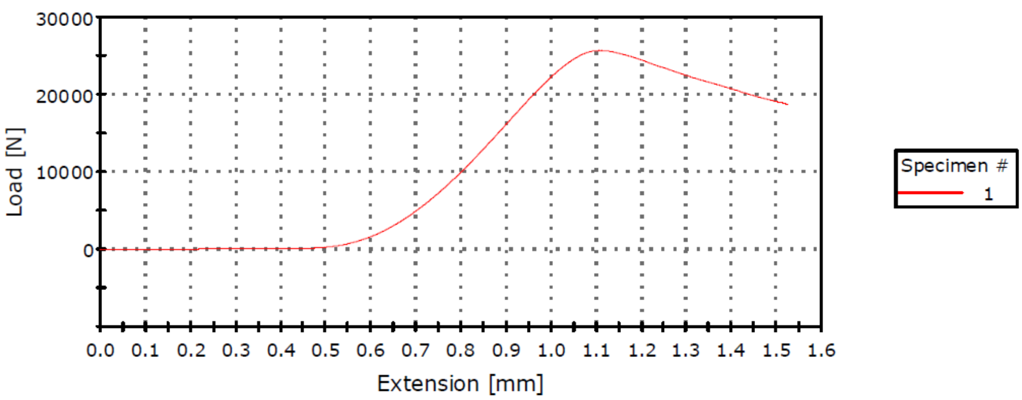
Specimen 1 to 1



	Maximum Load [N]	Extension at Maximum Load [mm]	Specimen note 1	Rate 1 [um/min]
1	24,171.82812	0.60230		150.00000

LMtk_6m_compressive_01

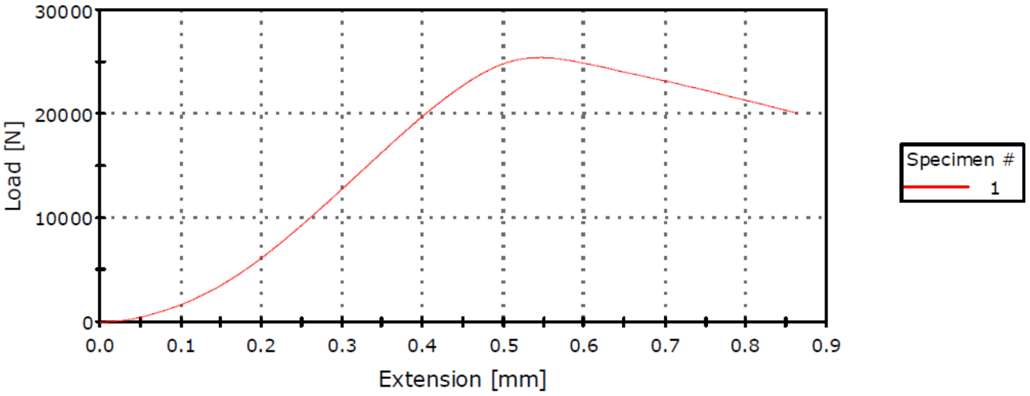
Specimen 1 to 1



	Maximum Load [N]	Extension at Maximum Load [mm]	Specimen note 1	Rate 1 [um/min]
1	25,662.42773	1.10703	LMtk_6m_Compr_01	150.00000

LMtk_6m_compressive_02

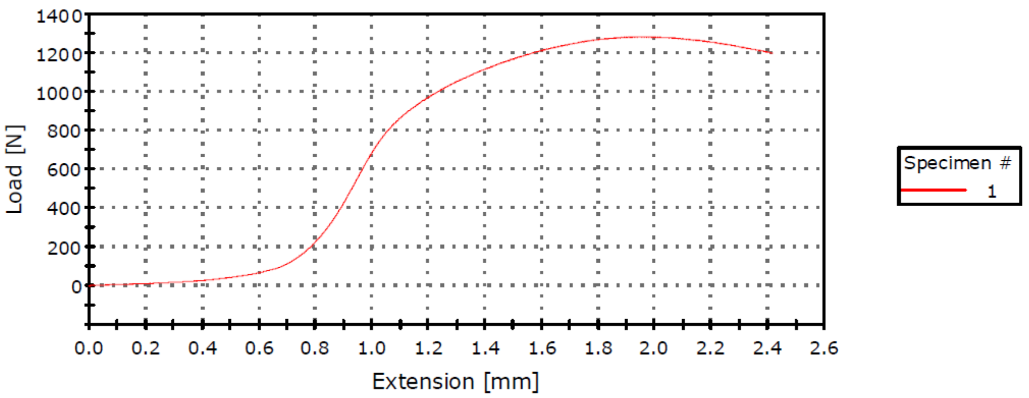
Specimen 1 to 1



	Maximum Load [N]	Extension at Maximum Load [mm]	Specimen note 1	Rate 1 [um/min]
1	25,403.47070	0.54628	LMtk_6m_Compr_02	150.00000

LTHRaw_6m_compressive_01

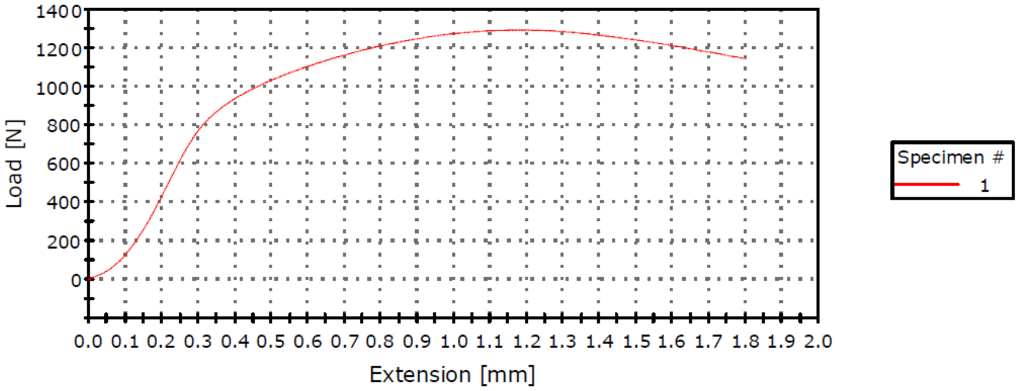
Specimen 1 to 1



	Maximum Load [N]	Extension at Maximum Load [mm]	Specimen note 1	Rate 1 [um/min]
1	1,281.79114	1.97031	LTH Raw_6m_compr_01	150.00000

LTHRaw_6m_compressive_02

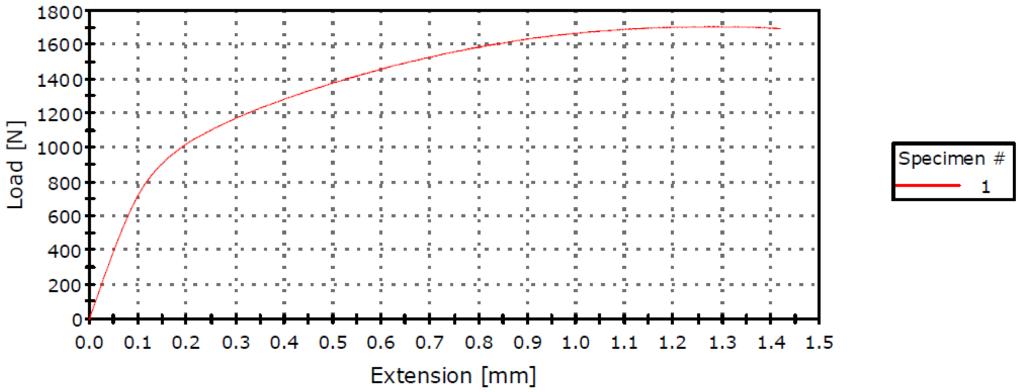
Specimen 1 to 1



	Maximum Load [N]	Extension at Maximum Load [mm]	Specimen note 1	Rate 1 [um/min]
1	1,292.31238	1.16932	LTHRaw_6m_compr_02	150.00000

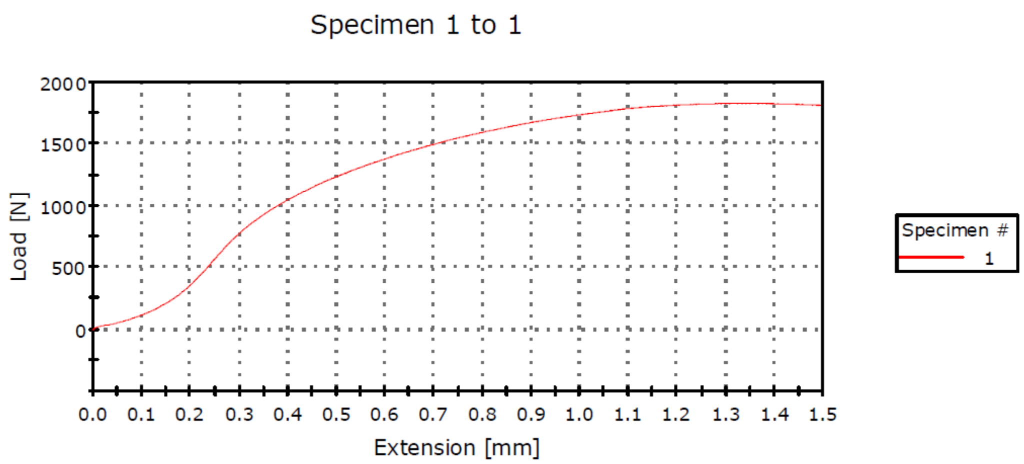
LTH550_28d_compressive_01

Specimen 1 to 1



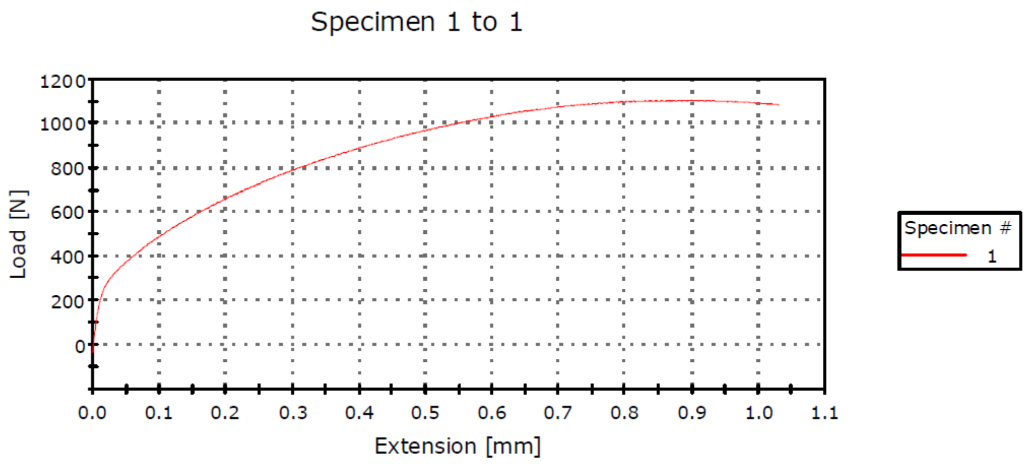
	Maximum Load [N]	Extension at Maximum Load [mm]	Specimen note 1	Rate 1 [um/min]
1	1,704.35327	1.28929		150.00000

LTH550_28d_compressive_02



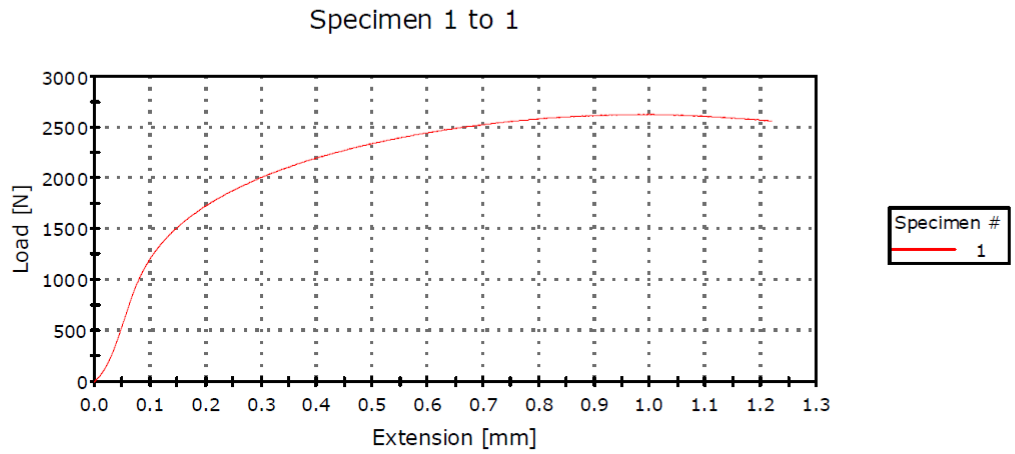
	Maximum Load [N]	Extension at Maximum Load [mm]	Specimen note 1	Rate 1 [um/min]
1	1,826.43030	1.35630		150.00000

LTH550_28d_compressive_03



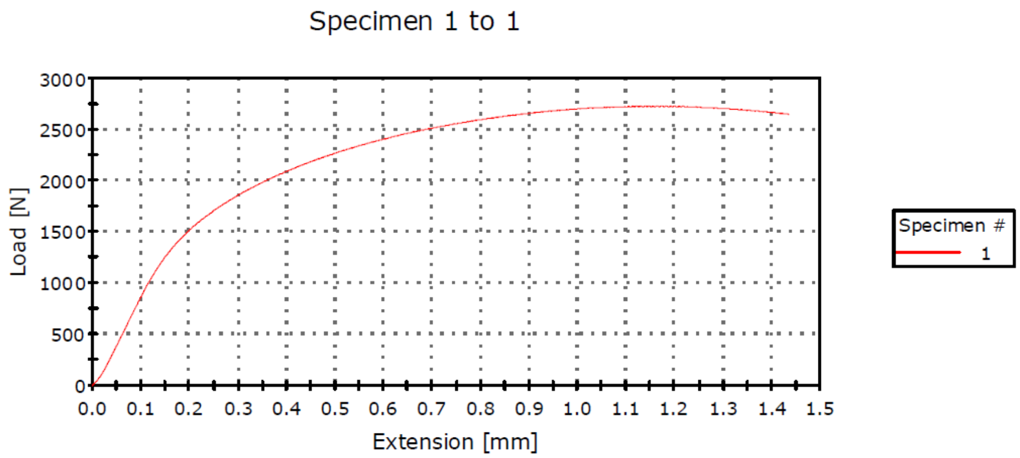
	Maximum Load [N]	Extension at Maximum Load [mm]	Specimen note 1	Rate 1 [um/min]
1	1,104.50464	0.89856		150.00000

LTH550_6m_compressive_01



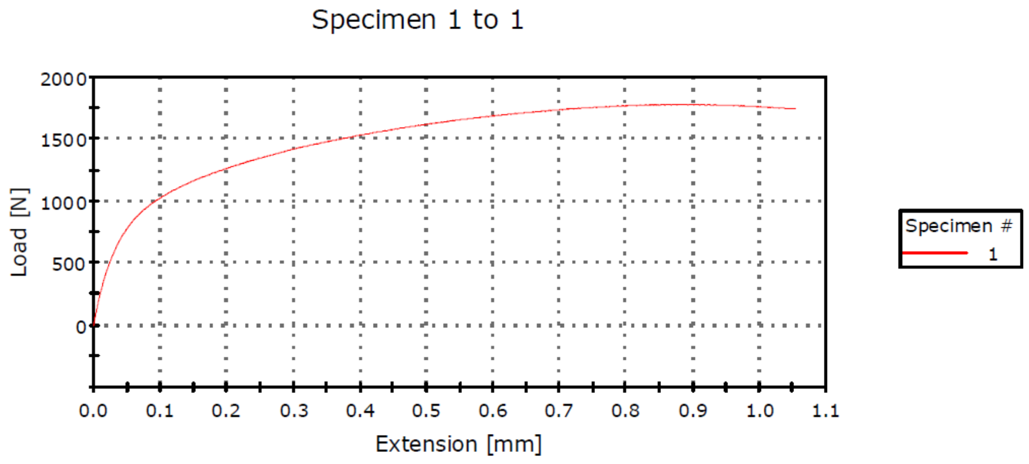
	Maximum Load [N]	Extension at Maximum Load [mm]	Specimen note 1	Rate 1 [um/min]
1	2,624.05347	1.00605	LTH550_6m_Compr_01	150.00000

LTH550_6m_compressive_02



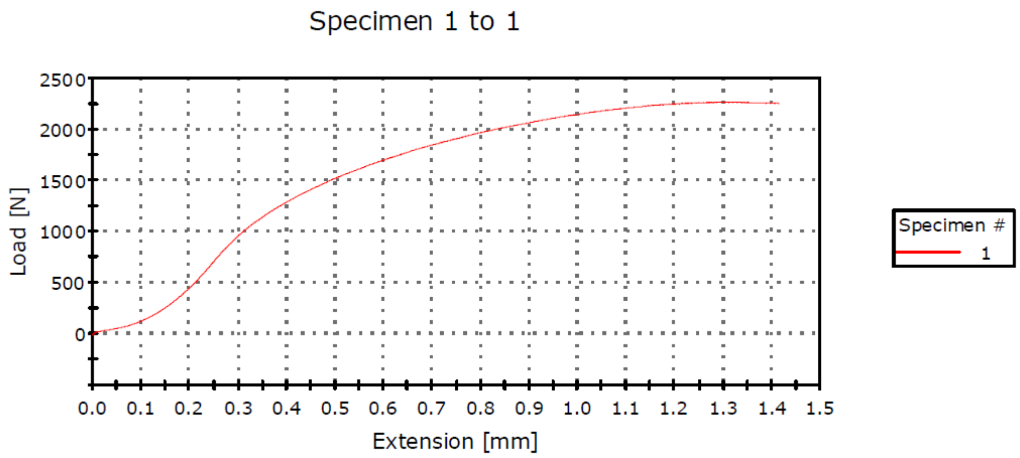
	Maximum Load [N]	Extension at Maximum Load [mm]	Specimen note 1	Rate 1 [um/min]
1	2,722.76807	1.13208	LTH550_6m_Compr_02	150.00000

LTH700_28d_compressive_01



	Maximum Load [N]	Extension at Maximum Load [mm]	Specimen note 1	Rate 1 [um/min]
1	1,777.13611	0.89006		150.00000

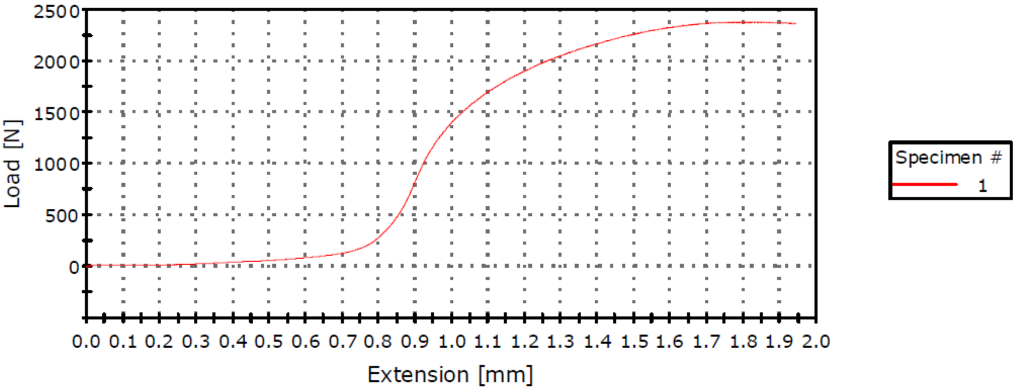
LTH700_28d_compressive_02



	Maximum Load [N]	Extension at Maximum Load [mm]	Specimen note 1	Rate 1 [um/min]
1	2,261.80127	1.29879		150.00000

LTH700_28d_compressive_03

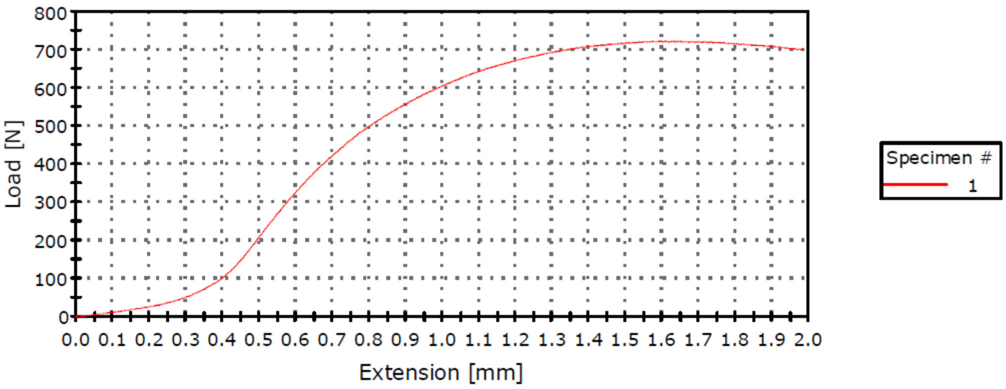
Specimen 1 to 1



	Maximum Load [N]	Extension at Maximum Load [mm]	Specimen note 1	Rate 1 [um/min]
1	2,372.51514	1.81855		150.00000

LASRaw_6m_compressive_01

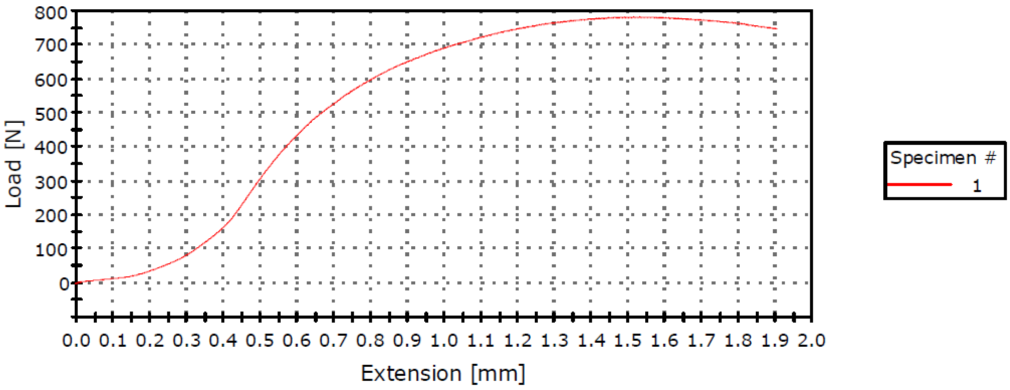
Specimen 1 to 1



	Maximum Load [N]	Extension at Maximum Load [mm]	Specimen note 1	Rate 1 [um/min]
1	721.76196	1.64232	01	150.00000

LASRaw_6m_compressive_02

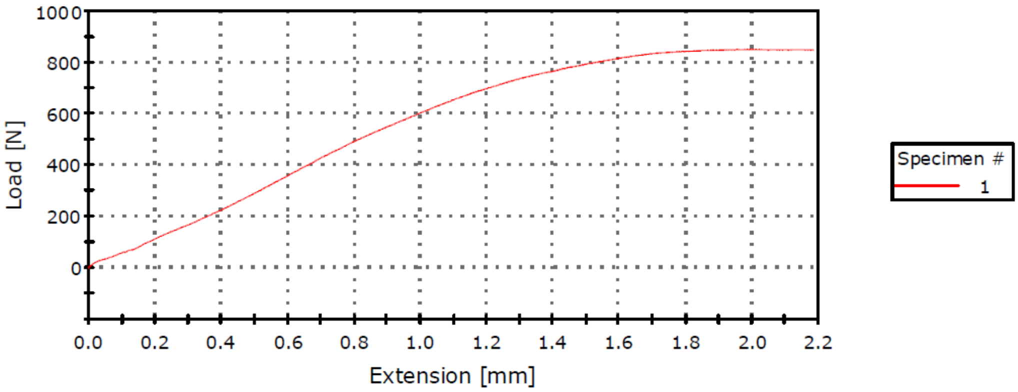
Specimen 1 to 1



	Maximum Load [N]	Extension at Maximum Load [mm]	Specimen note 1	Rate 1 [um/min]
1	781.58612	1.51682	LAS Raw_6m_compr_02	150.00000

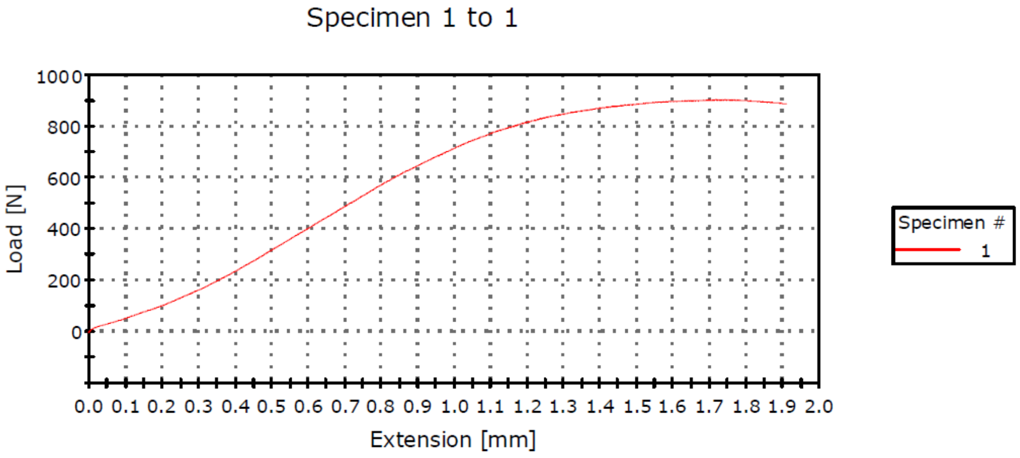
LAS580_28d_compressive_01

Specimen 1 to 1



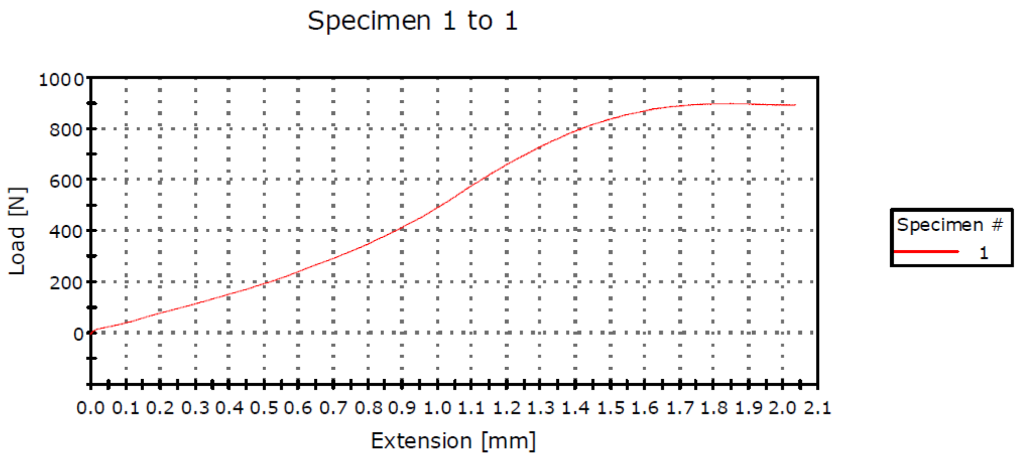
	Maximum Load [N]	Extension at Maximum Load [mm]	Specimen note 1	Rate 1 [um/min]
1	850.05554	2.00256		150.00000

LAS580_28d_compressive_02



	Maximum Load [N]	Extension at Maximum Load [mm]	Specimen note 1	Rate 1 [um/min]
1	902.76654	1.71659		150.00000

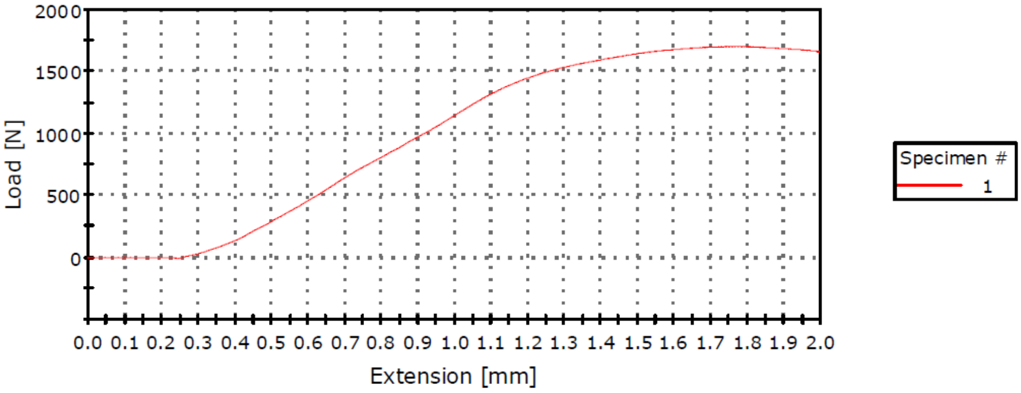
LAS580_28d_compressive_03



	Maximum Load [N]	Extension at Maximum Load [mm]	Specimen note 1	Rate 1 [um/min]
1	897.43280	1.84531		150.00000

LAS580_6m_compressive_01

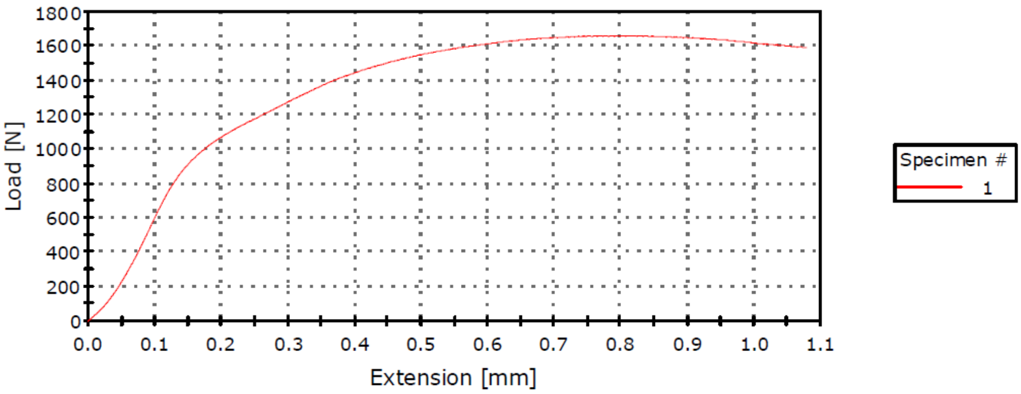
Specimen 1 to 1



	Maximum Load [N]	Extension at Maximum Load [mm]	Specimen note 1	Rate 1 [um/min]
1	1,700.65686	1.78830	LAS580_6m_Compr_01	150.00000

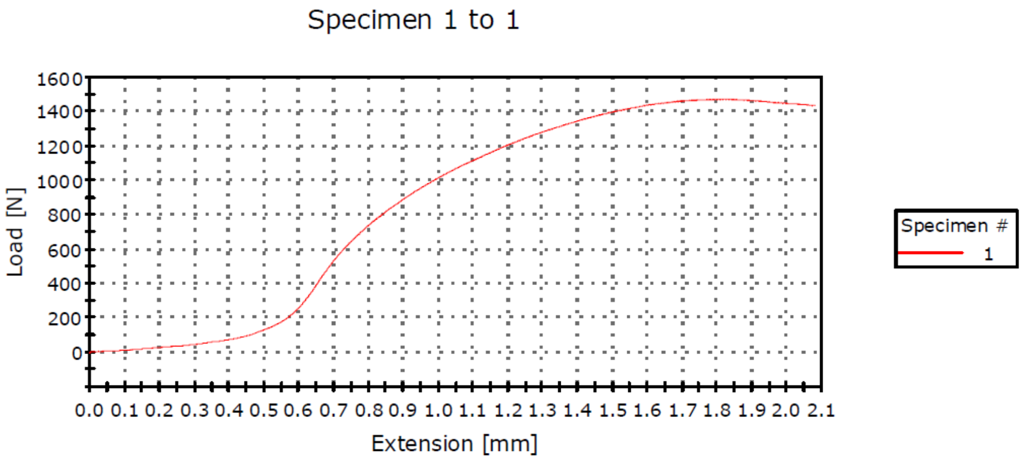
LAS580_6m_compressive_02

Specimen 1 to 1



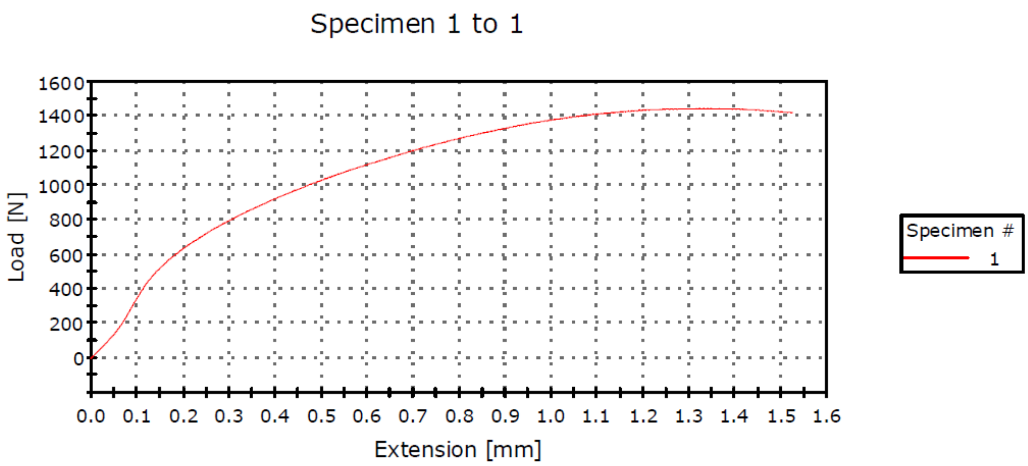
	Maximum Load [N]	Extension at Maximum Load [mm]	Specimen note 1	Rate 1 [um/min]
1	1,658.04834	0.78806	LAS580_6m_Compr_02	150.00000

LAS700_28d_compressive_01



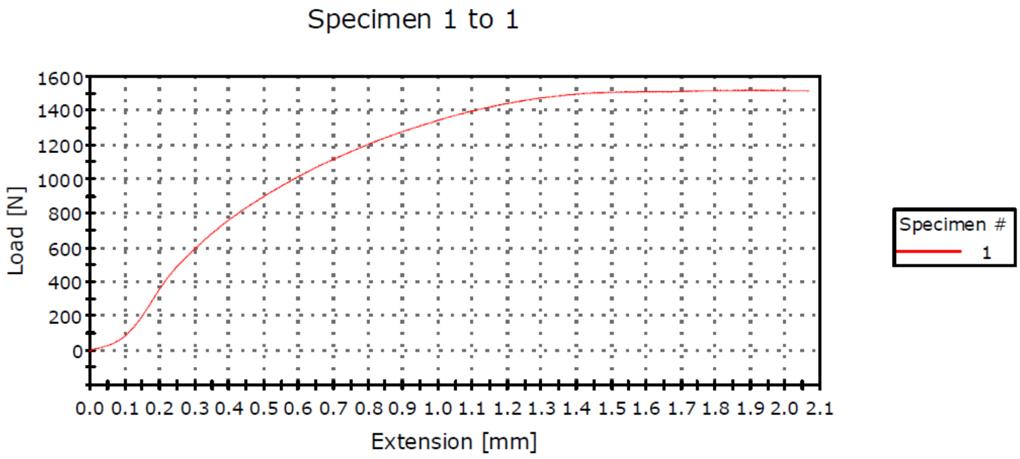
	Maximum Load [N]	Extension at Maximum Load [mm]	Specimen note 1	Rate 1 [um/min]
1	1,470.82886	1.80483		150.00000

LAS700_28d_compressive_02



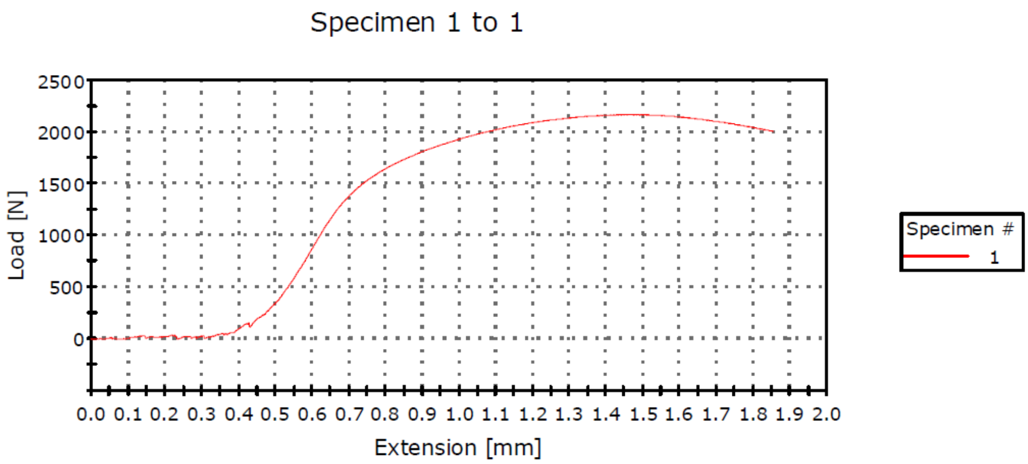
	Maximum Load [N]	Extension at Maximum Load [mm]	Specimen note 1	Rate 1 [um/min]
1	1,441.59949	1.33903		150.00000

LAS700_28d_compressive_03



	Maximum Load [N]	Extension at Maximum Load [mm]	Specimen note 1	Rate 1 [um/min]
1	1,518.47339	1.93030		150.00000

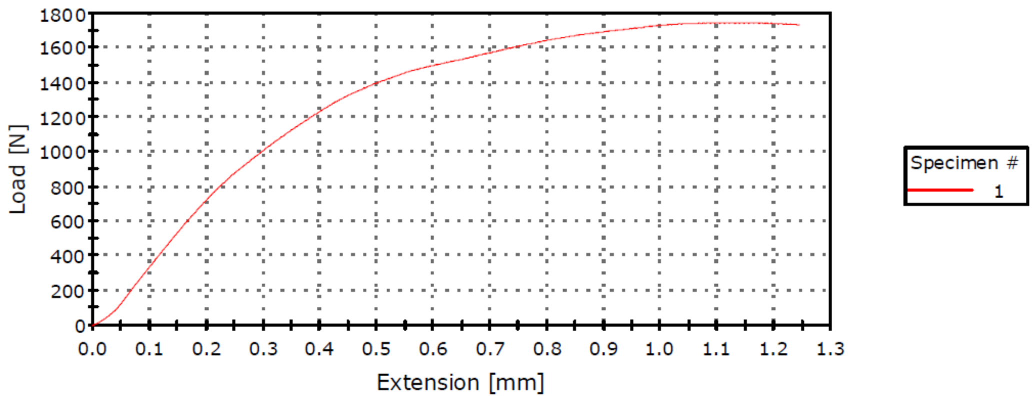
LAS700_6m_compressive_01



	Maximum Load [N]	Extension at Maximum Load [mm]	Specimen note 1	Rate 1 [um/min]
1	2,163.64478	1.46382	LAS700_6m_Compr_01	150.00000

LAS700_6m_compressive_02

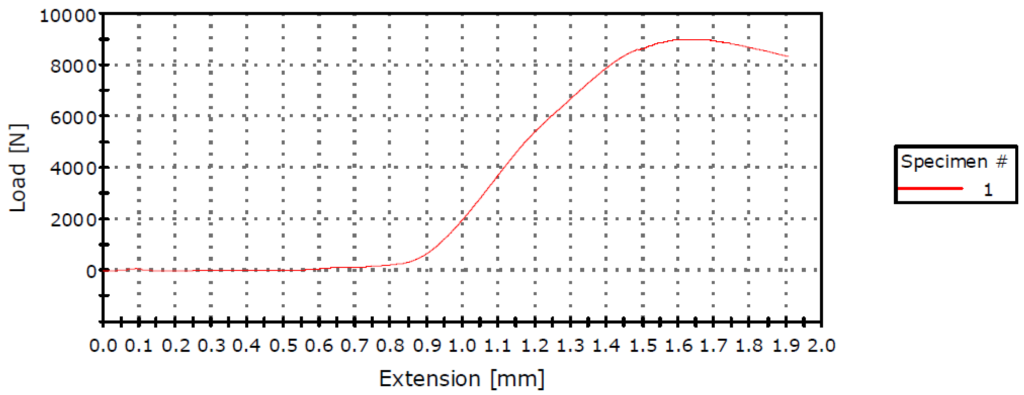
Specimen 1 to 1



	Maximum Load [N]	Extension at Maximum Load [mm]	Specimen note 1	Rate 1 [um/min]
1	1,743.06702	1.11705	LAS700_6m_Compr_02	150.00000

Mosaic_Chalkis_compressive

Specimen 1 to 1

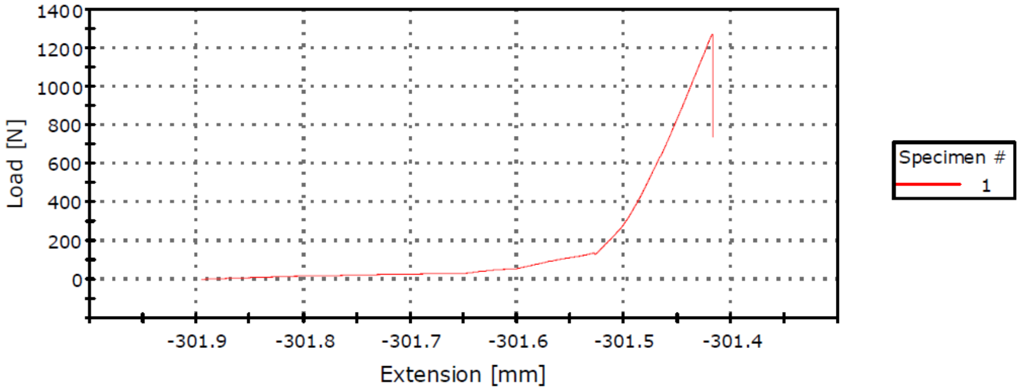


	Maximum Load [N]	Extension at Maximum Load [mm]	Specimen note 1	Rate 1 [um/min]
1	8,988.89062	1.63132		150.00000

IX. Appendix B – 3 point bending strength results

LMtk_28d_3pb_01

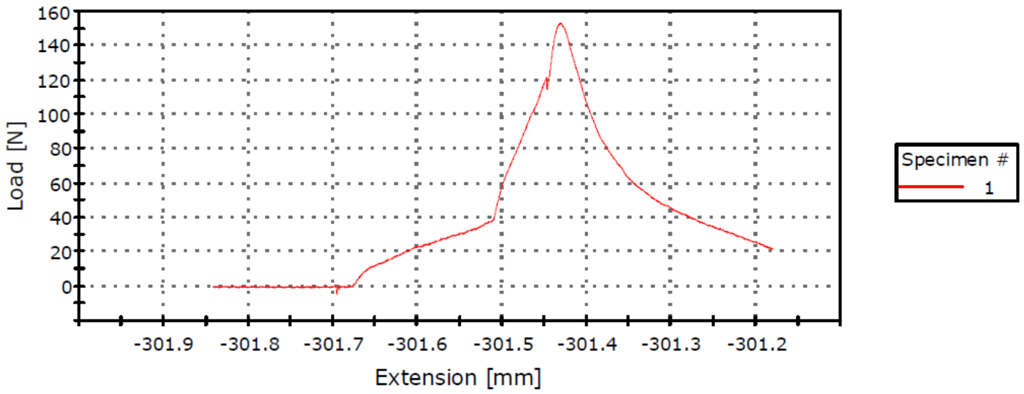
Specimen 1 to 1



	Maximum Load [N]	Extension at Maximum Load [mm]	Specimen note 1	Rate 1 [um/min]
1	1,268.01721	-301.41788	lime-metakaoline-sand 28days 3point bending	100.00000

LMtk_28d_3pb_01b

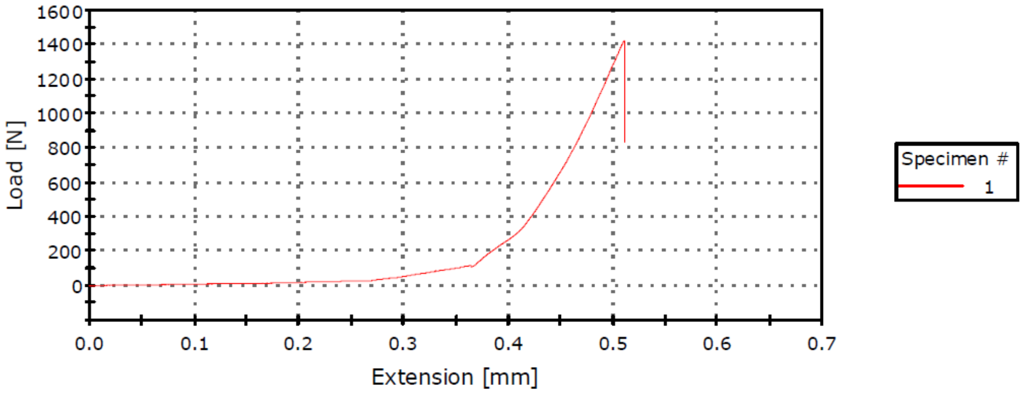
Specimen 1 to 1



	Maximum Load [N]	Extension at Maximum Load [mm]	Specimen note 1	Rate 1 [um/min]
1	152.85059	-301.42966		100.00000

LMtk_28d_3pb_02

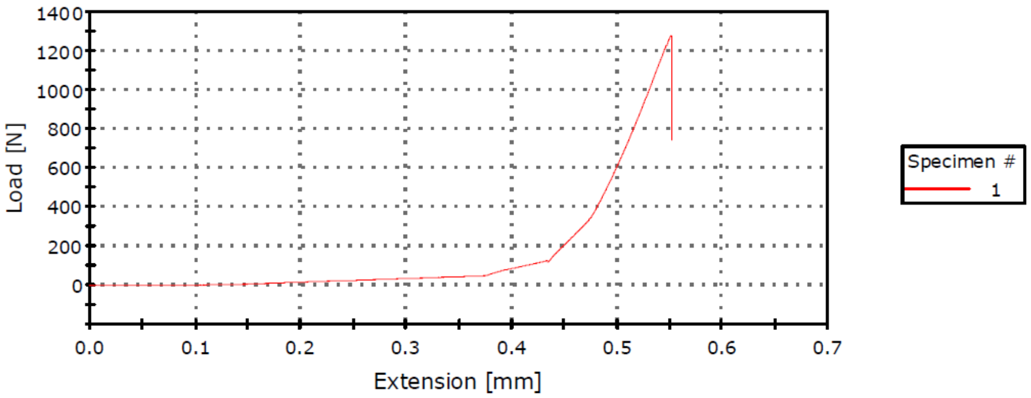
Specimen 1 to 1



	Maximum Load [N]	Extension at Maximum Load [mm]	Specimen note 1	Rate 1 [um/min]
1	1,421.22754	0.51115		100.00000

LMtk_28d_3pb_03

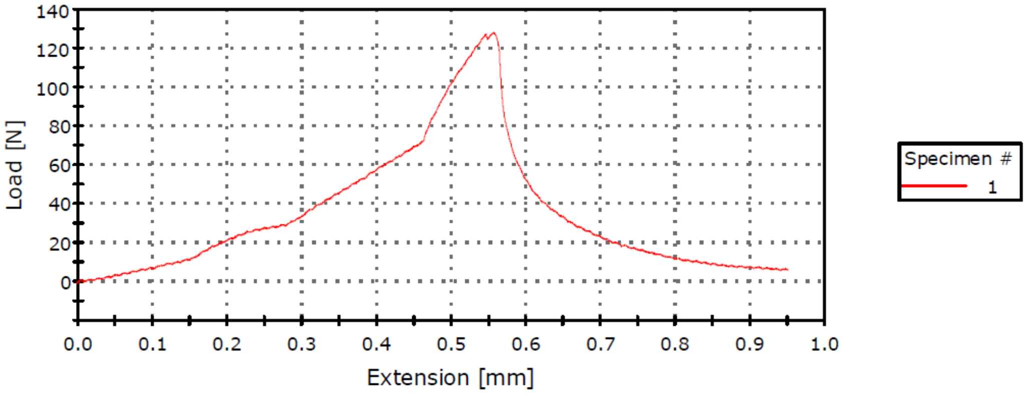
Specimen 1 to 1



	Maximum Load [N]	Extension at Maximum Load [mm]	Specimen note 1	Rate 1 [um/min]
1	1,275.91272	0.55100		100.00000

LTHRaw_6m_3pb_01

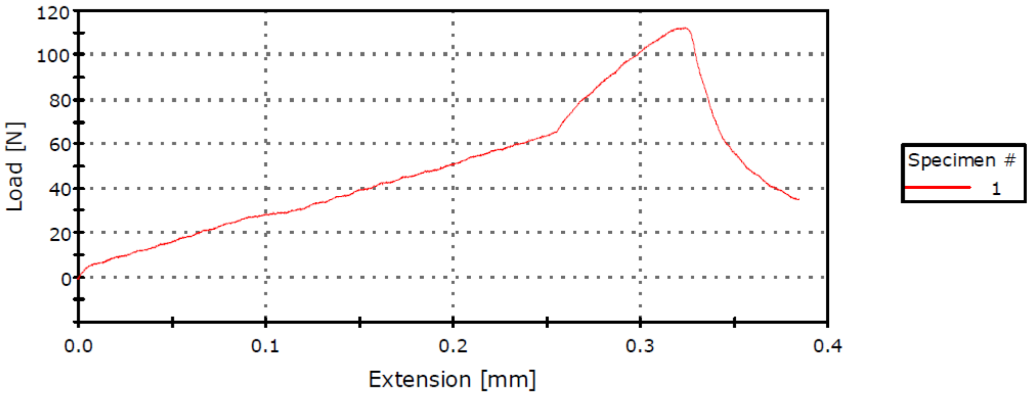
Specimen 1 to 1



	Maximum Load [N]	Extension at Maximum Load [mm]	Specimen note 1	Rate 1 [um/min]
1	128.11099	0.55700	LTHRaw_6m_3pb_01	100.00000

LTHRaw_6m_3pb_02

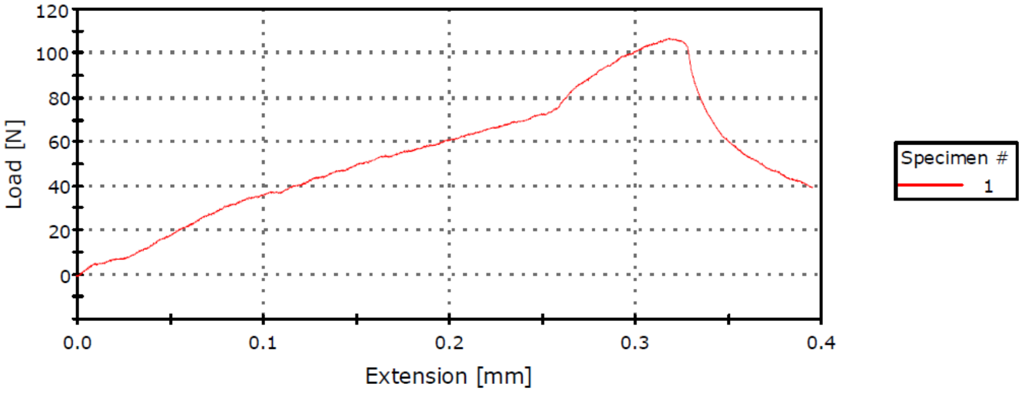
Specimen 1 to 1



	Maximum Load [N]	Extension at Maximum Load [mm]	Specimen note 1	Rate 1 [um/min]
1	112.24255	0.32265	LTHRaw_6m_3pb_02	100.00000

LTHRaw_6m_3pb_03

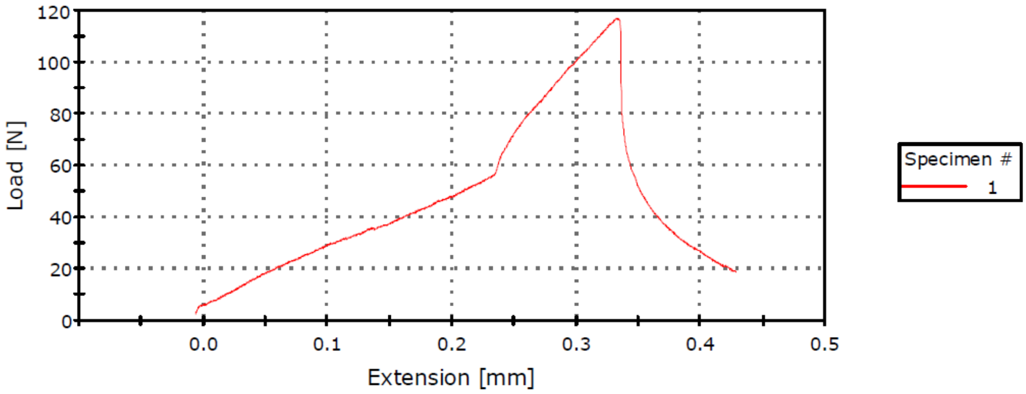
Specimen 1 to 1



	Maximum Load [N]	Extension at Maximum Load [mm]	Specimen note 1	Rate 1 [um/min]
1	106.68684	0.31769	LTHRaw_6m_3pb_03	100.00000

LTH550_28d_3pb_02

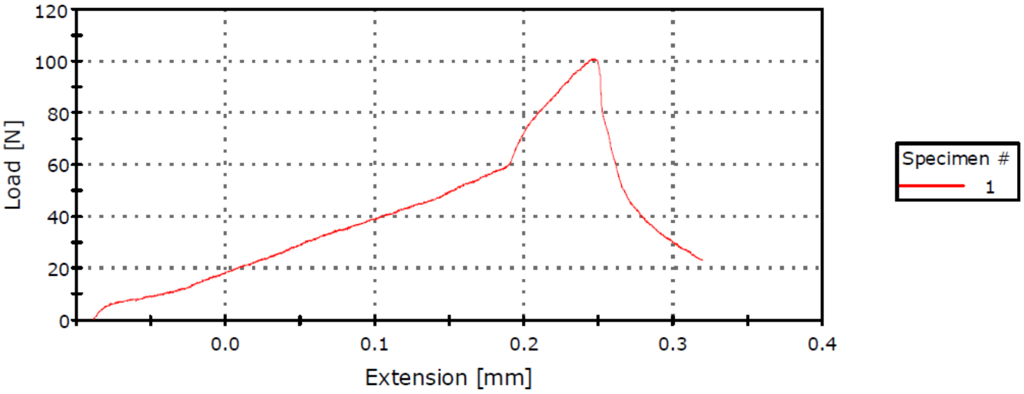
Specimen 1 to 1



	Maximum Load [N]	Extension at Maximum Load [mm]	Specimen note 1	Rate 1 [um/min]
1	116.79079	0.33279		100.00000

LTH550_28d_3pb_03

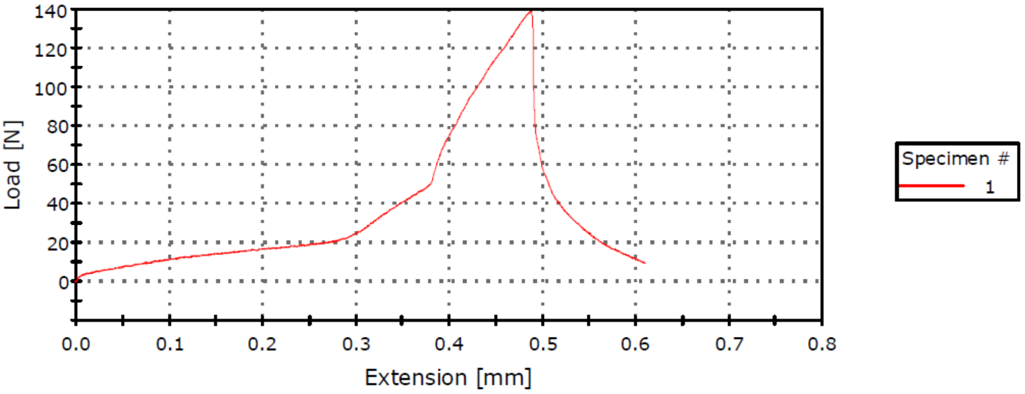
Specimen 1 to 1



	Maximum Load [N]	Extension at Maximum Load [mm]	Specimen note 1	Rate 1 [um/min]
1	100.81753	0.24787		100.00000

LTH700_28d_3pb_01

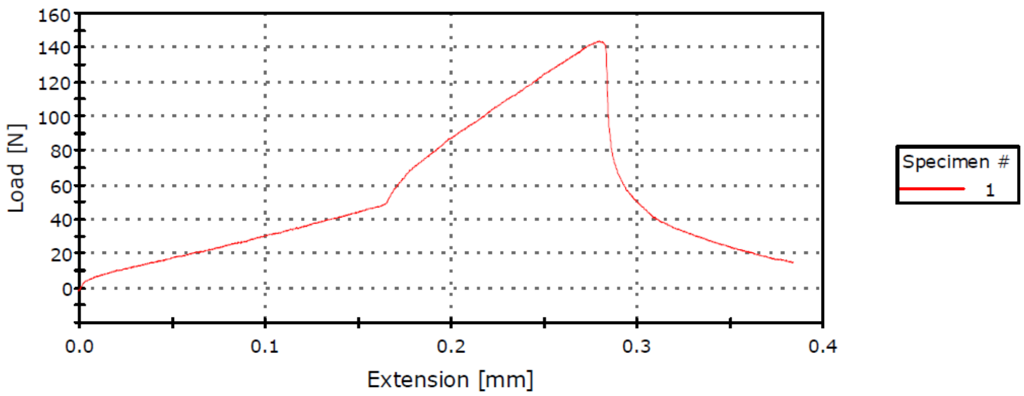
Specimen 1 to 1



	Maximum Load [N]	Extension at Maximum Load [mm]	Specimen note 1	Rate 1 [um/min]
1	138.77747	0.48849		100.00000

LTH700_28d_3pb_02

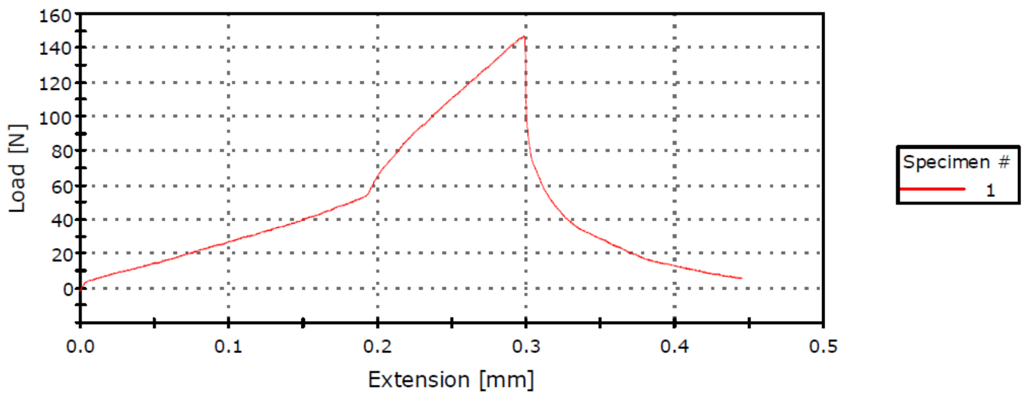
Specimen 1 to 1



	Maximum Load [N]	Extension at Maximum Load [mm]	Specimen note 1	Rate 1 [um/min]
1	143.73338	0.27983		100.00000

LTH700_28d_3pb_03

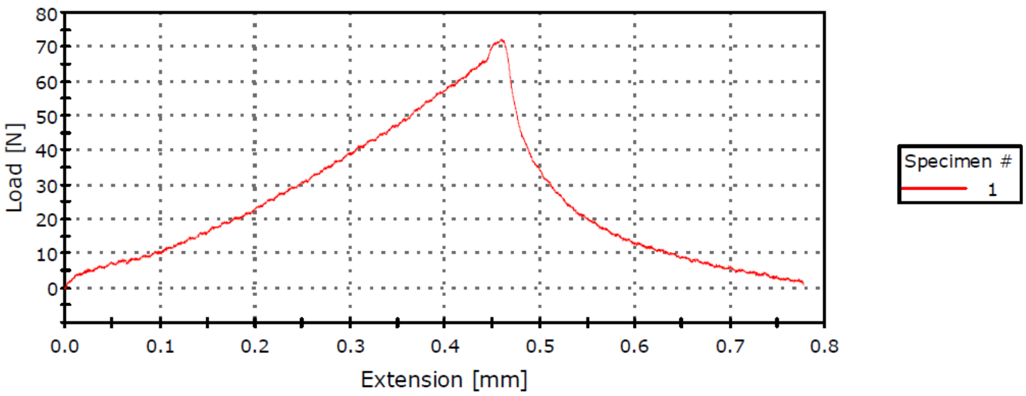
Specimen 1 to 1



	Maximum Load [N]	Extension at Maximum Load [mm]	Specimen note 1	Rate 1 [um/min]
1	146.82645	0.29858		100.00000

LASRaw_6m_3pb_01

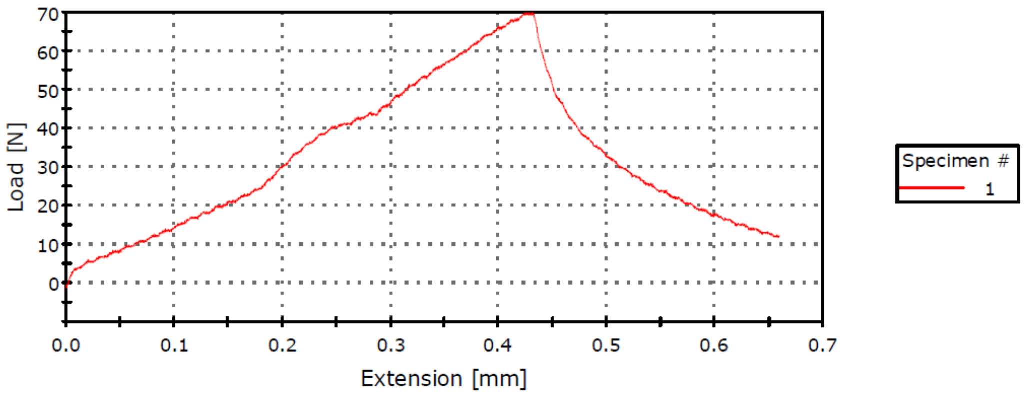
Specimen 1 to 1



	Maximum Load [N]	Extension at Maximum Load [mm]	Specimen note 1	Rate 1 [um/min]
1	72.18319	0.45921	LASRaw_6m_3pb_01	100.00000

LASRaw_6m_3pb_02

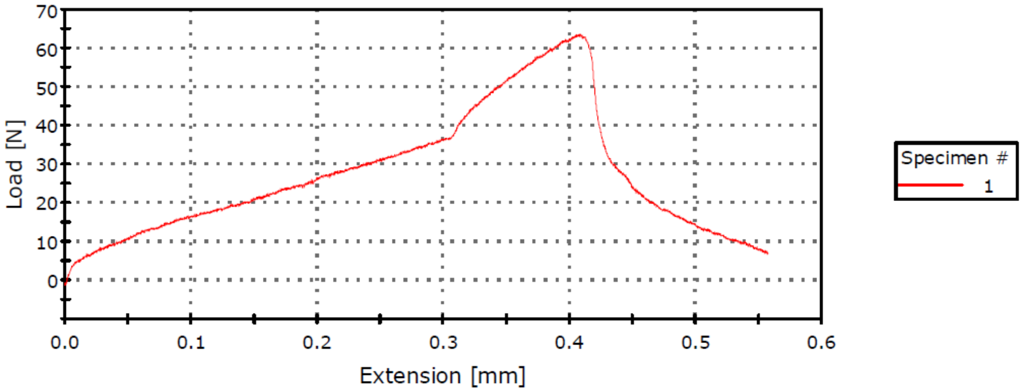
Specimen 1 to 1



	Maximum Load [N]	Extension at Maximum Load [mm]	Specimen note 1	Rate 1 [um/min]
1	69.76888	0.42437	LASRaw_6m_3pb_02	100.00000

LAS580_28d_3pb_01

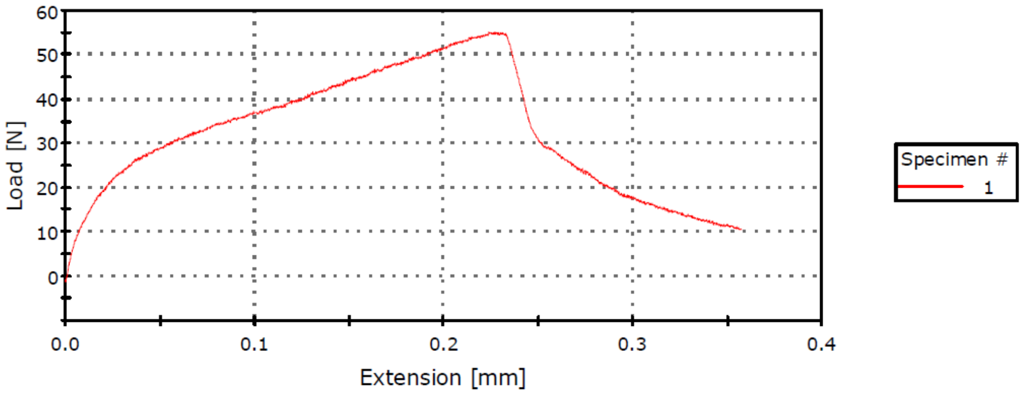
Specimen 1 to 1



	Maximum Load [N]	Extension at Maximum Load [mm]	Specimen note 1	Rate 1 [um/min]
1	63.52948	0.40866		100.00000

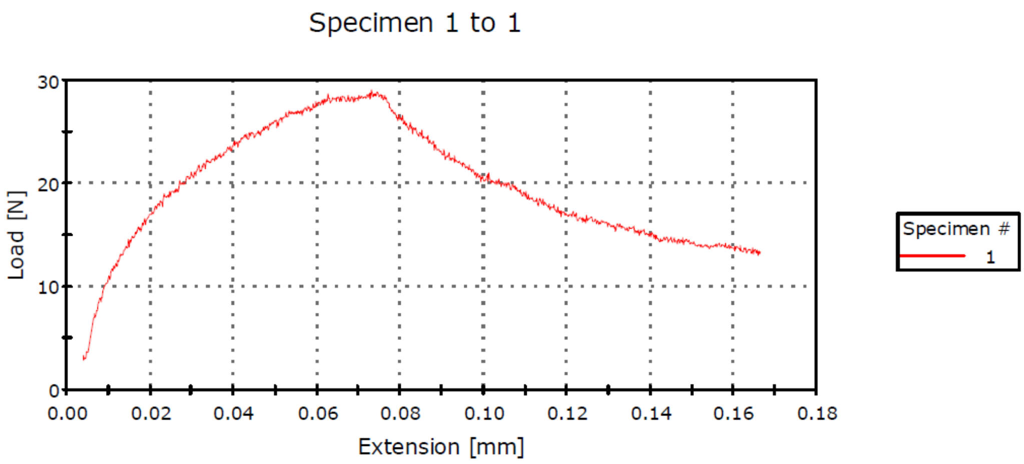
LAS580_28d_3pb_02

Specimen 1 to 1



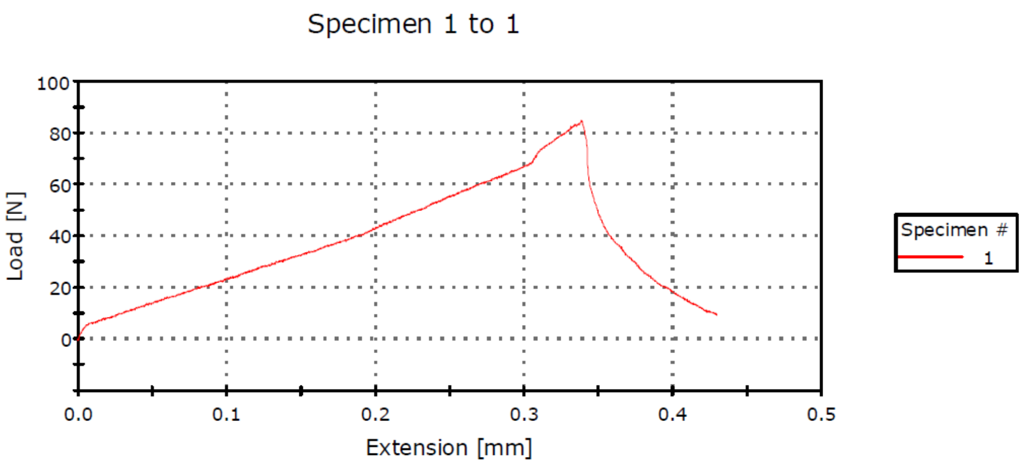
	Maximum Load [N]	Extension at Maximum Load [mm]	Specimen note 1	Rate 1 [um/min]
1	55.19258	0.22718		100.00000

LAS580_28d_3pb_03



	Maximum Load [N]	Extension at Maximum Load [mm]	Specimen note 1	Rate 1 [um/min]
1	29.02239	0.07321		100.00000

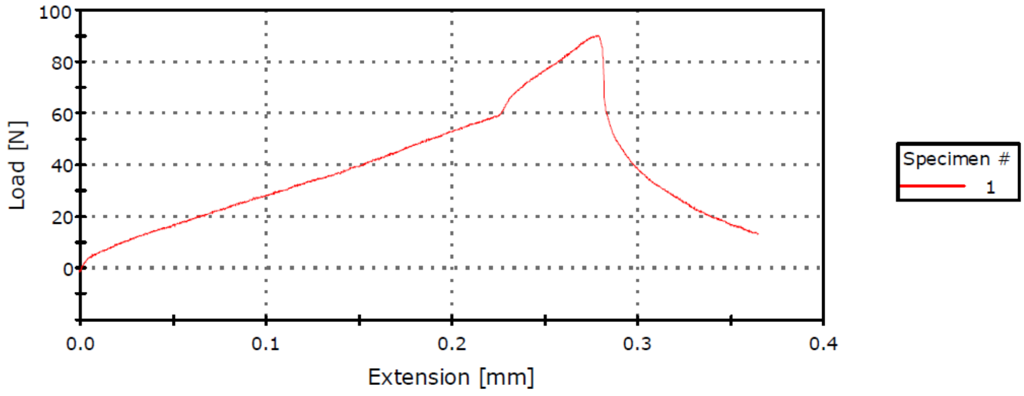
LAS700_28d_3pb_01



	Maximum Load [N]	Extension at Maximum Load [mm]	Specimen note 1	Rate 1 [um/min]
1	84.69062	0.33904		100.00000

LAS700_28d_3pb_02

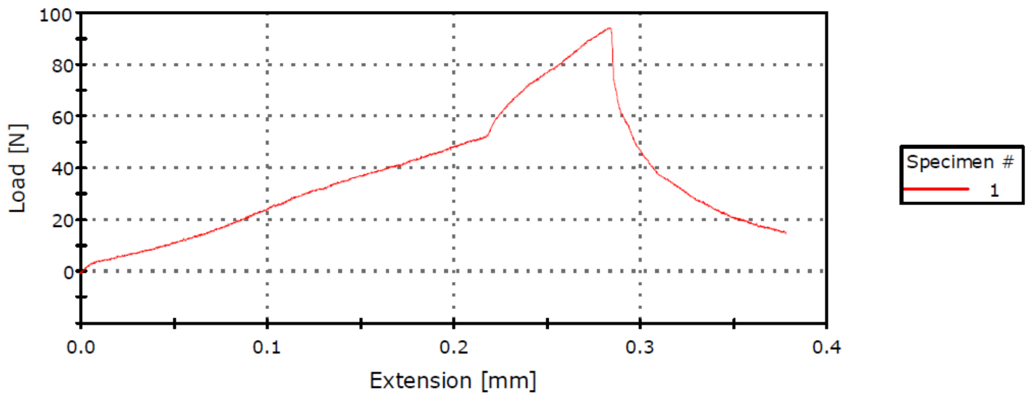
Specimen 1 to 1



	Maximum Load [N]	Extension at Maximum Load [mm]	Specimen note 1	Rate 1 [um/min]
1	90.26001	0.27904		100.00000

LAS700_28d_3pb_03

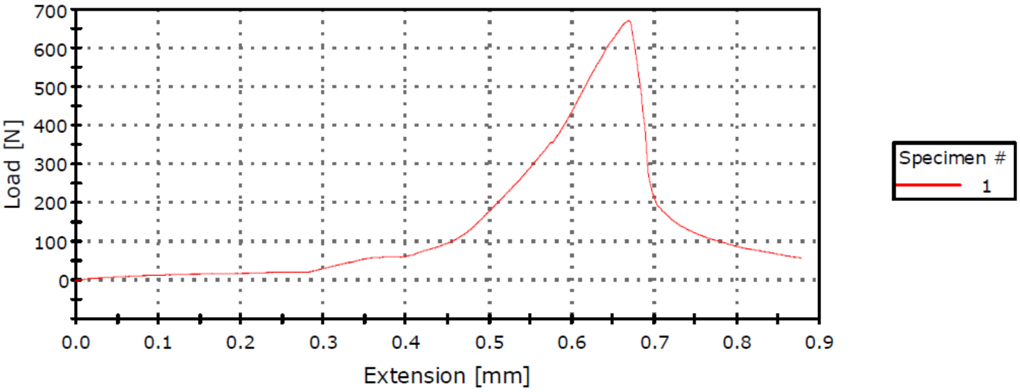
Specimen 1 to 1



	Maximum Load [N]	Extension at Maximum Load [mm]	Specimen note 1	Rate 1 [um/min]
1	94.00603	0.28348		100.00000

Mosaic_Chalkis_3pb

Specimen 1 to 1



	Maximum Load [N]	Extension at Maximum Load [mm]	Specimen note 1	Rate 1 [um/min]
1	669.97754	0.66901		100.00000