Università degli Studi di Padova

European regulations and scientific literaturare on binders and mortars for restoration

Universidad de Granada

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Department of Mineralogy and Petrology
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CONTENTS:

EUROPEAN STANDARDS ON:

MORTAR COMPONENTS

- binders

- aggregates

- additives and admixtures

MORTAR CLASSIFICATION

CHARACTERISATION OF HISTORIC MORTARS

REQUIREMENTS FOR RESTORATION MORTARS

DESIGN AND CHARACTERISATION OF RESTORATION MORTARS

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CHARACTERISATION OF HISTORIC MORTARS

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DESIGN AND CHARACTERISATION OF RESTORATION MORTARS

Definition of a **MORTAR**

English Version

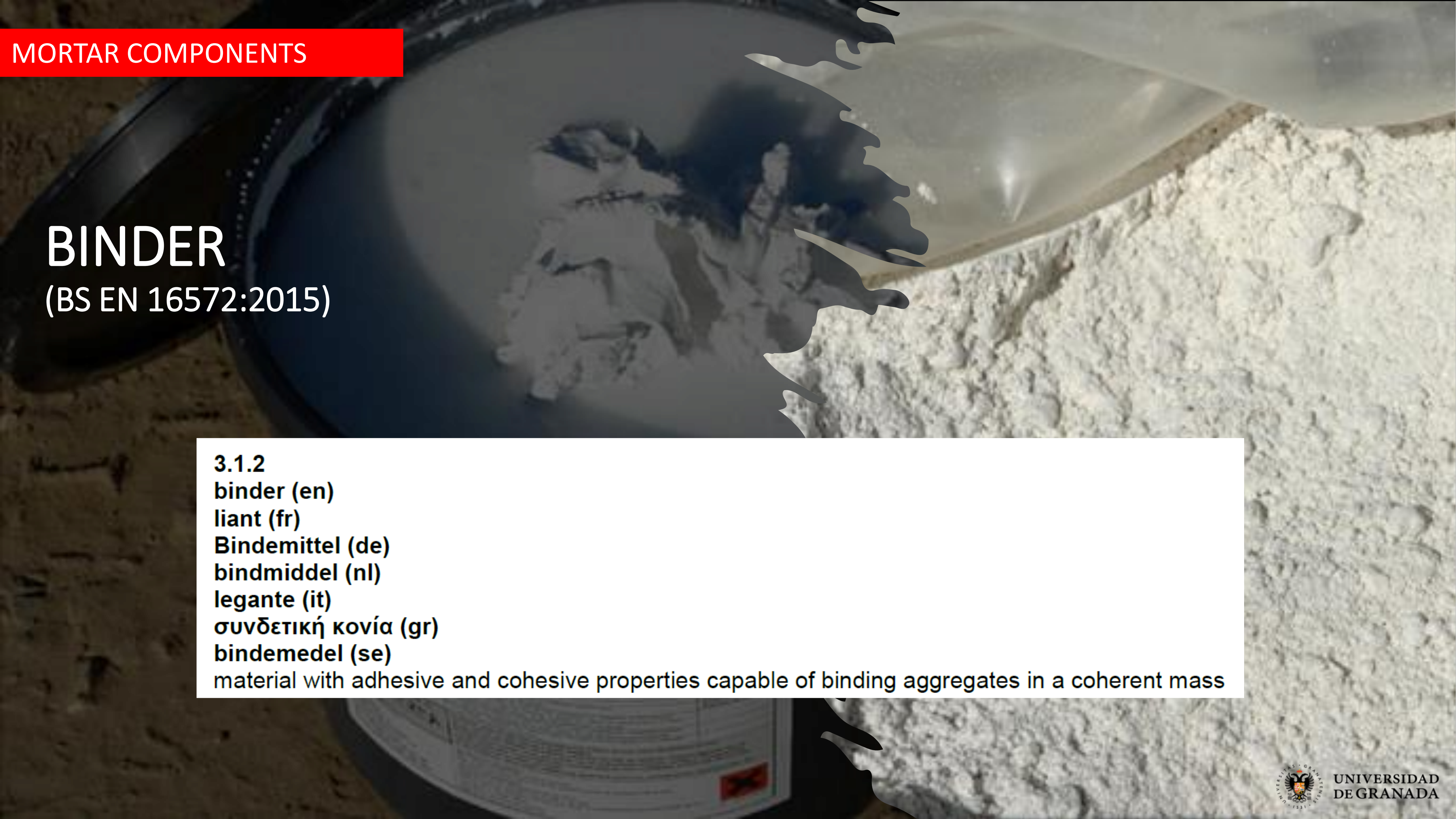
Conservation of Cultural Heritage - Glossary of technical terms concerning mortars for masonry, renders and plasters used in cultural heritage

BSI Standards Publication

BS EN 16572:2015

3.1 General terms

3.1.1
mortar (en)
mortier (fr)
mörtel (de)
mortel (nl)
malta (it)
κονίαμα (gr)
bruk (se)
material traditionally composed of one or more inorganic binders, aggregates, water, additives and admixtures combined to form a paste used in masonry to provide for bedding, jointing and bonding of masonry units



MORTAR COMPONENTS

BINDER

(BS EN 16572:2015)

3.1.2
binder (en)
liant (fr)
Bindemittel (de)
bindmiddel (nl)
legante (it)
συνδετική κονία (gr)
bindemedel (se)
material with adhesive and cohesive properties capable of binding aggregates in a coherent mass

European specifications on LIME (EN 459:1 2012)

3.1
lime
calcium oxide and/or hydroxide, and calcium-magnesium oxide and/or hydroxide produced by the thermal decomposition (calcination) of naturally occurring calcium carbonate (for example limestone, chalk, shells) or naturally occurring calcium magnesium carbonate (for example dolomitic limestone, dolomite)

3.2
building lime
group of lime products, exclusively consisting of two families: air lime and lime with hydraulic properties, used in applications or materials for construction, building and civil engineering

3.3
air lime[1)]
lime (see 3.1) which combines and hardens with carbon dioxide present in air

NOTE Air lime has no hydraulic properties. Air lime is divided into two sub-families, calcium lime (CL) and dolomitic lime (DL).

3.4
lime with hydraulic properties
building lime (see 3.2) consisting mainly of calcium hydroxide, calcium silicates and calcium aluminates

NOTE It has the property of setting and hardening when mixed with water and/or under water. Reaction with atmospheric carbon dioxide is part of the hardening process. Lime with hydraulic properties is divided into three sub-families, natural hydraulic lime (NHL), formulated lime (FL) and hydraulic lime (HL).

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European specifications on AIR (or AERIAL) LIME (EN 459:1 2012)

According to their chemical composition
- Calcium (or *calcitic*) lime (**CL**)
- Dolomitic lime (**DL**)

According to their state
- Quicklime (**Q**)
- Hydrated (or *slaked*) lime (**S**)
- Semi-hydrated dolomitic lime (**S1**)

According to their form
- Powder (**S**)
- Putty (**S PL**)
- Slurry (or *milk of lime*) (**S ML**)

European specifications on AIR (or AERIAL) LIME (EN 459:1 2012)

According to their chemical composition → Calcium (or *calcitic*) lime (**CL**) → Dolomitic lime (**DL**)

Fat lime (CL)

Lean lime (DL)

According to the content in (CaO+MgO) and MgO

- CL 90
- CL 80
- CL 70
- DL 90-30
- DL90-5
- DL85-30
- DL80-5

Table 2 — Chemical requirements of calcium lime given as characteristic values

Type of calcium lime	Values given as mass fraction in percent				
	CaO + MgO	MgO[a]	CO_2[b]	SO_3	Available lime[c]
CL 90	≥ 90	≤ 5	≤ 4	≤ 2	≥ 80
CL 80	≥ 80	≤ 5	≤ 7	≤ 2	≥ 65
CL 70	≥ 70	≤ 5	≤ 12	≤ 2	≥ 55

The values for CaO + MgO, MgO, CO_2 and SO_3 are applicable to all forms of calcium lime. For quicklime these values correspond to the finished product; for all other forms of lime (hydrated lime, lime putty and milk of lime) the values are based on the product after subtraction of its free water and bound water content.

Table 9 — Chemical requirements of dolomitic lime given as characteristic values

Type of dolomitic lime	Values given as mass fraction in percent			
	CaO + MgO	MgO	CO_2	SO_3
DL 90-30	≥ 90	≥ 30	≤ 6	≤ 2
DL 90-5	≥ 90	> 5	≤ 6	≤ 2
DL 85-30	≥ 85	≥ 30	≤ 9	≤ 2
DL 80-5	≥ 80	> 5	≤ 9	≤ 2

The values are applicable to all kinds of dolomitic lime. For dolomitic quicklime these values correspond to the finished product; for hydrated dolomitic lime the values are based on the product after subtraction of its free water and bound water content.

Main differences between calcic and dolomitic limes

	CALCIC LIMES	DOLOMITIC LIMES
Lime cycle	open	closed
Carbonation products	$CaCO_3$ (mainly calcite)	$CaCO_3$ Hydrated carbonates and hidroxicarbonates of Mg Mixed carbonates of Ca and Mg Never dolomite ($CaMg(CO_3)_2$) and very rarely magnesite ($MgCO_3$)
Carbonation cinetics	Slow	Very slow
Plast		
Mec		
In th sulp		ma .)

Cement and Concrete Research 173 (2023) 107301

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Cement and Concrete Research

journal homepage: www.elsevier.com/locate/cemconres

ELSEVIER

Check for updates

Carbonation mechanisms and kinetics of lime-based binders: An overview

Carlos Rodriguez-Navarro *, Teodora Ilić, Encarnación Ruiz-Agudo, Kerstin Elert

Materials and Structures (2021) 54:63
https://doi.org/10.1617/s11527-021-01648-3

RILEM TECHNICAL COMMITTEE

RILEM TC 277-LHS report: a review on the mechanisms of setting and hardening of lime-based binding systems

J. I. Alvarez · R. Veiga · S. Martínez-Ramírez · M. Secco · P. Faria · P. N. Maravelaki · M. Ramesh · I. Papayianni · J. Válek

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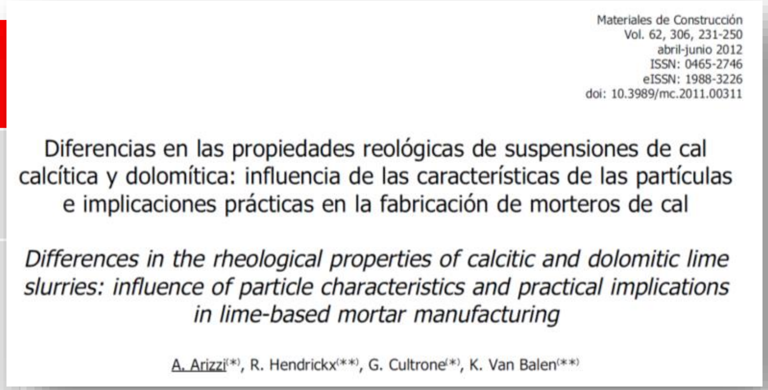
Carbonation cinetics	Slow	Very slow
Plasticity	Medium to high	Medium to high
Mechanical resistances	low	Feebly higher
In the presence of SO_2 or sulphates	Gypsum formation ($CaSO_4 \cdot 2H_2O$)	Soluble salts formation (epsomite, hexahidrite, etc.)


Materiales de Construcción
Vol. 62, 306, 231-250
abril-junio 2012
ISSN: 0465-2746
eISSN: 1988-3226
doi: 10.3989/mc.2011.00311

Diferencias en las propiedades reológicas de suspensiones de cal calcítica y dolomítica: influencia de las características de las partículas e implicaciones prácticas en la fabricación de morteros de cal

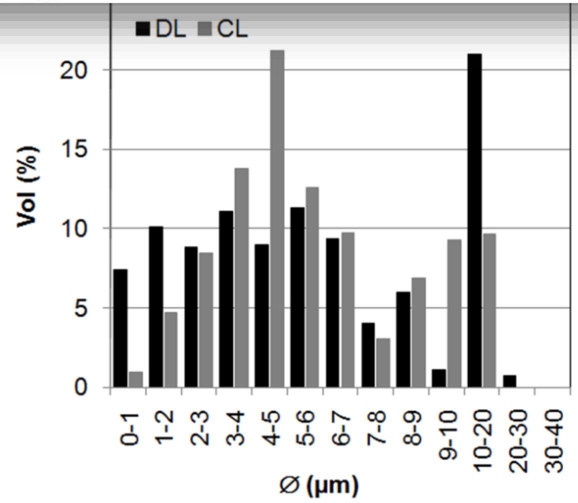
Differences in the rheological properties of calcitic and dolomitic lime slurries: influence of particle characteristics and practical implications in lime-based mortar manufacturing

A. Arizzi(*), R. Hendrickx(**), G. Cultrone(*), K. Van Balen(**)


Cement and Concrete Research 42 (2012) 818–826
Contents lists available at SciVerse ScienceDirect
Cement and Concrete Research
journal homepage: http://ees.elsevier.com/CEMCON/default.asp

The difference in behaviour between calcitic and dolomitic lime mortars set under dry conditions: The relationship between textural and physical–mechanical properties

A. Arizzi *, G. Cultrone



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Available online at www.sciencedirect.com
SCIENCE @ DIRECT
Cement and Concrete Research 36 (2006) 951 – 960
Cement and Concrete Research

Mechanical properties of masonry repair dolomitic lime-based mortars

J. Lanas [a], J.L. Pérez Bernal [b], M.A. Bello [b], J.I. Alvarez [a,*]

Materials and Structures (2010) 43:283–296
DOI 10.1617/s11527-009-9488-9
ORIGINAL ARTICLE

Physical properties of magnesian lime mortars

L. Chever · S. Pavía · R. Howard

Main differences between calcic and dolomitic limes

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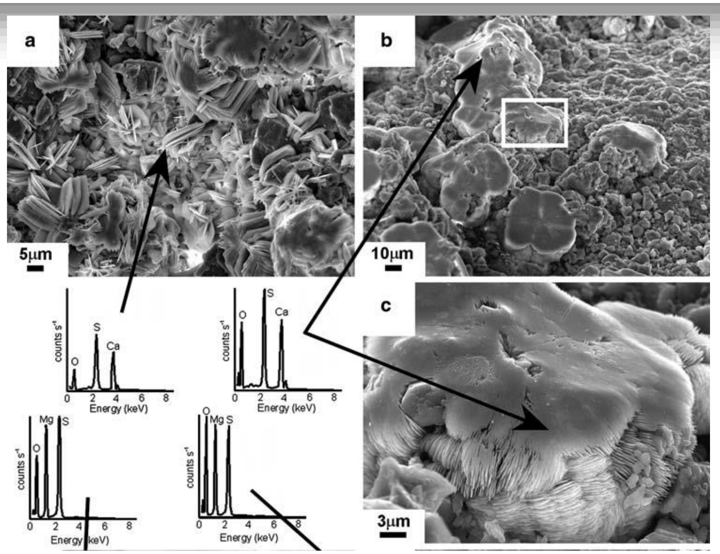
Environ Geol
DOI 10.1007/s00254-008-1379-9
SPECIAL ISSUE

Sulfation of calcitic and dolomitic lime mortars in the presence of diesel particulate matter

G. Cultrone · A. Arizzi · E. Sebastián · C. Rodriguez-Navarro



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- Hydrated (or *slaked*) lime (**S**)
- Semi-hydrated dolomitic lime (**S1**)

According to their form

- Powder (**S**)
- Putty (**S PL**)
- Slurry (or *milk of lime*) (**S ML**)

In the form of a powder

In the form of lumps (or clods)

In the form of a putty (or a paste)

In the form of a slurry

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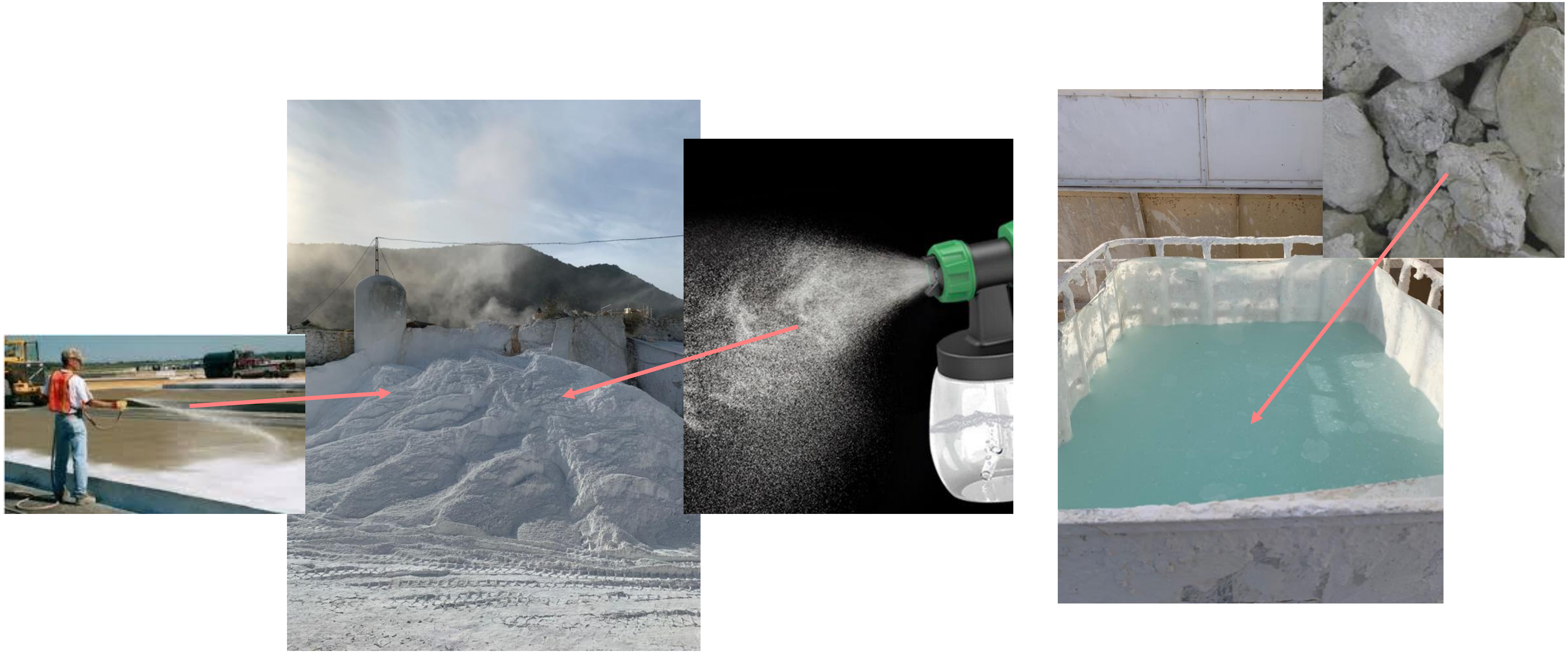
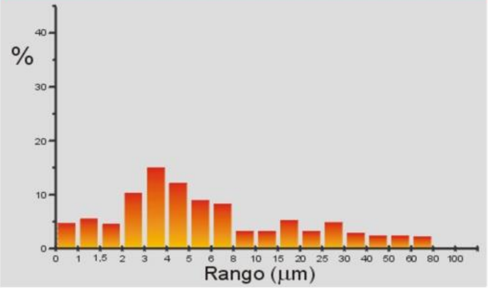
Influence of the slaking method on the quality of the lime



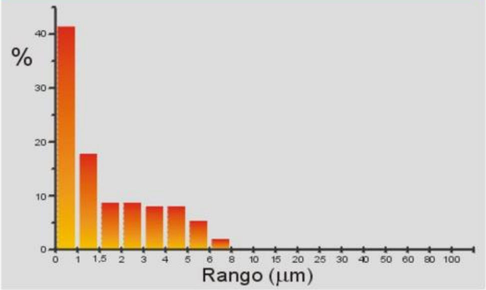
Main differences between lime powder and putty

	POWDERED LIME	PUTTY LIME
plasticity	-	+
reactivity	-	+

Powdered calcic lime



Putty lime (14 years storage)



Environmental Science & Technology — Article — pubs.acs.org/est

Dissolution and Carbonation of Portlandite [$Ca(OH)_2$] Single Crystals

Encarnación Ruiz-Agudo,[*,†,‡] Krzysztof Kudlacz,[§,†] Christine V. Putnis,[‡] Andrew Putnis,[‡] and Carlos Rodriguez-Navarro[†]

Langmuir **2005,** *21,* 10948−10957

Nanostructure and Irreversible Colloidal Behavior of $Ca(OH)_2$: Implications in Cultural Heritage Conservation

C. Rodriguez-Navarro,[*,†] E. Ruiz-Agudo,[†] M. Ortega-Huertas,[†] and E. Hansen[‡]

journal — J. Am. Ceram. Soc., 83 [5] 1070–76 (2000)

Aging of Lime Putty: Effects on Traditional Lime Mortar Carbonation

Olga Cazalla, Carlos Rodriguez-Navarro,[†] Eduardo Sebastian, and Giuseppe Cultrone

Departamento de Mineralogia y Petrologia, Universidad de Granada, Granada, Spain

Maria Jose De la Torre

Langmuir | 3b2 | ver.9 | 7/11/09 | 3:45 | Msc: la-2009-03430z | TEID: drh00 | BATID: 00000 | Pages: 9.15

Langmuir Article

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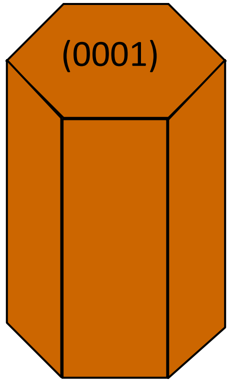
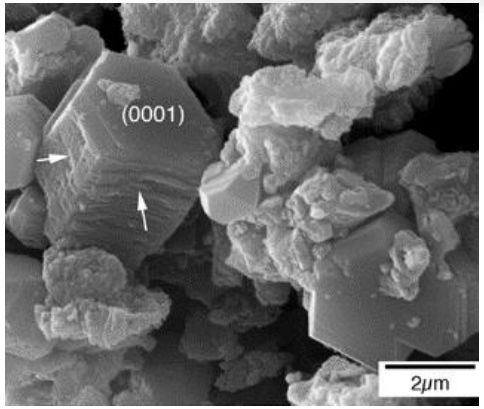
Microstructure and Rheology of Lime Putty

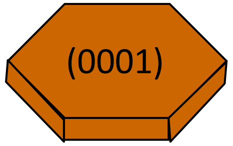
E. Ruiz-Agudo[†] and C. Rodriguez-Navarro*

Fresh





Aged



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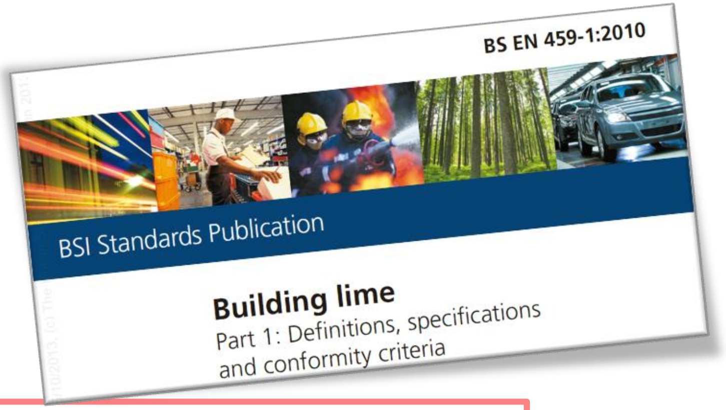
European specifications on NATURAL HYDRAULIC LIMES



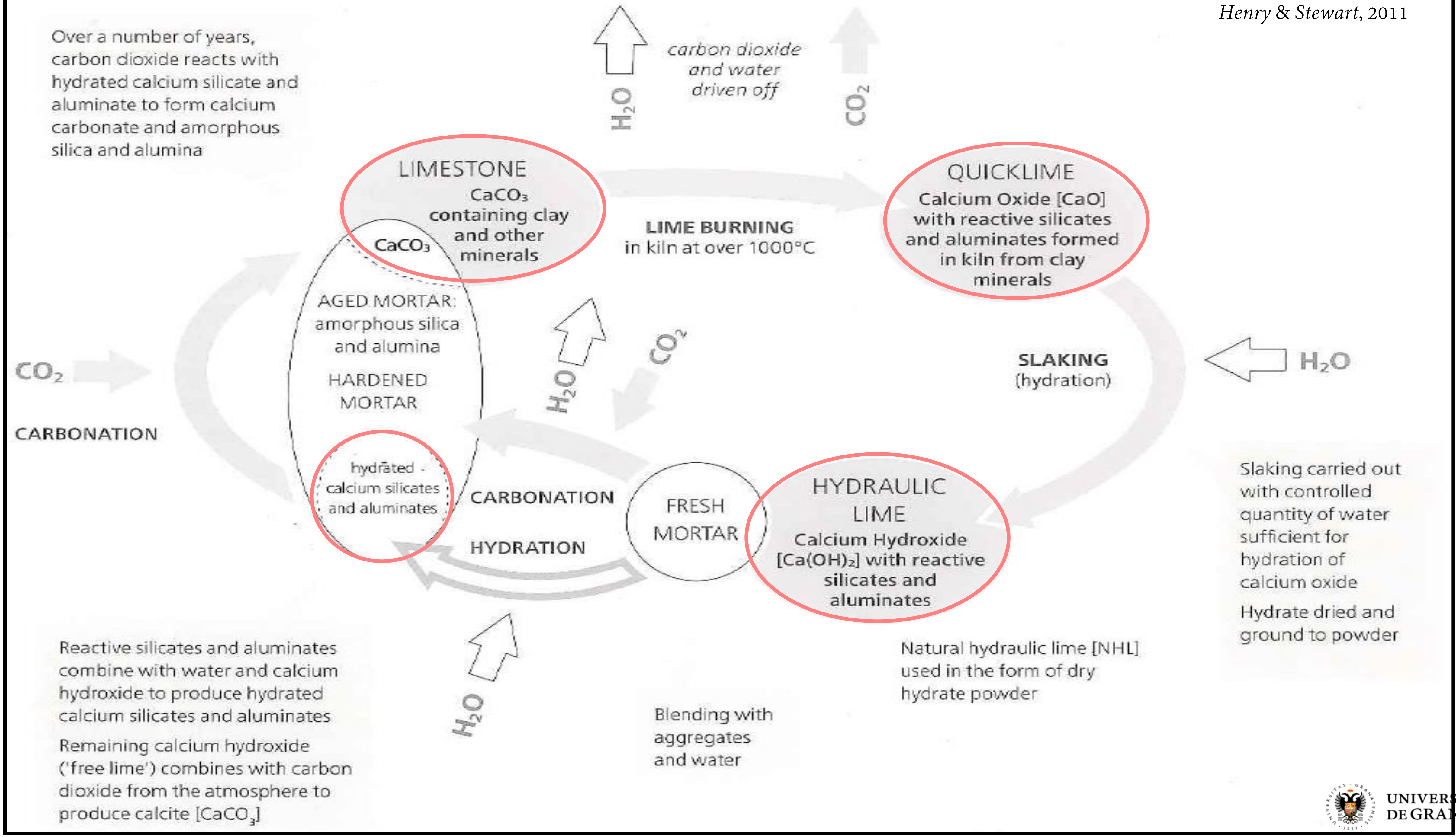
NHL

5.2 Sub-families of lime with hydraulic properties

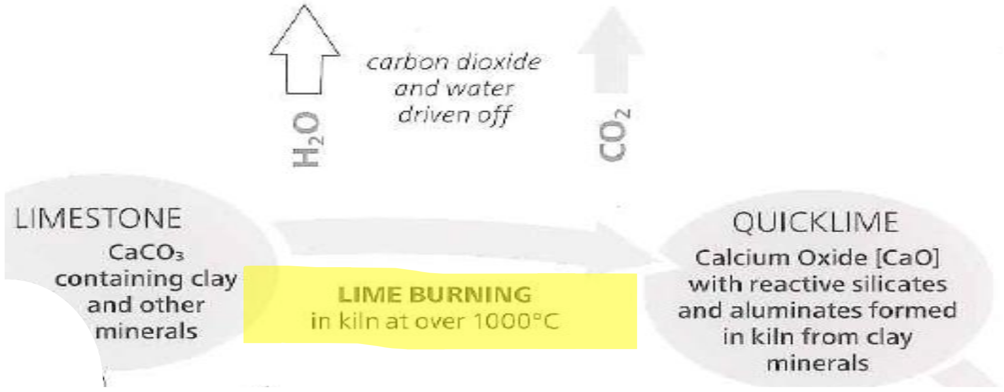
5.2.1 Natural hydraulic lime (NHL)

Natural hydraulic lime is a lime with hydraulic properties produced by burning of more or less argillaceous or siliceous limestones (including chalk) with reduction to powder by slaking with or without grinding. It has the property of setting and hardening when mixed with water and by reaction with carbon dioxide from the air (carbonation).

Henry & Stewart, 2011



Reactions ocurring during lime burning



T = 400-600 ºC → **dehydration and partial or total decomposition of clay minerals** into silicon, iron and aluminium oxides

T = 600-800 ºC → **decomposition of calcium carbonate** into calcium oxide (lime)

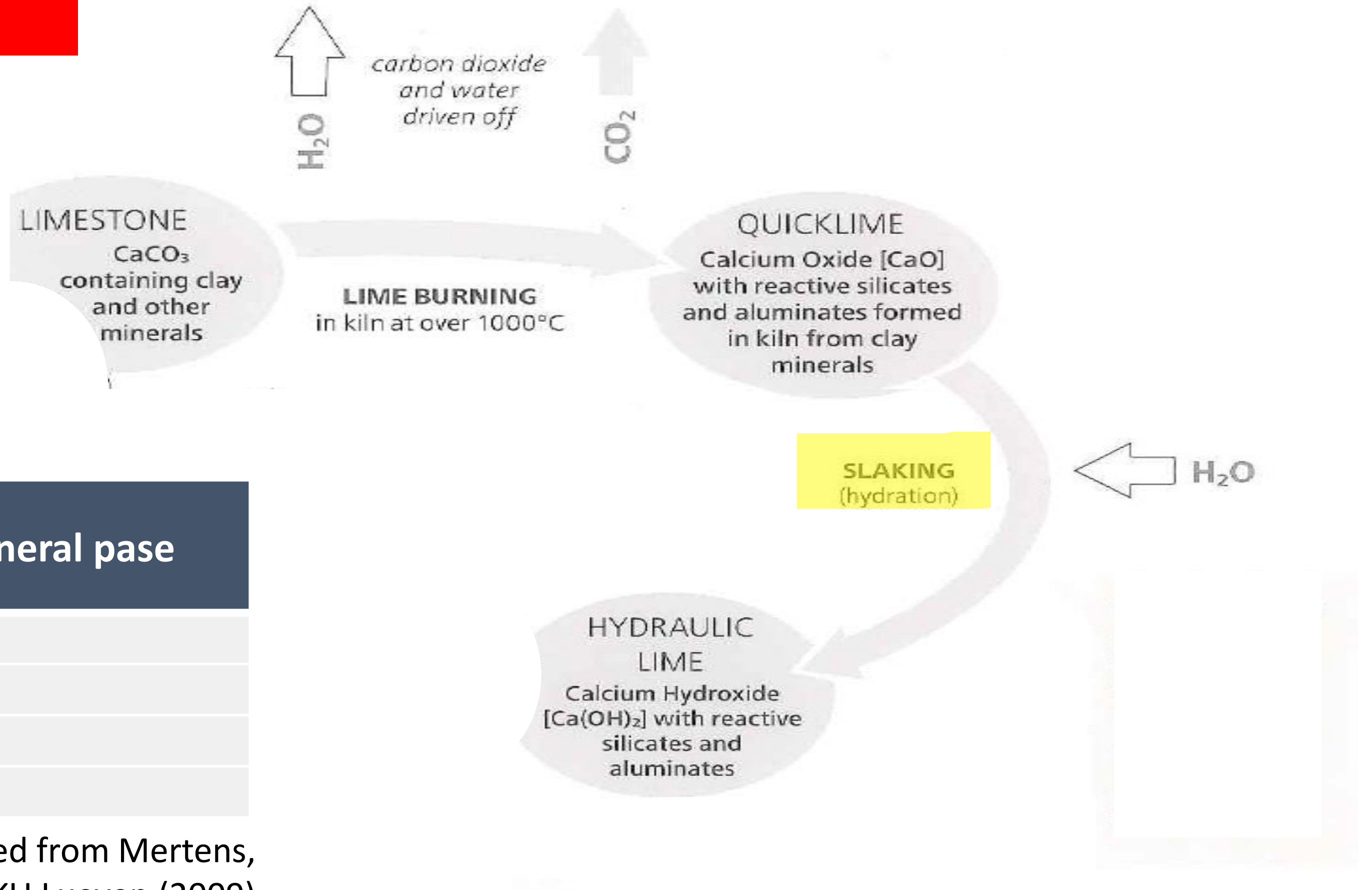
T = 950-1250 ºC → **combination** of the formed oxides to generate **various silicates and calcium aluminates**

notation	Chemical formula	Name of the mineral pase
C_2S	Ca_2SiO_4	Belite/larnite
C_2AS	$Ca_2Al(AlSi)O_7$	Gehlenite
CS	$CaSiO_3$	Wollastonite
C	CaO	Lime

Table modified from Mertens, PhD thesis KU Lueven (2009)

Reactions ocurring during lime slaking

Slaking is carried out with **controlled quantity of water**, sufficient for **hydration of calcium oxide**



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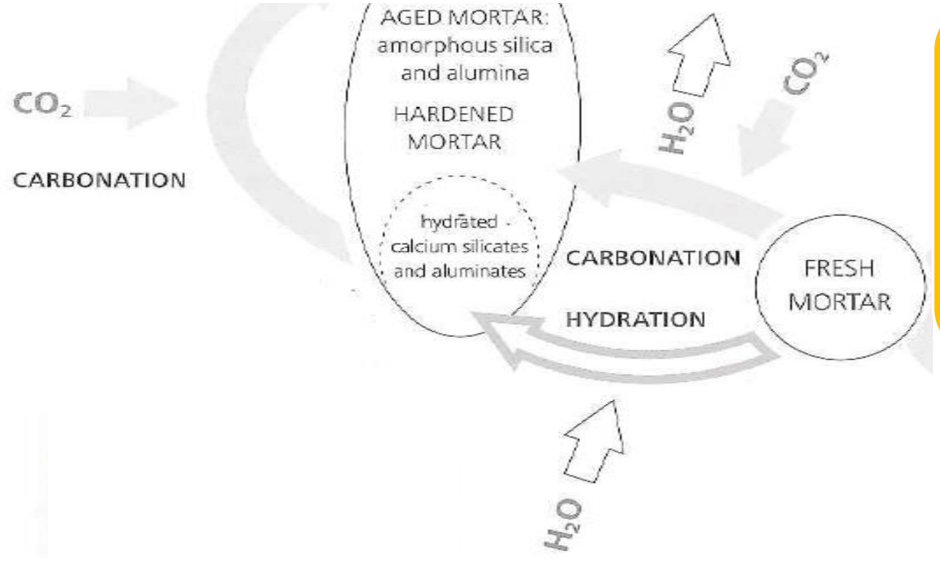
C	CaO	Lime

Table modified from Mertens, PhD thesis KU Lueven (2009)

↓ **+ H_2O**

$Ca(OH)_2$

Reactions ocurring during lime setting



NHL

Reactive silicates and aluminates combine with wáter and calcium hydroxide to produce hydrated calcium silicates and aluminates

Remaining calcium hydroxide (“free lime”) combines with CO_2 to precipitate $CaCO_3$

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C_2AS	$Ca_2Al(AlSi)O_7$	Gehlenite
CS	$CaSiO_3$	Wollastonite
C	CaO	Lime
CH	$Ca(OH)_2$	Portlandite

+ H_2O →

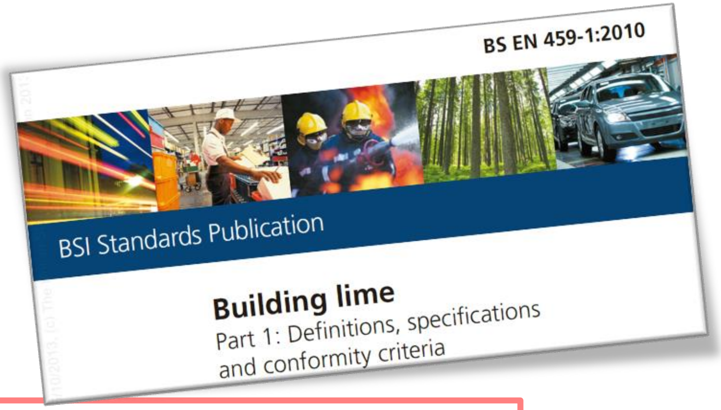
Hydration products
C-S-H
C-A-H
C-A-S-H
Others…

+ CO_2 ↓

$CaCO_3$

Tables modified from Mertens, PhD thesis KU Lueven (2009)

Other limes with hydraulic features



NHL

- NHL2
- NHL3,5
- NHL5

HL

- HL2
- HL3,5
- HL5

5.2 Sub-families of lime with hydraulic properties

5.2.1 Natural hydraulic lime (NHL)

Natural hydraulic lime is a lime with hydraulic properties produced by burning of more or less argillaceous or siliceous limestones (including chalk) with reduction to powder by slaking with or without grinding. It has the property of setting and hardening when mixed with water and by reaction with carbon dioxide from the air (carbonation).

The hydraulic properties exclusively result from the special chemical composition of the natural raw material. Grinding agents up to 0,1 % are allowed. Natural hydraulic lime does not contain any other additions.

5.2.2 Formulated lime (FL)

Formulated lime is a lime with hydraulic properties mainly consisting of air lime (CL) and/or natural hydraulic lime (NHL) with added hydraulic and/or pozzolanic material. It has the property of setting and hardening when mixed with water and by reaction with carbon dioxide from the air (carbonation).

5.2.3 Hydraulic lime (HL)

Hydraulic lime is a binder consisting of lime and other materials such as cement, blast furnace slag, fly ash, limestone filler and other suitable materials. It has the property of setting and hardening under water. Atmospheric carbon dioxide contributes to the hardening process.

Other limes with hydraulic features

NHL

- NHL2
- NHL3,5
- NHL5

HL

- HL2
- HL3,5
- HL5

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Only little information is given in the European standard

Binder type	Name according to EN 459:1	Mechanical resistance at 28 days (Mpa)
Aerial lime	CL90-S Fat lime	-
	DL90-S Lean lime	-
Hydraulic lime	**NHL2 (o HL2)**	**≥ 2 to ≤ 7**
	NHL3.5 (o HL3,5)	**≥ 3.5 to ≤ 10**
	NHL5 (o HL5)	**≥ 5 to ≤ 15**
Natural cement	-	-

The EN-459:1 standard distinguishes the three types of natural hydraulic limes **according to the compressive strengths** obtained in standardised mortars made with these limes

The standard does not indicate a range of percentages of clayey phases that must be present in the raw material to obtain each of these types of lime.

Only the minimum percentage of free lime is indicated, without making any mention of the silicate and aluminate content, which are responsible for the hydraulic nature of the lime, as indicated above

A more rigorous classification is possible

Cementation index (Eckel, 1922)

$$IC = \frac{2{,}8\ (\%SiO_2) + 1{,}1\ (\%Al_2\ O_3) + 0{,}7\ (\%Fe_2\ O_3)}{(\%CaO) + 1{,}4\ (\%MgO)}$$

Binder type	Name according to EN 459:1	Mechanical resistance at 28 days (Mpa)	Description of the hydraulic feature	IC	Content in clay phases	Total reactive oxides ($SiO_2+Al_2O_3+Fe_2O_3$)	CaO+MgO (%)
Aerial lime	CL90-S Fat lime	-	Non hydraulic	~0	As impurities	0%-2%	>94
	DL90-S Lean lime	-	Non hydraulic	0-0.2	As impurities	2%-8%	>70
Hydraulic lime	**NHL2 (o HL2)**	**≥ 2 to ≤ 7**	**Moderate**	**0.3-0.5**	**~8%**	**<12%**	**>65**
	NHL3.5 (o HL3,5)	**≥ 3.5 to ≤ 10**	**Intermediate**	**0.5-0.7**	**~15%**	**12%-18%**	**>60**
	NHL5 (o HL5)	**≥ 5 to ≤ 15**	**High**	**0.7-1.1**	**~25%**	**18%-25%**	**>55**
Natural cement	-	-	-	>1.1-1.7	Up to 45%	Up to 55%	>45

Issues raised

INFLUENCE OF

- Clay content
- Clay type
- Burning temperature and duration

of the raw material and firing process

ON

- Chemical and mineralogical composition
- Textural features

of the LIME

and

- Hydraulicity
- Physical-mechanical properties
- Durability

of the MORTAR

Issues raised

These key aspects, not considered in European regulations, give rise to the **existence of natural hydraulic limes** on the market which, despite having the same index (2, 3.5 or 5) in their denomination or technical data sheet, have **very different compositional and textural characteristics**

CONSECUENCES:

- Difficulty of discerning one product from another
- Great **uncertainty about which hydraulic mortar is the most appropriate for use in the restoration of historic buildings**

SOLUTIONS:

- To increase the knowledge on natural hydraulic lime (scientific studies)

CONTENTS:

EUROPEAN STANDARDS ON:

MORTAR COMPONENTS

- binders
- **aggregates**
- additives and admixtures

MORTAR CLASSIFICATION

CHARACTERISATION OF HISTORIC MORTARS

REQUIREMENTS FOR RESTORATION MORTARS

DESIGN AND CHARACTERISATION OF RESTORATION MORTARS

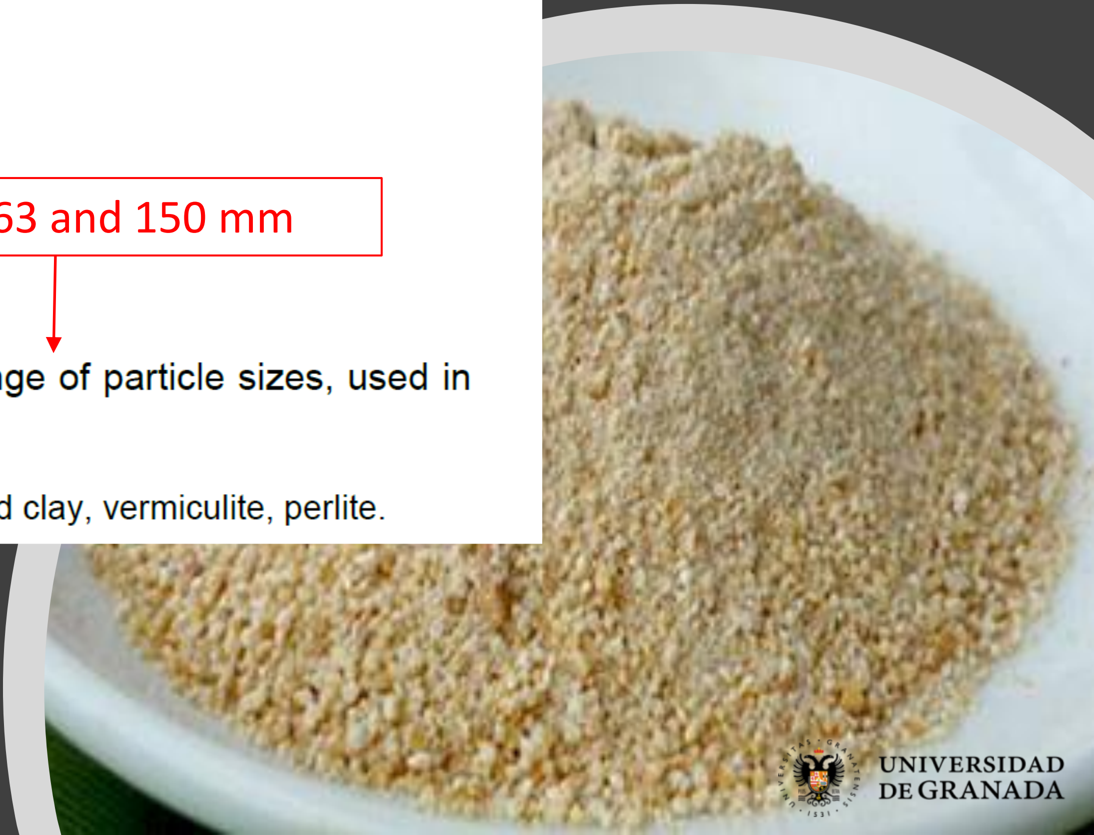
AGGREGATE
(BS EN 16572:2015)

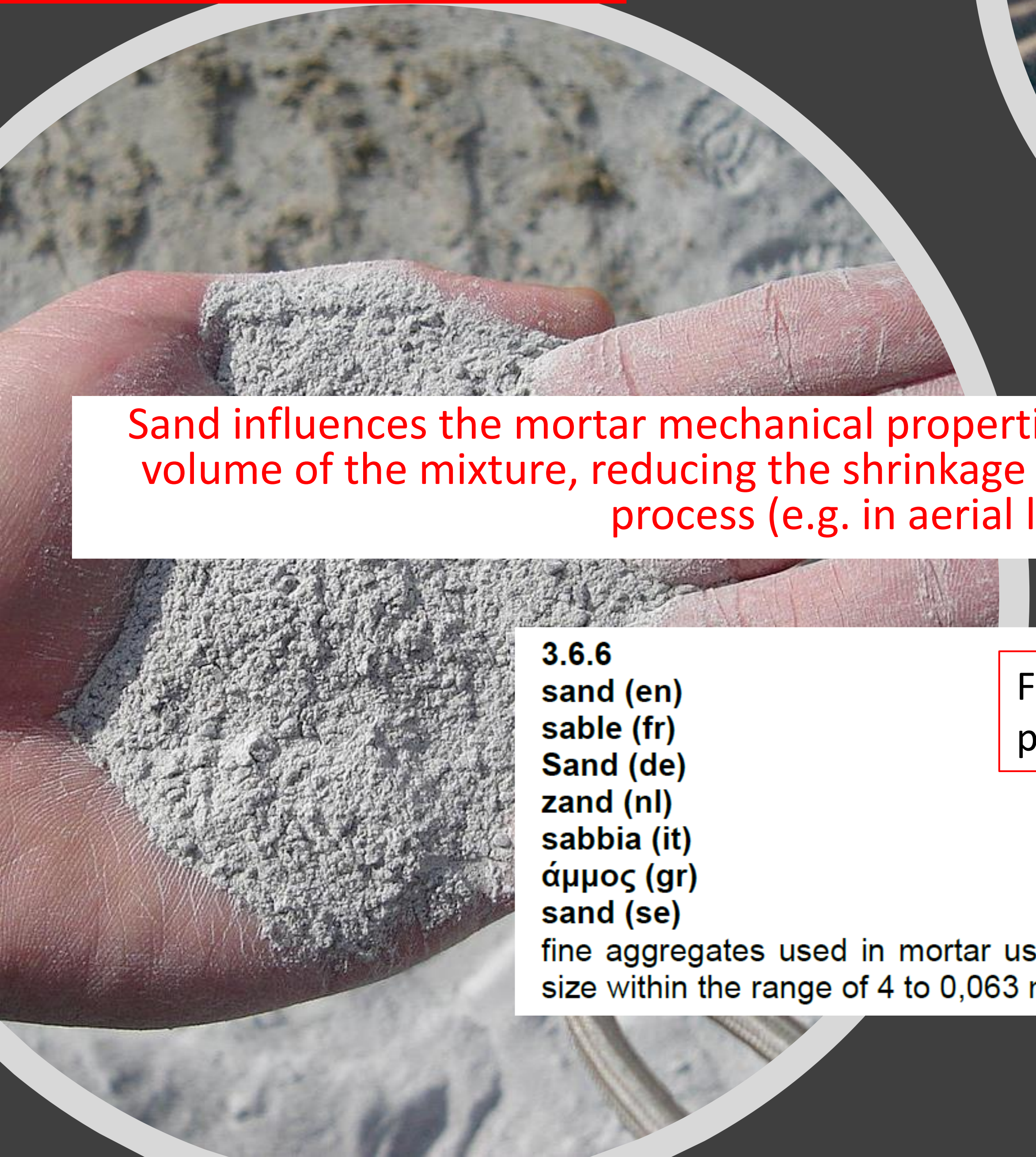
3.1.3
Aggregate (en)
Agrégat (fr)
Zuschlag (de)
aggregaat (nl)
aggregato (it)
αδρανές (gr)
ballast (se)

particles of (sometimes) rock, naturally occurring or artificially crushed, with a range of particle sizes, used in the mortar (see also Sand)

From 0.063 and 150 mm

NOTE 1 to entry   Apart from rock aggregates, light-weight aggregates exist like expanded clay, vermiculite, perlite.





SAND

(BS EN 16572:2015)

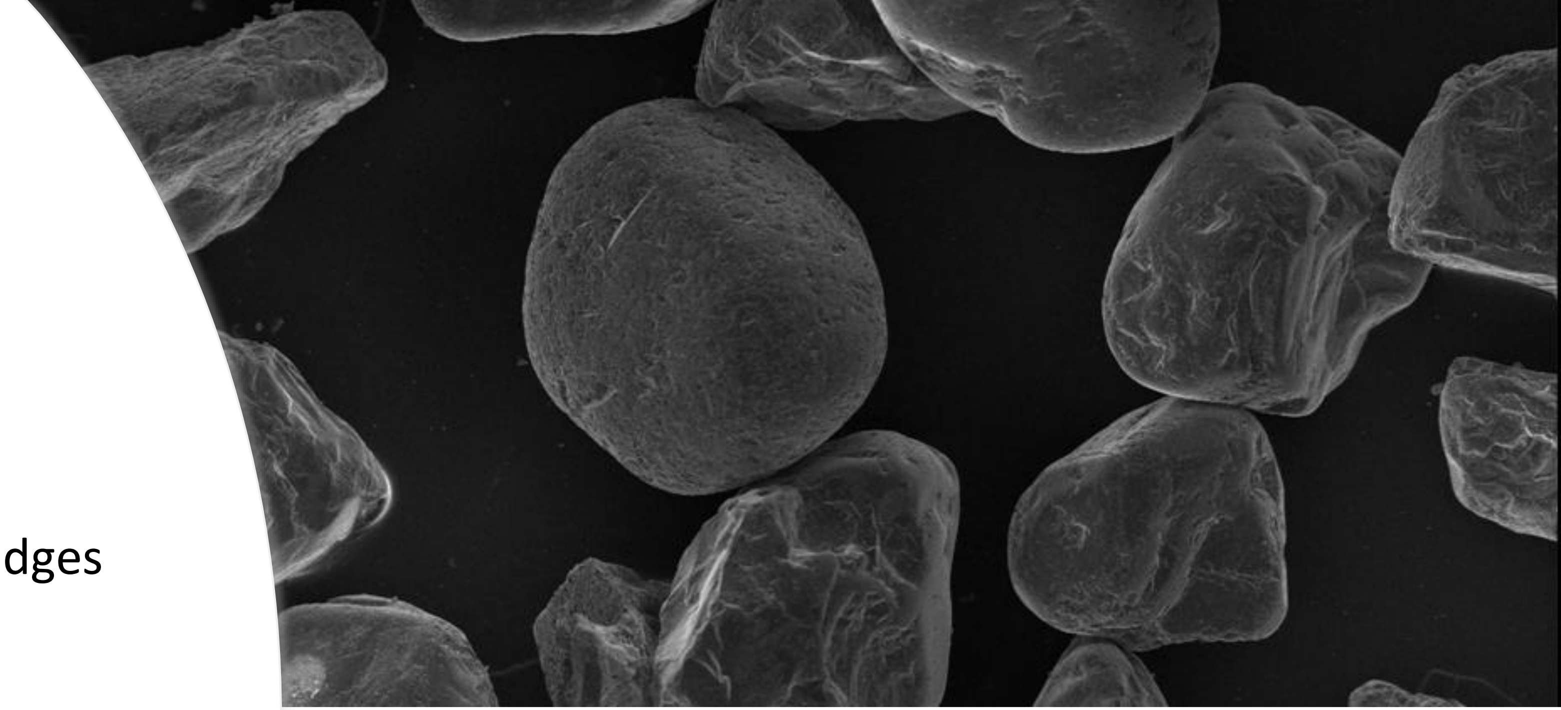
Sand influences the mortar mechanical properties and confers stability to the volume of the mixture, reducing the shrinkage that occurs during the drying process (e.g. in aerial lime)

3.6.6
sand (en)
sable (fr)
Sand (de)
zand (nl)
sabbia (it)
άμμος (gr)
sand (se)

fine aggregates used in mortar usually consisting of quartz and silica or silicates/carbonates with a particle size within the range of 4 to 0,063 mm

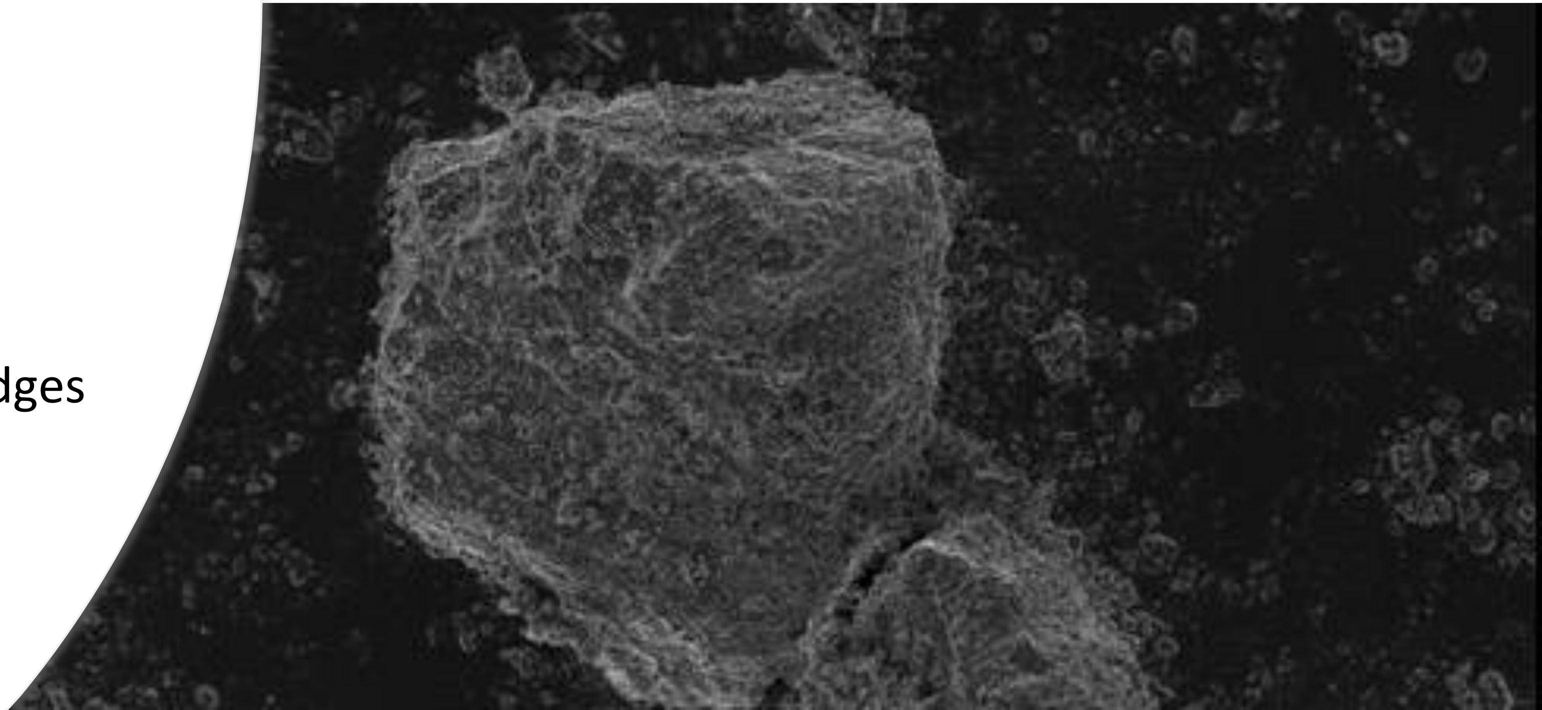
Fine aggregate (or filler): aggregate whose percentage by mass passing the **0.063 sieve is greater than 70%** (EN 13139:2002)

Types of sand



Natural - granular:

River terraces
Washing and classification
Rounded shape, smooth surfaces and no edges
Mainly of siliceous composition



Natural - crushed:

Quarries
Extraction, crushing, grinding, classification
Angular shape, rough surfaces and sharp edges
Mainly limestone aggregates

Types of sand

Recycled:

They result from the treatment of inorganic materials previously used in construction, and obtained from the demolition of buildings (mortars, *cocciopesto*)

Artificial:

By-products or residues of industrial processes, resulting from a process involving thermal or other modification (iron and steel slag, fly ash from coal combustion, ash, etc)

Lightweighting:

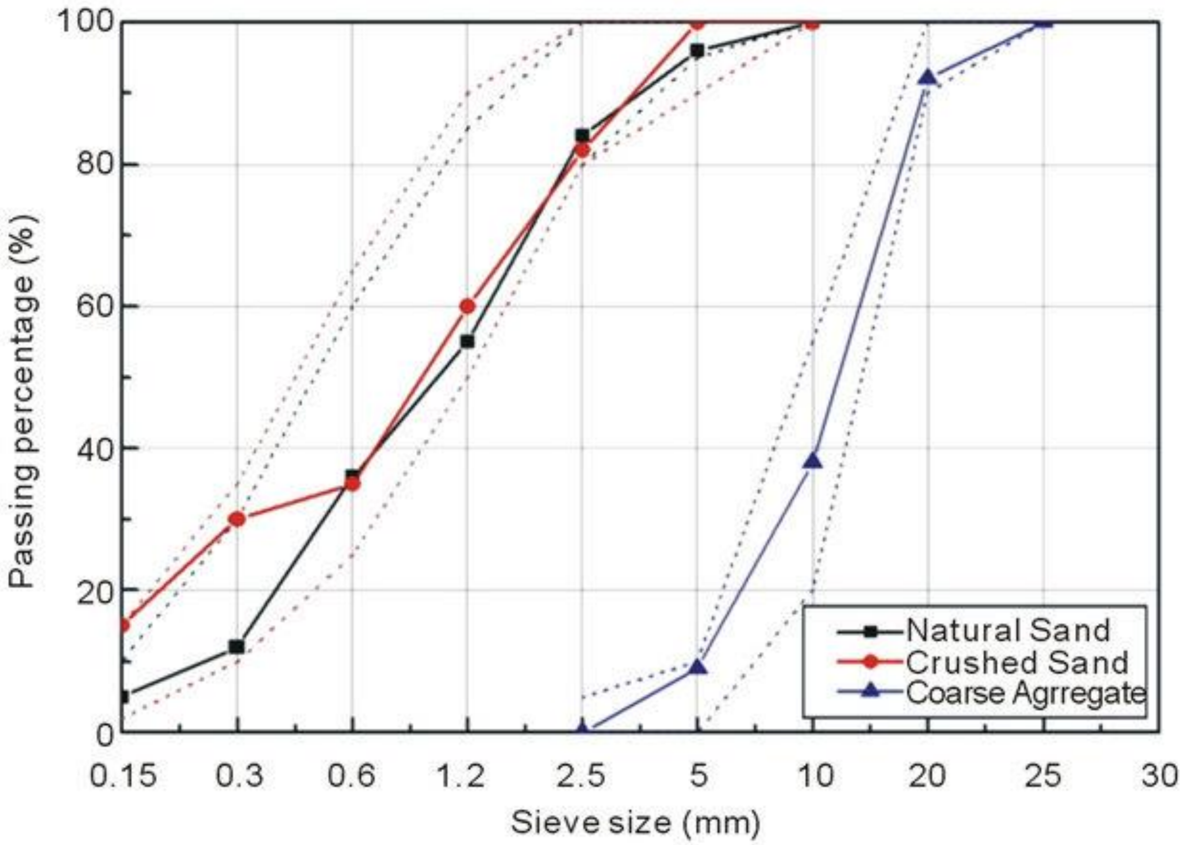
Natural or artificial. Used for the production of lightweight and/or insulating mortars

Grading of sand

Grading defines the size range and the number of grains of each size.

The size range is determined using sieves (EN933-2) with mesh sizes: **0.063-0.125-0.250-0.500-1-2-4** mm.

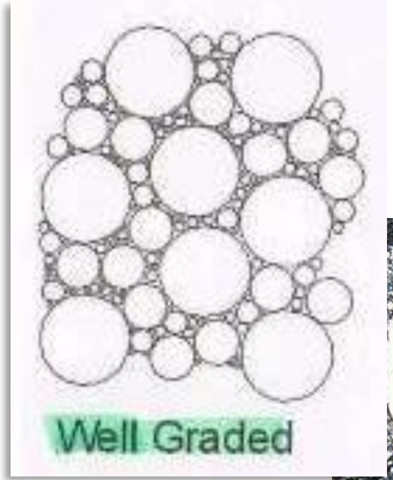
Once the sample has been sieved, the results obtained are plotted on a graph where the percentages that pass through each sieve are shown on the vertical axis and their size on the horizontal axis.
The curve obtained is called a **granulometric curve**.

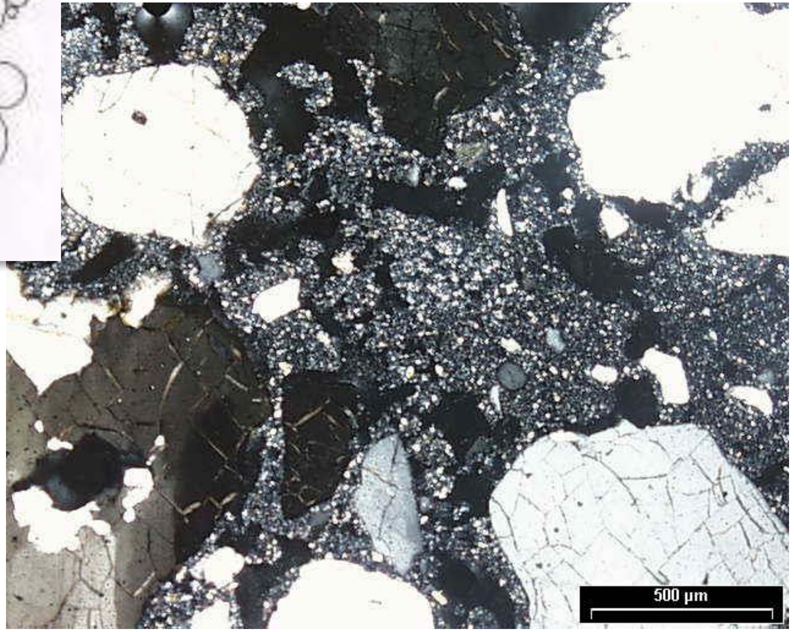


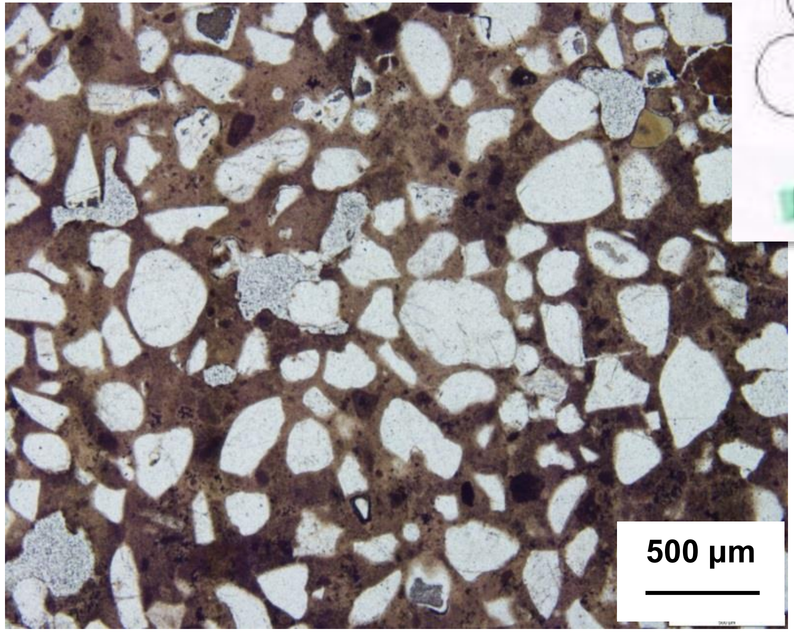
Grading of sand

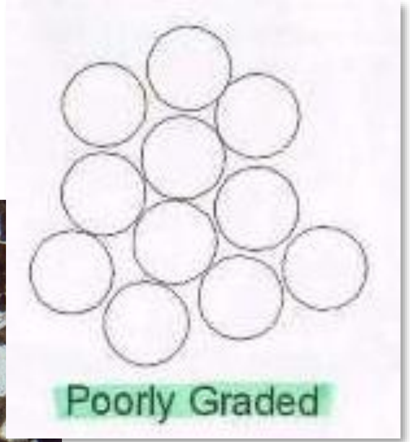
- With the graphical representation of a sand, it is possible to quickly identify whether the sand has an excess of coarse or fine fractions or the presence of discontinuities in the size distribution.

- The type of curve influences the properties of the mortar (especially porosity and mechanical strength), depending on the packing achieved.









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CONTENTS:

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- binders
- aggregates
- **additives and admixtures**

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ADDITIVES AND ADMIXTURES

(BS EN 16572:2015)

3.1.4
Additive (en)
adjuvant (fr)
Zusatzmittel (de)
Additief (nl)
Additive (it)
Πρόσθετο (gr)
Tillsatsmaterial (se)

additive (EN) or addition (ASTM): constituent usually added up to 1 % w/w to binder to improve its manufacture or properties (for example accelerators, plasticizers and air-entraining agents)

3.1.5
Admixture (en)
additive (fr)
Zusatzstoff (de)
Toeslagstof (nl)
Aggiunta (it)
Πρόσμικτο (gr)
Tillsatsmedel (se)

substance other than binder, aggregate or water, added in quantities of at least 1 % w/w to the mix to alter its properties. Pigments as well as pozzolana (as long as added in small quantities and not as a latent binder) and fibrous substances are admixtures

Additives and admixtures in ancient times

…Blood, Hairs, Straw, Milk, Eggs, Rice, Oils, Cactus juice, Gums, Animal glues, Fibres, …

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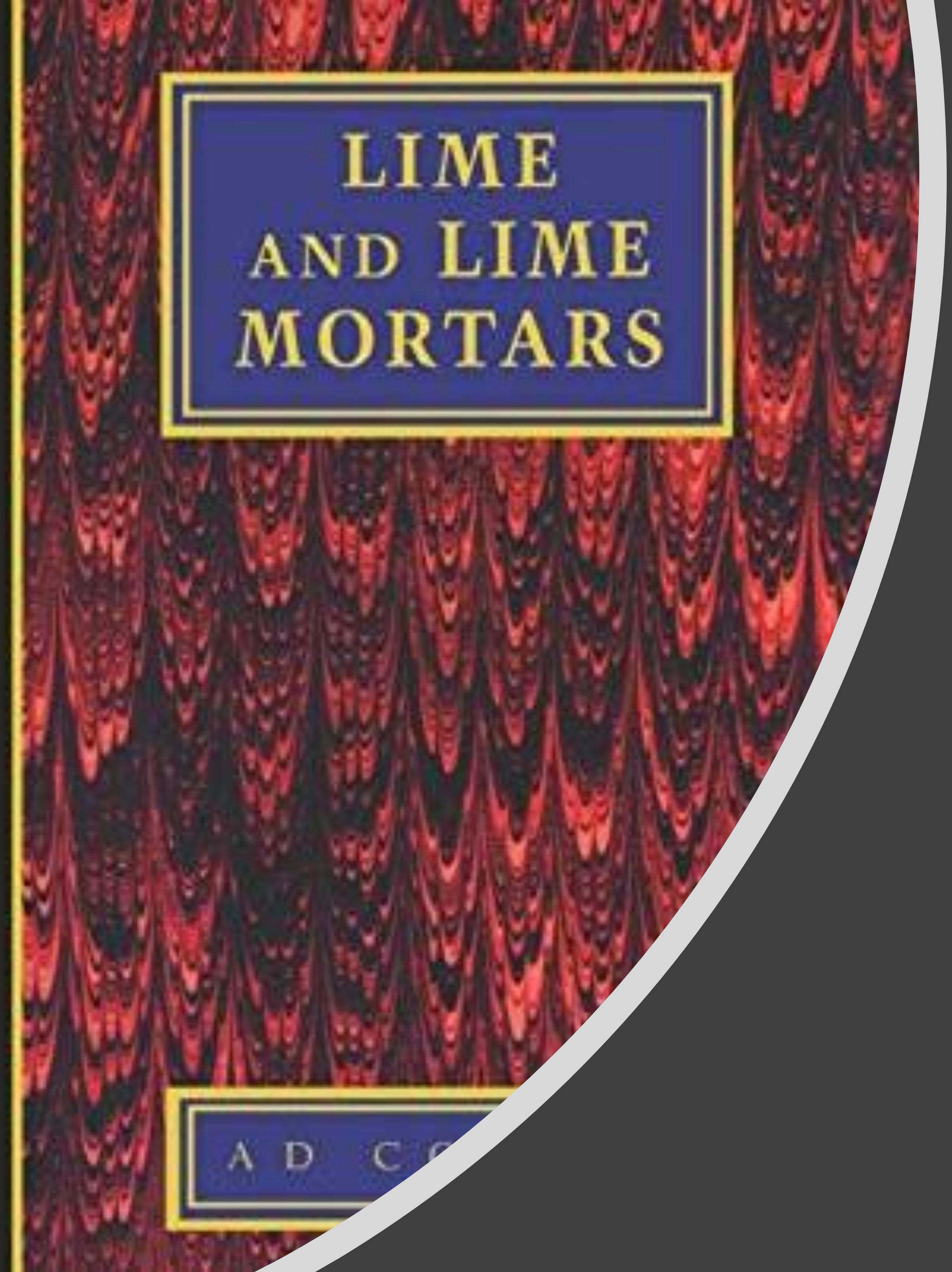

Cowper (1925):

"A curious aspect of the history of the use of lime is the diversity of materials that have been added to lime and mortars, generally with the aim of slowing down the setting time and allowing longer handling of the material in artistic works"

Cowper mentions some examples of traditionally used additives:

Egg
Sugar (in India)
Fruit
Elm bark (possibly in the form of an infusion)
Barley water
Ox blood
Cow dung
Waxes
Beer
Milk
Gluten
Cheese
etc.

archaeometry

Archaeometry 58, Suppl. 1 (2016) 218–229 doi: 10.1111/arcm.12225

A NEW METHOD IN DETECTING THE STICKY RICE COMPONENT IN TRADITIONAL CHINESE TABIA*

Journal of Cultural Heritage 15 (2014) 144–150

ELSEVIER Available online at SciVerse ScienceDirect www.sciencedirect.com Elsevier Masson France EM|consulte www.em-consulte.com/en

Original article

The identification of organic additives in traditional lime mortar

Shi Qiang Fang[a,c], Hui Zhang[b], Bing Jian Zhang[a,b,*], Ye Zheng[a]

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International Journal of Adhesion & Adhesives 48 (2014) 224–230

http://dx.doi.org/10.1016/j.ijadhadh.2013.09.034

Contents lists available at ScienceDirect

ELSEVIER International Journal of Adhesion & Adhesives

journal homepage: www.elsevier.com/locate/ijadhadh

A study of Tung-oil–lime putty—A traditional lime based mortar

Shiqiang Fang[a], Hui Zhang[b], Bingjian Zhang[a,b,*], Guoqing Li[c]

[a] Department of Chemistry, Zhejiang University, 310027 Hangzhou, China
[b] Department of Cultural Heritage and Museology, Zhejiang University, 310028 Hangzhou, China
[c] Museum of Overseas Communication History, 362000 Quanzhou, China

Construction and Building Materials 25 (2011) 3313–3318

Contents lists available at ScienceDirect

ELSEVIER Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Traditional organic additives improve lime mortars: New old materials for restoration and building natural stone fabrics

L. Ventolà *, M. Vendrell, P. Giraldez, L. Merino

Departament de Cristallografia, Mineralogia i Dipòsits Minerals, Facultat de Geologia, Universitat de Barcelona, Martí i Franquès s/n, E-08028 Barcelona, Spain

Cement and Concrete Research 76 (2015) 232–241

Contents lists available at ScienceDirect

ELSEVIER Cement and Concrete Research

journal homepage: http://ees.elsevier.com/CEMCON/default.asp

A study of traditional blood lime mortar for restoration of ancient buildings

Shiqiang Fang[a], Kun Zhang[b,c], Hui Zhang[b], Bingjian Zhang[a,b,*]

[a] Department of Chemistry, Zhejiang University, Hangzhou 310027, P.R. China
[b] Department of Cultural Heritage and Museology, Zhejiang University, Hangzhou 310028, P.R. China
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Holmes and Wingate (1997) defined 5 main groups of mortar additives and admixtures:

1) RETARDERS

- For lime mortars: glues; oils; sugar dissolved in beer or vinegar
- for gypsum mortars: keratin; sodium citrate

2) ACCELERATORS

- Calcium chloride / Gypsum / Alum / Borax / Pozzolans / Bone ash

3) HARDENERS

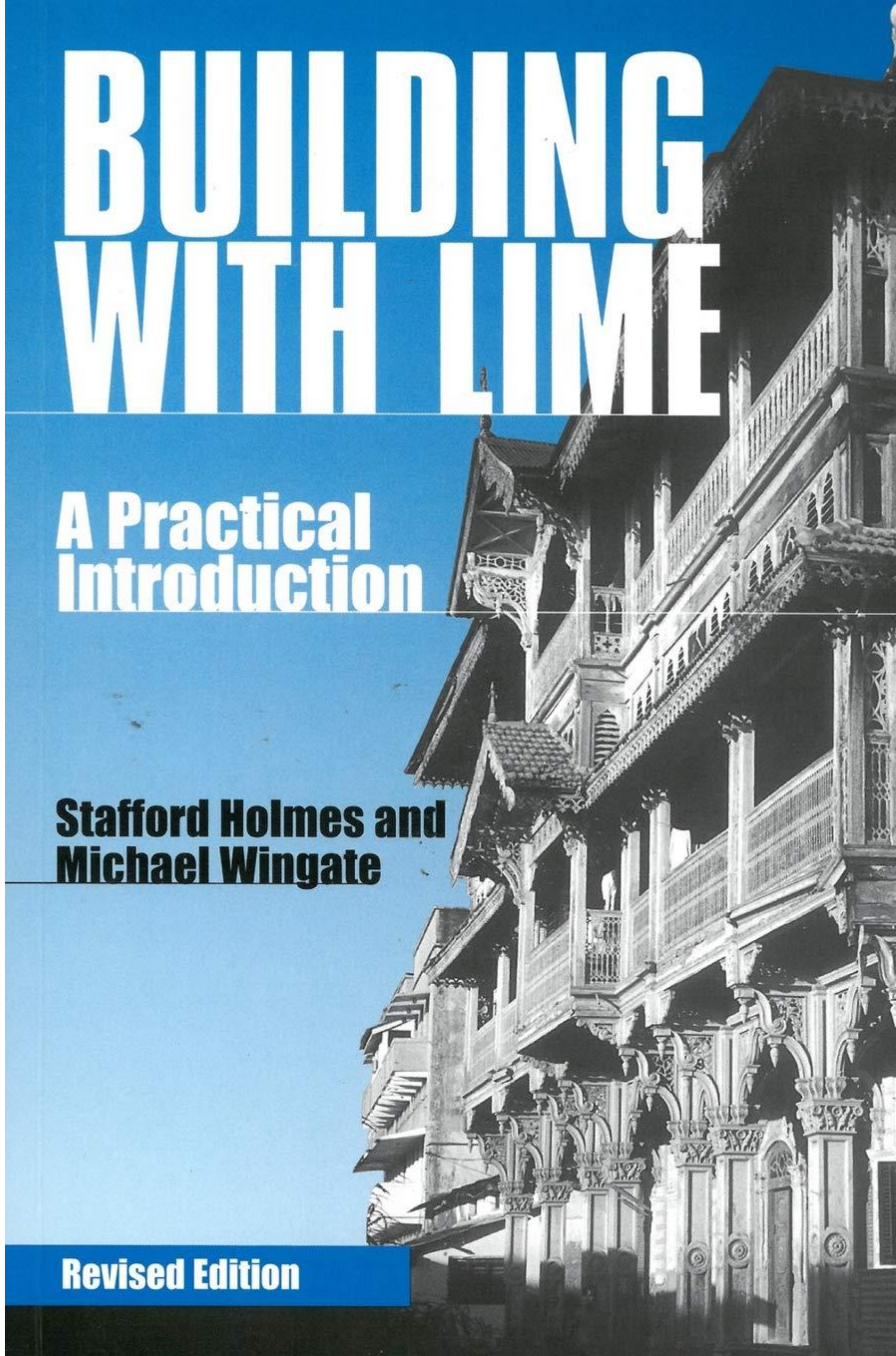
- Ground shells / Talcum powder / Marble or granite dust / Bone ash / Alum / Sugar (molasses) / Rye flour / Oils / Pozzolans

4) AIR ENTRAINERS

- Brick and tile fragments / beer / Coal / Ash residues

5) BONDING AGENTS

- Sugar (molasses) / Acrylic emulsions / Egg whites / Gums



Henry and Stewart (2011) described more types of additives for mortars:

- **PLASTICISERS**
- **WATER RETAINERS**
- **WATER REPELLENTS**
- **AIR ENTRAINERS**

The American standard defines 8 types of concrete admixtures (ASTM C494/C494M - 08a):

- Type A-Water-reducing admixtures
- Type B-Delaying admixtures
- Type C-Accelerating admixtures
- Type D-Water Reducing and Retarding Additives
- Type E-Water-reducing and accelerating additives
- Type F-High-range water-reducing additives
- Type G-High-range water-reducing additives and retarding agents
- Type S-Specific behaviour additives

ADDITIVES

- Substances or materials added, before or during the mixing of the mortar, in small quantities in relation to the mass of the binder (≤1% by mass in relation to the binder, according to EN 16572)

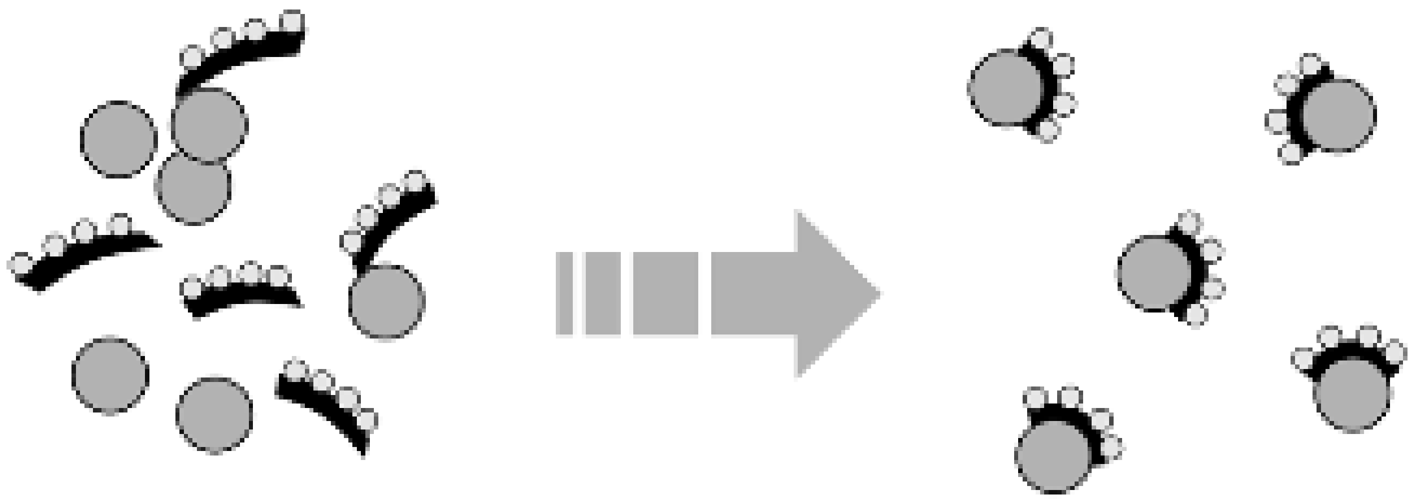
- **Their function is to improve the properties of the mortar or to provide certain well-defined and permanent modifications**

- These components can produce a single change in the characteristics of the mortar **(primary function)** or, in addition, additional changes **(secondary function)**

- Additives suitable for mortars must meet the requirements of EN 934 and EN 16572

Examples of ADDITIVES

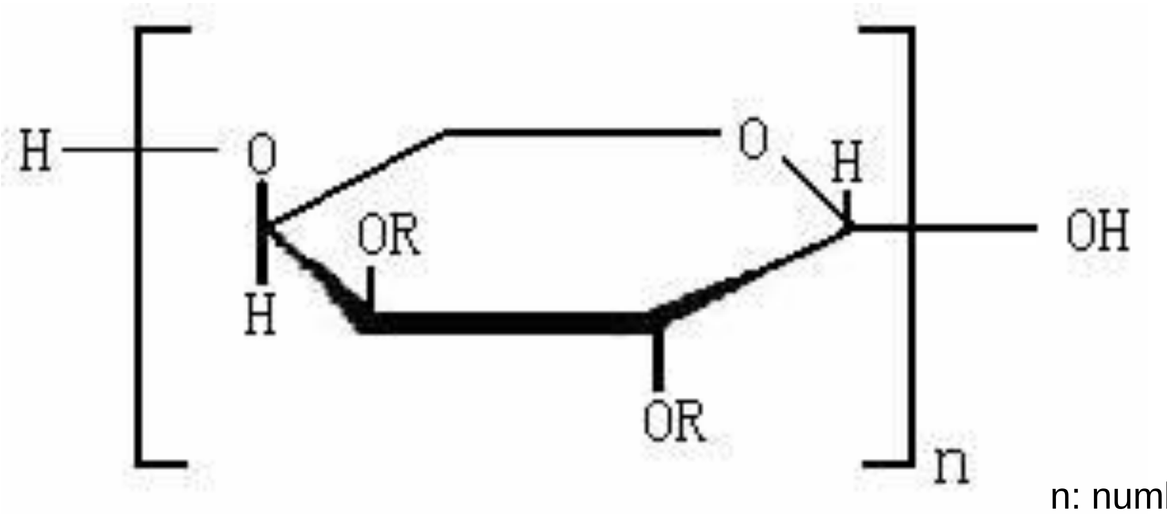
PLASTICISERS



They modify the rheology in the fresh state thanks to the temporary dispersion of the binder particles, which results in:

- reduction of the water/binder ratio to the benefit of mechanical strength and durability
- increase in the plasticity of the mortar, with the mixture remaining workable for a longer period of time

WATER-RETAINING AGENTS



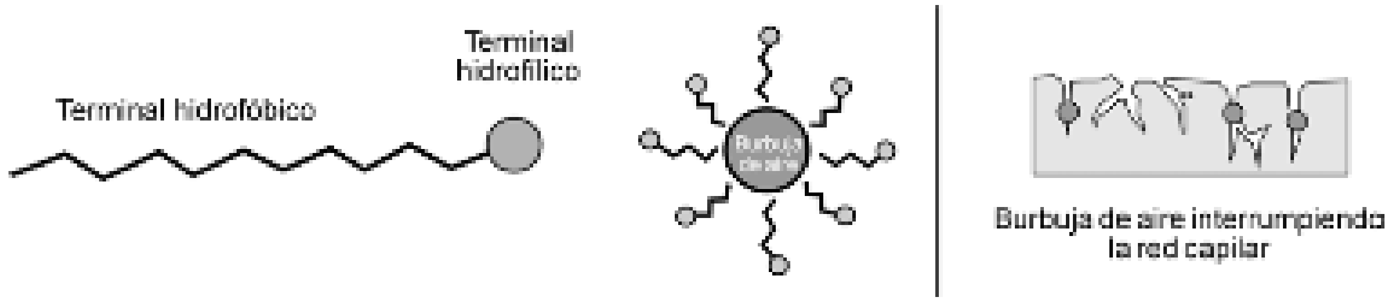
n: number of glucose units;
R = CH_3 or H or CH_2CH_2OR

They delay the evaporation of the mixing water and thus prevent the mortar from losing water too quickly. The viscosity of the paste increases, with the following effects:

- they reduce the absorption of water and its tendency to evaporate
- they modulate the viscosity of the mortar mass
- they attenuate the tendency to exudation in cases of incorrect particle size or lack of fines

Examples of ADDITIVES

AIR-ENTRAINING AGENTS



- They modify the air content by introducing small air bubbles with a diameter between 10 and 500 microns into the mortar mass during mixing
- Due to their spherical and flexible shape, they act as a lubricant for the mortar in its fresh state, improving workability
- They interrupt the capillary network of the mortar mass, preventing the penetration of water, protecting the mass from the effect of frost
- By including air, they decrease the apparent density of the fresh mortar, which, together with the above, tends to prevent segregation and exudation of the mortar in the fresh state

According to the AFAM report (Spanish Association of Mortar Manufacturers):

" To ensure that the function of all these additives is really effective and to avoid undesired effects, it is essential to provide quantitatively and qualitatively an adequate mixture of all the components

Due to the industrial process involved in the manufacture of dry mortar, this product guarantees the correct dosage of additives, as well as their dispersion and homogenisation in the mortar mass due to its dry mixing"

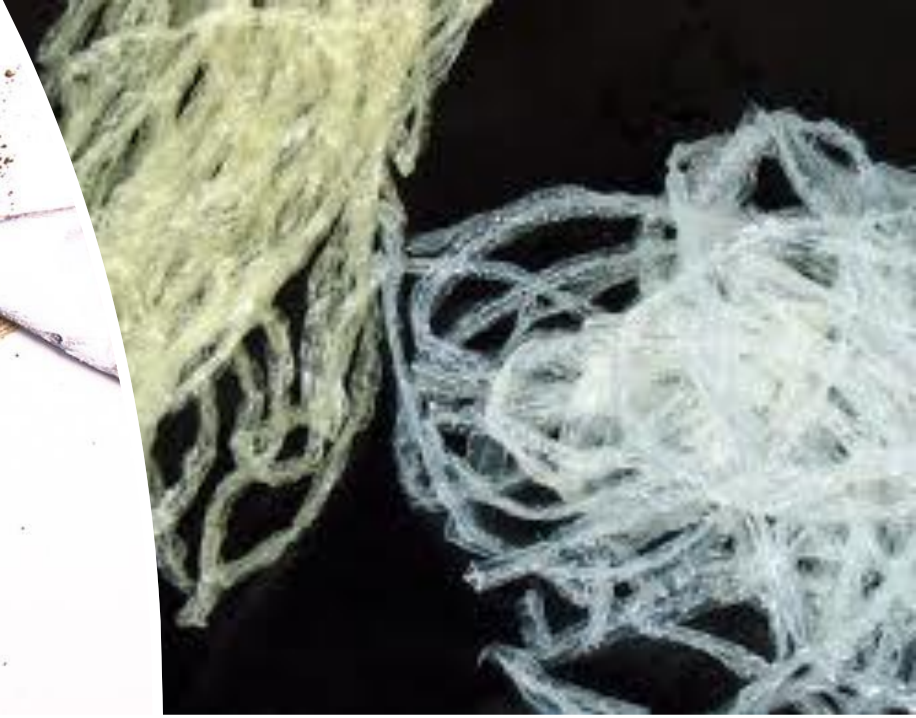
asociación nacional de fabricantes de mortero

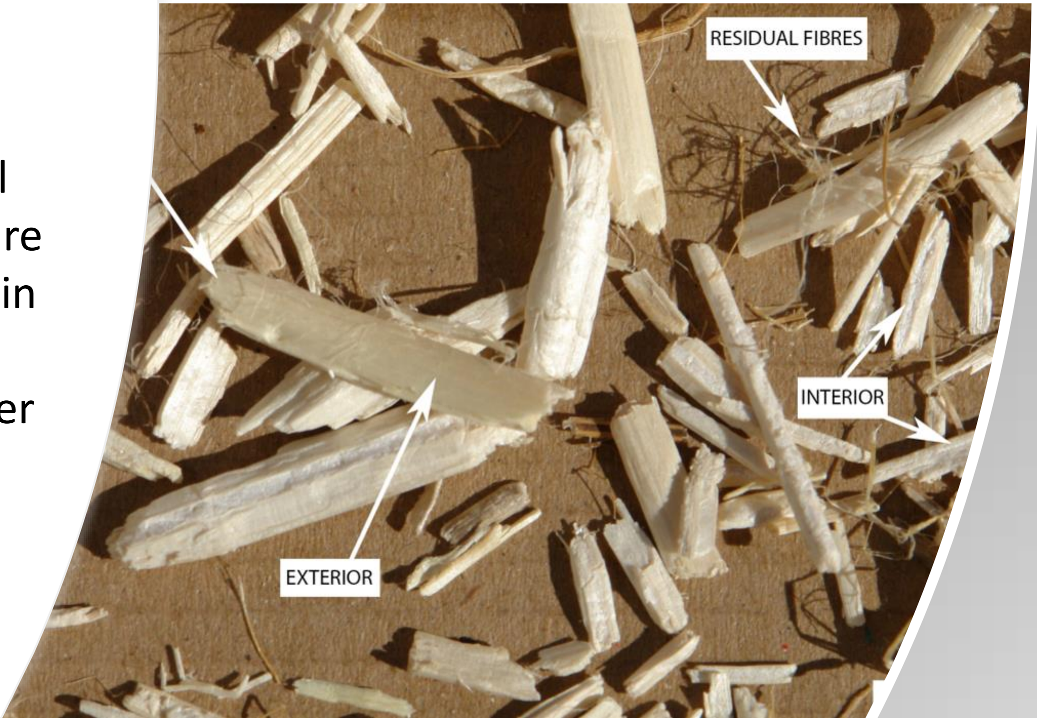
MORTAR COMPONENTS

ADMIXTURES

Admixtures are inorganic materials that can be used in the manufacture of mortars in order to improve certain properties or to achieve special properties

They are preferably inorganic materials such as pigments, mineral fillers, and pozzolans (when these are not considered as a binder), added in quantities of at least 1% by weight with respect to the amount of binder (EN 16572)





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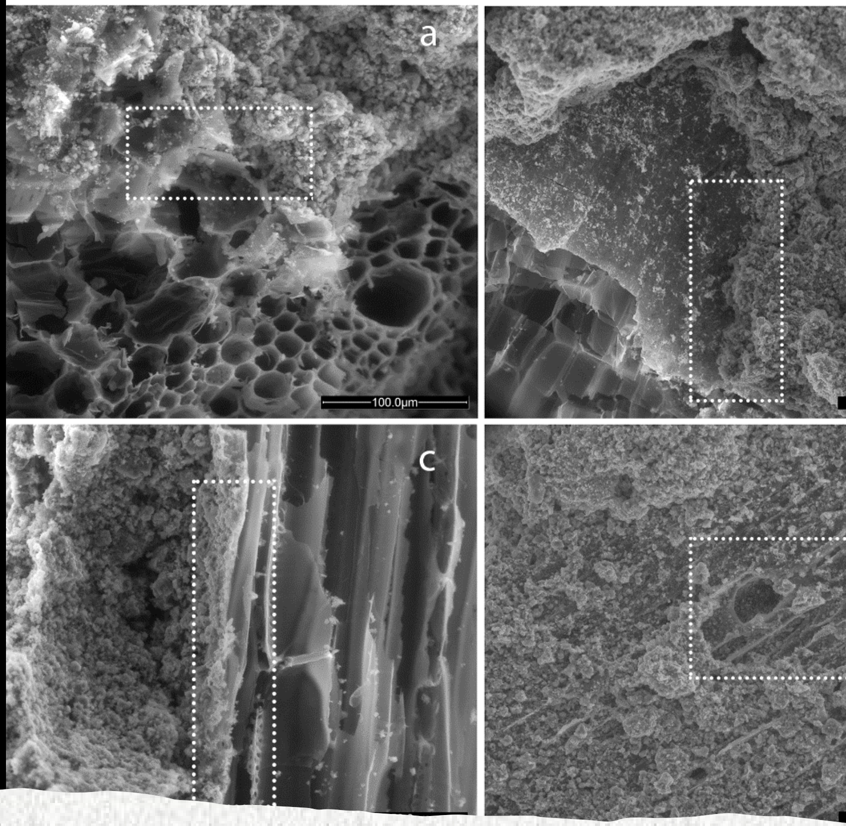


- Natural resource
- Insulating properties (thermal and acoustic)
- High heat capacity
- No shrinkage
- Lightweight material
- CO_2 capture
- Versatility (various applications in the building)

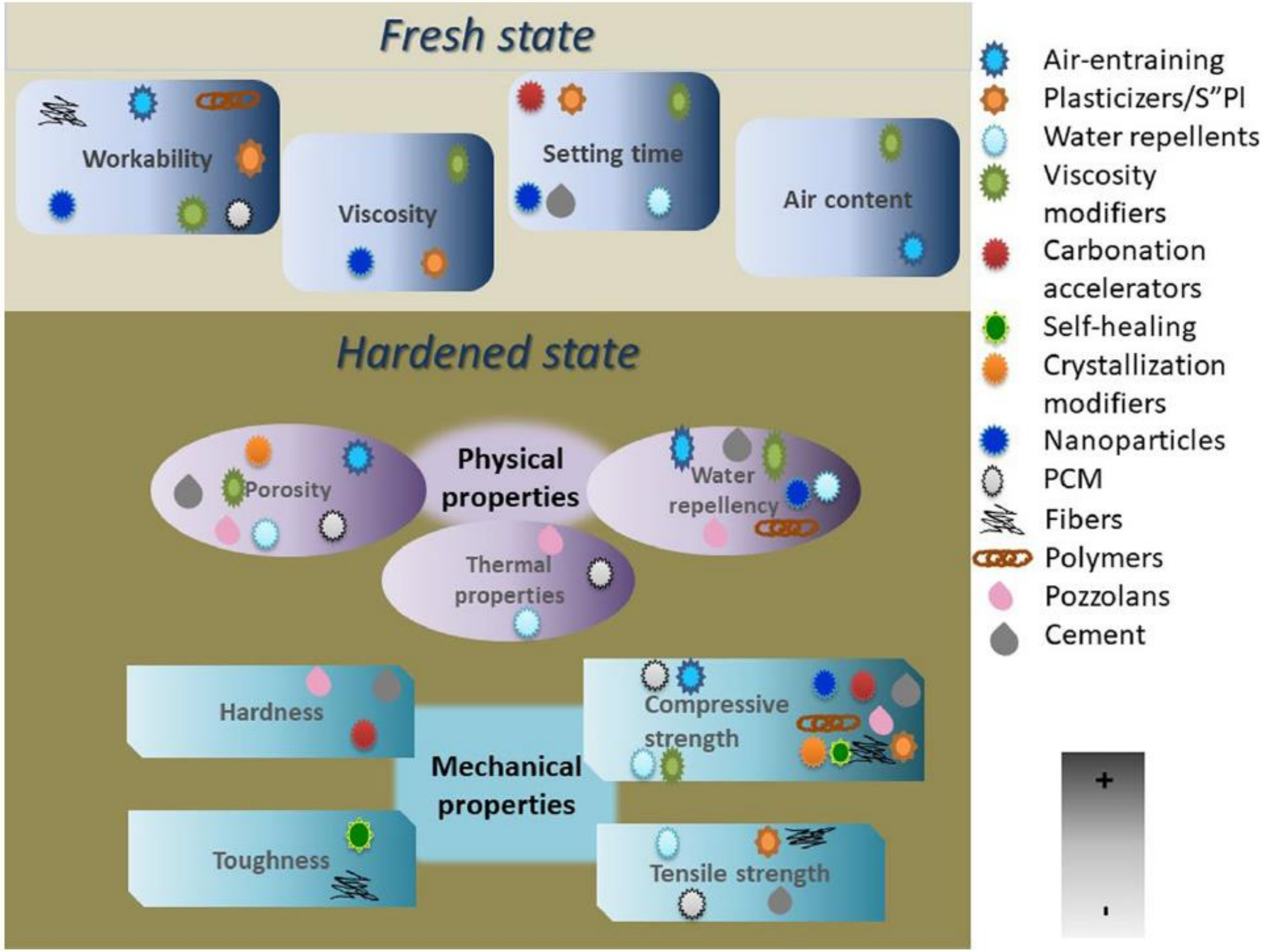
Effect of additives and admixtures on the mortar performances

Materials and Structures (2023) 56:106
https://doi.org/10.1617/s11527-023-02175-z

RILEM TC REPORT

RILEM TC 277-LHS report: additives and admixtures for modern lime-based mortars

Pagona-Noni Maravelaki · Kali Kapetanaki · Ioanna Papayianni · Ioannis Ioannou · Paulina Faria · Jose Alvarez · Maria Stefanidou · Cristiana Nunes · Magdalini Theodoridou · Liberato Ferrara · Lucia Toniolo



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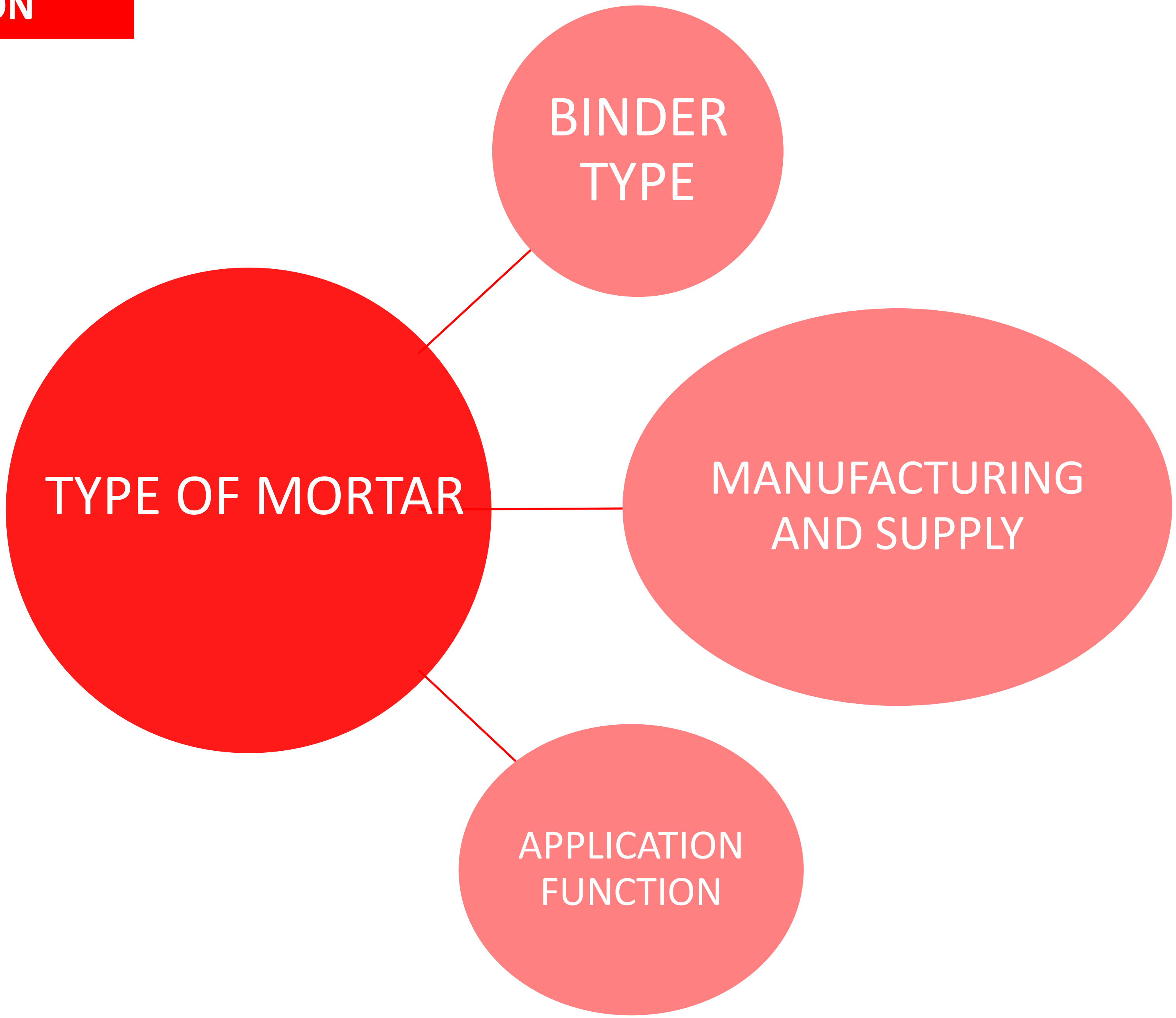
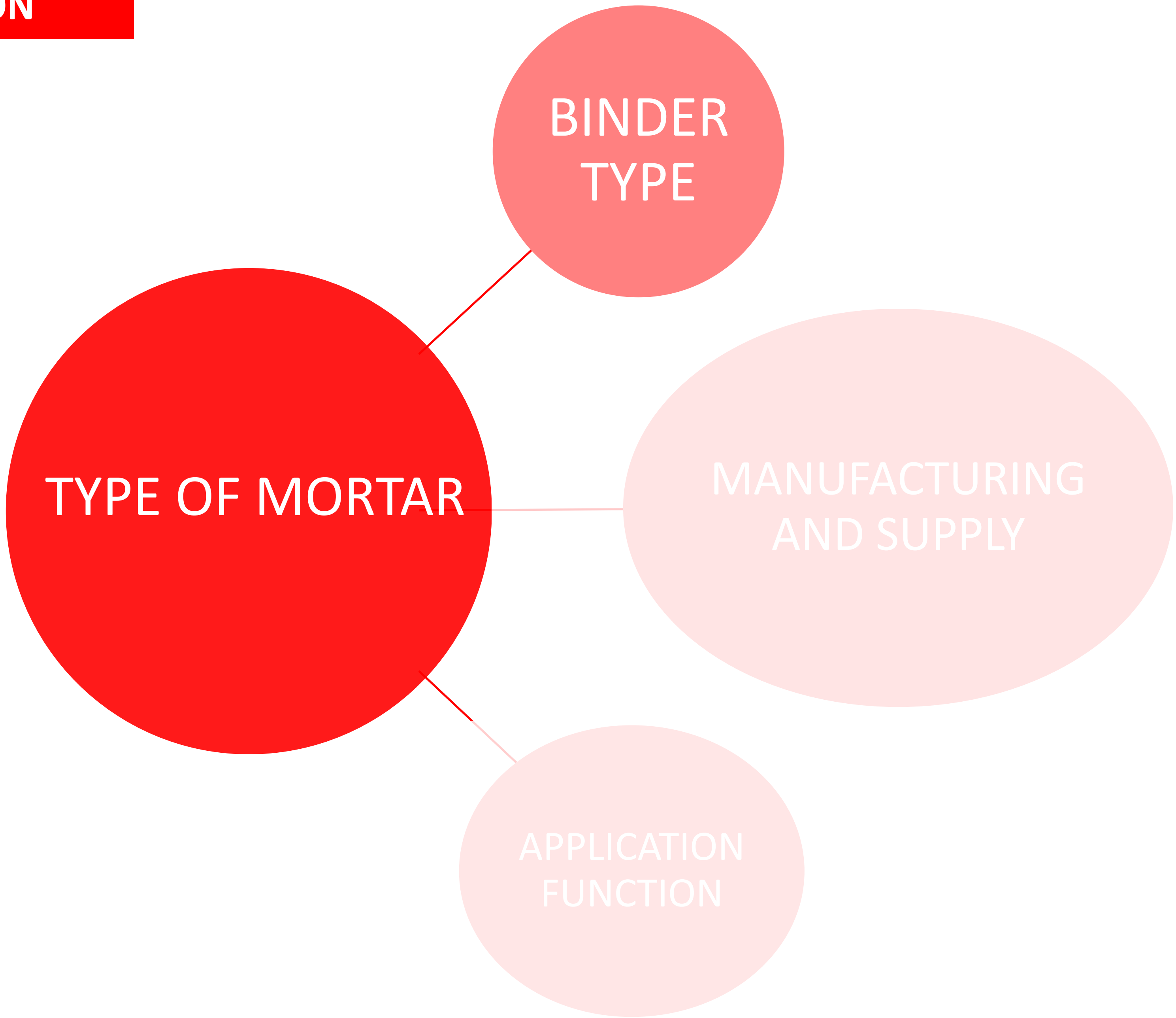
MORTAR CLASSIFICATION



MORTAR CLASSIFICATION



MORTAR CLASSIFICATION

TYPE OF MORTAR

BINDER TYPE

GYPSUM MORTAR

It is one of the most ancient mortars used by man (especially by the Egyptians, 4000-2000 B.C.), due to:

- low calcination temperature
- low hardness
- very fast setting
- fire resistance
- good thermal and acoustic insulation
- high adhesion to substrates

MORTAR CLASSIFICATION

BINDER TYPE

TYPE OF MORTAR

LIME MORTAR

One of the most ancient mortars and used for the longest time throughout history

- Aerial lime mortar

Mortar that hardens by reaction with atmospheric CO_2 in the presence of humidity, forming carbonate. It does not harden under water or in the absence of CO_2

- Hydraulic lime mortar

Mortar that partly sets by reaction with water and partly hardens by reaction with atmospheric CO_2

MORTAR CLASSIFICATION

HOT LIME MORTAR

Traditional method of in-situ mortar manufacture, which consists of slaking quicklime directly with the aggregate.

The quicklime is added to the aggregate in a pre-defined dosage (by volume) and the mixture is kept moist for a period of time before the mixing water is added.

Less water is usually needed compared to a normal mortar. This results in a mortar with higher plasticity when fresh and better mechanical strength when hardened.

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MORTAR CLASSIFICATION

TYPE OF MORTAR

BINDER TYPE

CEMENT MORTAR

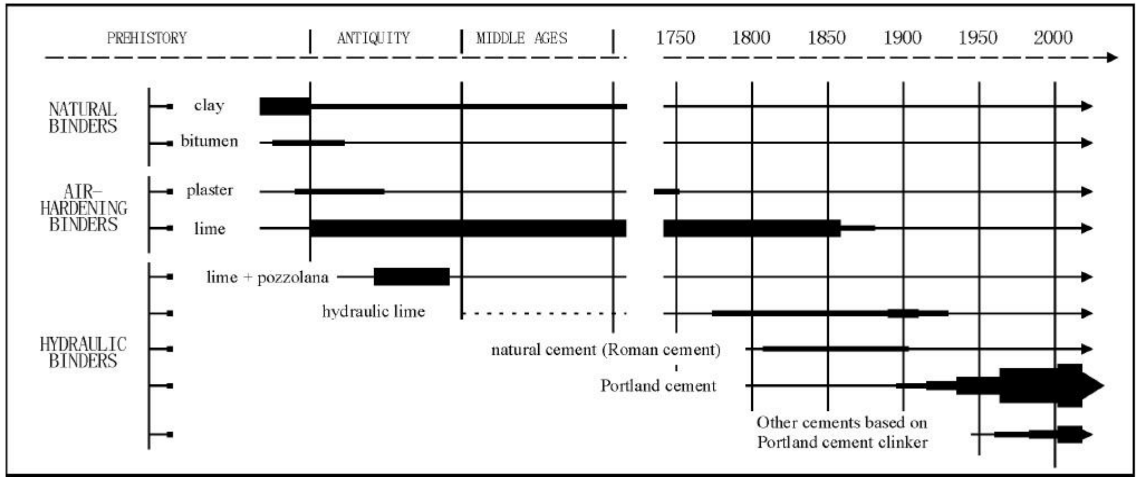
The modern mortar par excellence, which has replaced most mortars in new construction and renovation works

- Natural cement mortar

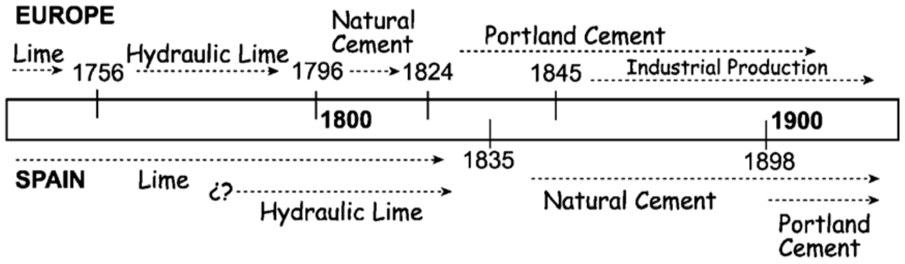
Mortar with hydraulic binder, produced by calcination of carbonate rocks with clay content, at temperatures below sintering temperature

- Portland cement mortar

Portland cement mortar. Set exposed to the air or immersed in water

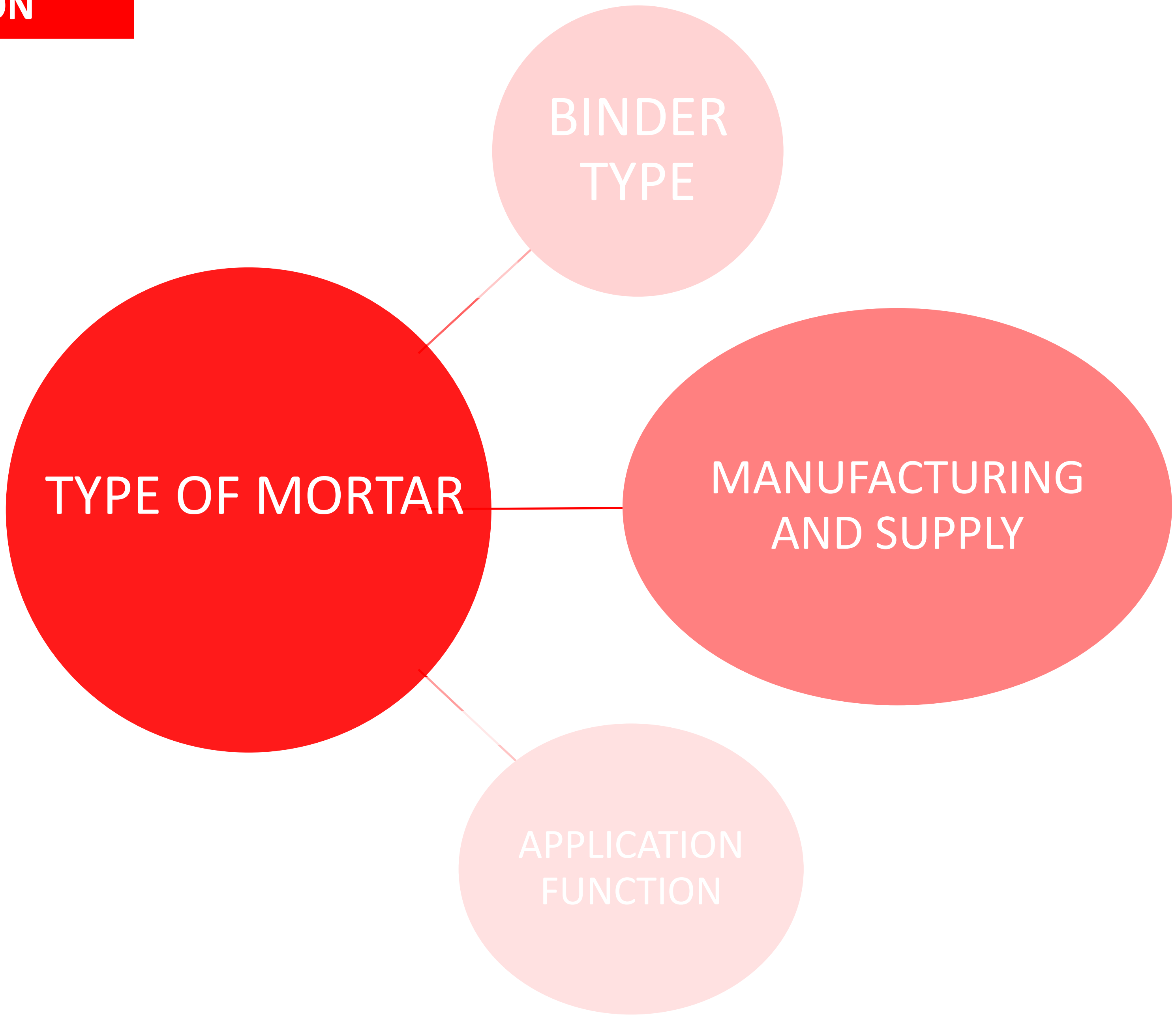


Elsen et al., 2010



Varas et al. (2005)

MORTAR CLASSIFICATION



MORTAR CLASSIFICATION

- **INDUSTRIAL (ready-to-use) MORTAR**

Dosing and mixing are carried out in the factory

TYPE OF MORTAR

MANUFACTURING AND SUPPLY

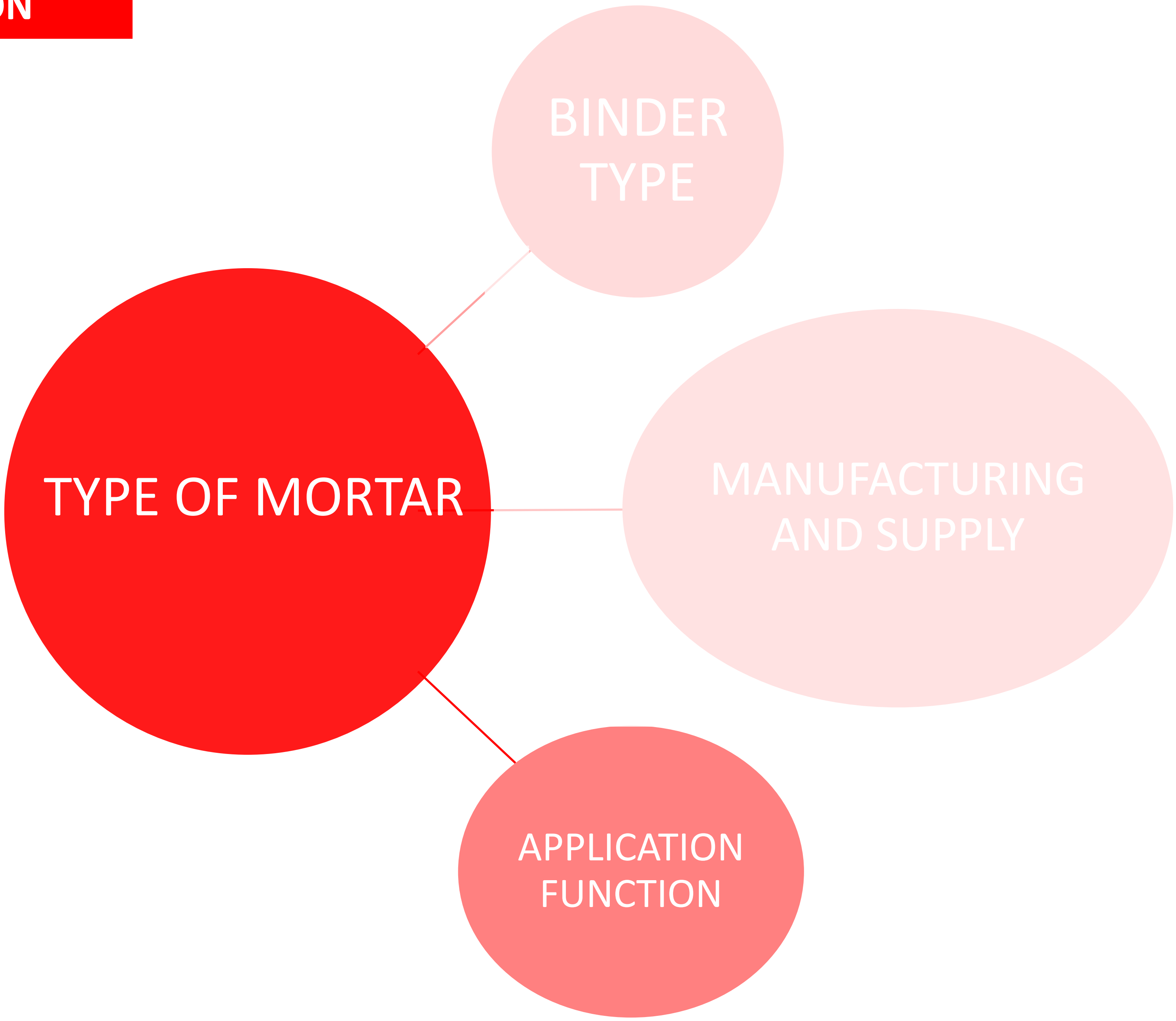
- **MORTAR MADE ON SITE**

Dosing and mixing are carried out on site, it is the handmade mortar

- **PRE-MIXED MORTAR**

It is dosed in the factory and mixed on site

MORTAR CLASSIFICATION



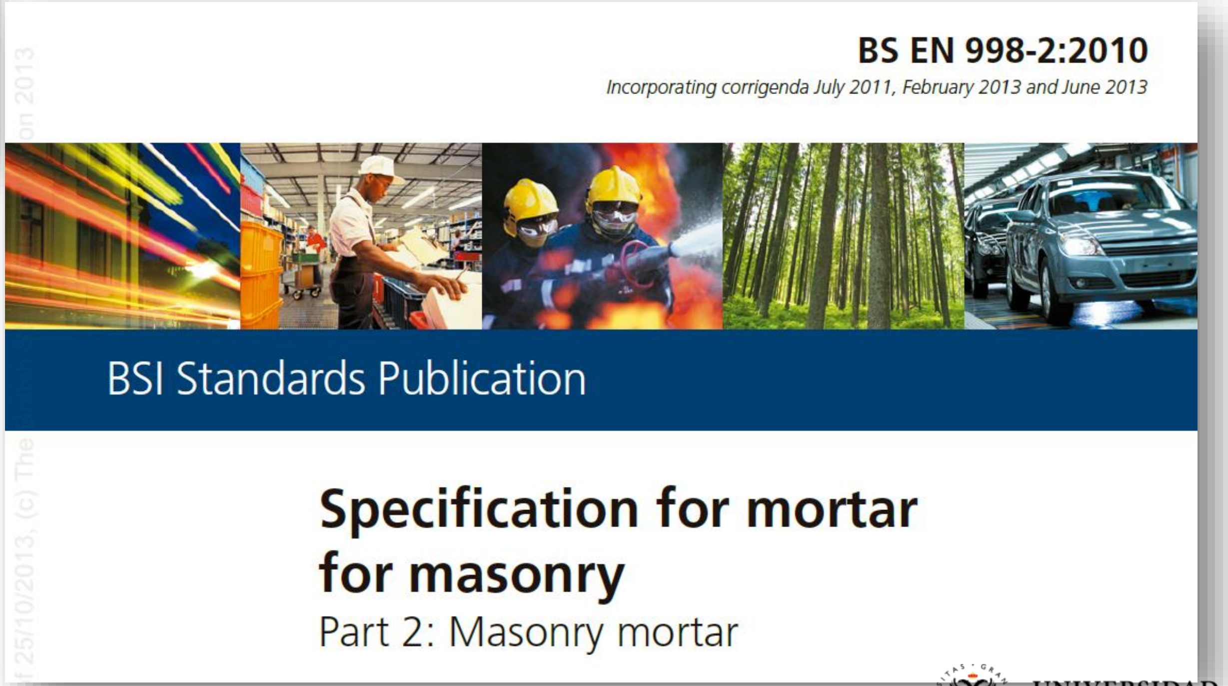
EUROPEAN SPECIFICATIONS FOR MORTAR FOR MASONRY (998-1 AND -2: 2010)


BS EN 998-1:2010

BSI Standards Publication

Specification for mortar for masonry

Part 1: Rendering and plastering mortar


BS EN 998-2:2010

Incorporating corrigenda July 2011, February 2013 and June 2013

BSI Standards Publication

Specification for mortar for masonry

Part 2: Masonry mortar

BUT

These standards have been conceived for CEMENT MORTARS!!

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- **MASONRY MORTAR / STRUCTURAL MORTAR**

Mortar used for masonry, i.e. for joining ashlars and bricks in walls, facades, etc.

TYPE OF MORTAR

APPLICATION FUNCTION

MORTAR CLASSIFICATION

- **REPOINTING MORTAR**

A mortar used to fill joints between ashlars, bricks, etc. where there has been a loss of structural mortar

TYPE OF MORTAR

APPLICATION FUNCTION

MORTAR CLASSIFICATION

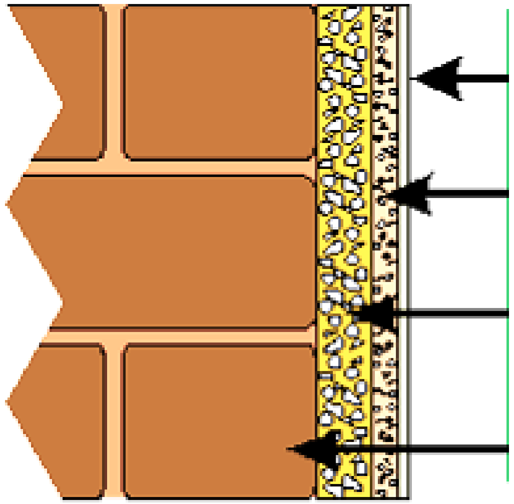
TYPE OF MORTAR

APPLICATION FUNCTION

- **COATING MORTAR/FINISHING MORTAR**
  Mortar used for protective purposes
  It is applied in 1-3 layers

  Mainly with a protective function, or the basis for decoration

  When used on exteriors it is called **rendering**, while on interiors it is called **plastering**



MORTAR CLASSIFICATION

TYPE OF MORTAR

APPLICATION FUNCTION

DECORATIVE MORTAR

Mortar applied for ornamental purposes

- SCRAVING

Sgraffito is a decorative render in which a white layer is applied over a brown, red or black base coat and then scraped off and removed to leave the base coat visible

- STUCCO

It is a mortar for finishing or decorating walls and ceilings, interior or exterior. In addition to its decorative function, it reinforces the wall and waterproofs it, allowing natural transpiration

MORTAR CLASSIFICATION

- **REPAIR MORTAR / RESTORATION MORTAR**

Applied for the purpose of replacing damaged materials on site

TYPE OF MORTAR

APPLICATION FUNCTION

CONTENTS:

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EUROPEAN SPECIFICATIONS FOR THE CHARACTERISATION OF HISTORIC MORTARS (EN 17187: 2020)

BS EN 17187:2020

Conservation of Cultural Heritage. Characterizatio
of mortars used in cultural heritage

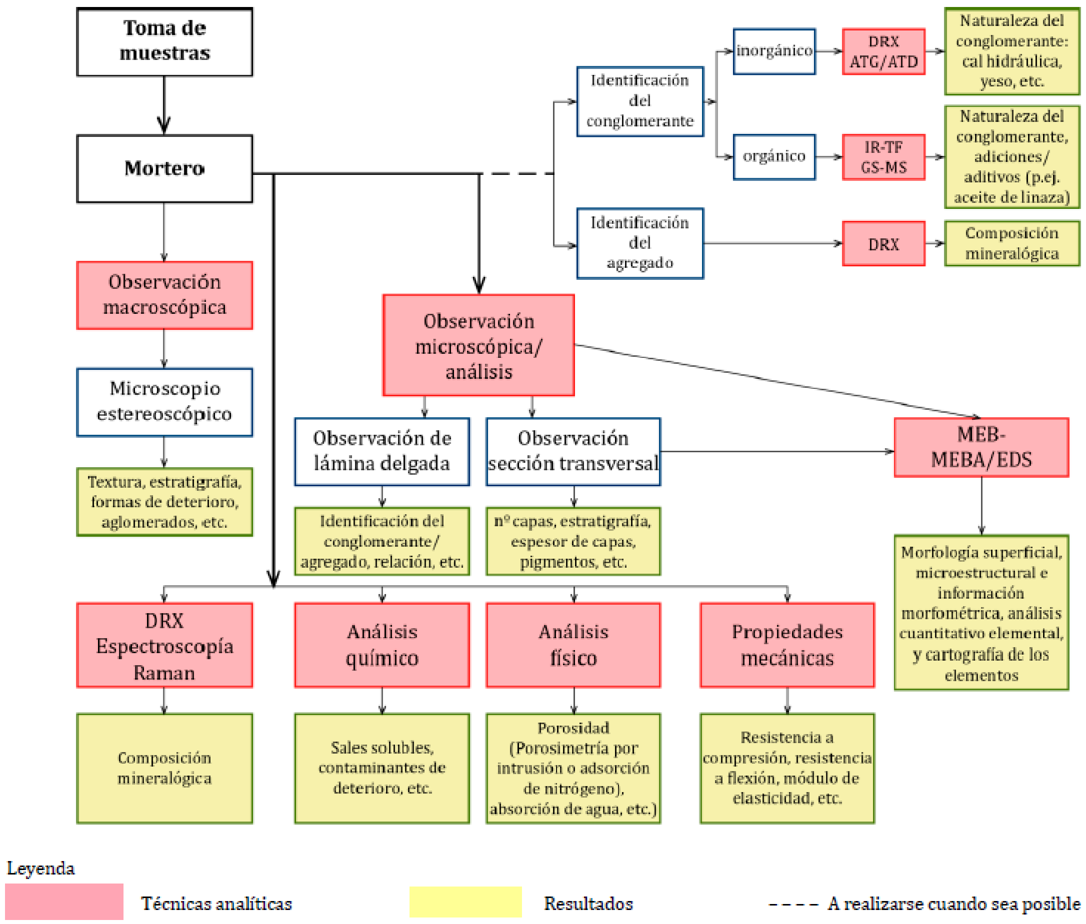

Figura 2 – Caracterización química, mineralógica y petrográfica de los morteros: conglomerante y agregado (s)

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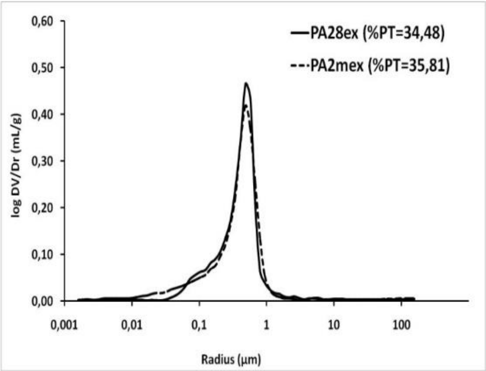
Characterisation of historic mortars

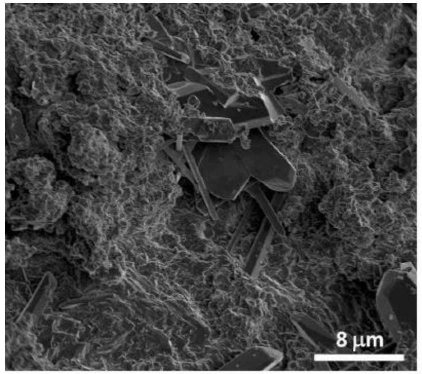
1st PHASE → **Previous bibliographic search** → **Visual inspection and photos** → **Sampling**

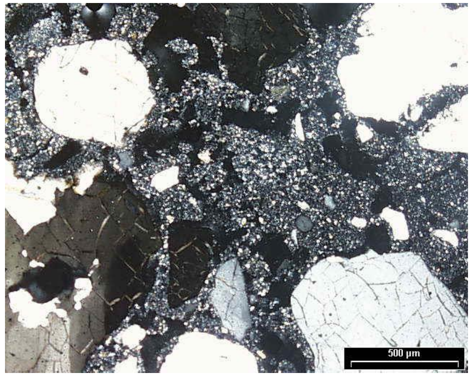
Characterisation of historic mortars

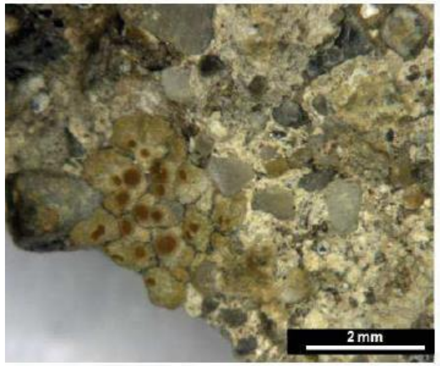
1st PHASE: Previous bibliographic search → Visual inspection and photos → Sampling

2nd PHASE: Chemical-mineralogical characterisation → Petrographic study → Physical study → Dating









Visual inspection and photographing

- Identification of small macro-textural differences that can be used to classify different samples.
- State of conservation / general appearance
- Previous interventions
- Type of deterioration and pathologies

Previous bibliographic research

- Written historical documentation
- Graphic documentation
- Literary sources

Sampling

- Maximum representativeness
- Number of samples (1-3)
- Condition of samples (dust, fragments)
- Sample quantity (few gr)
- Place of sampling (outdoor/indoor)
- Location and description of samples
- Type of sampling (scalpel; hammer; etc.)

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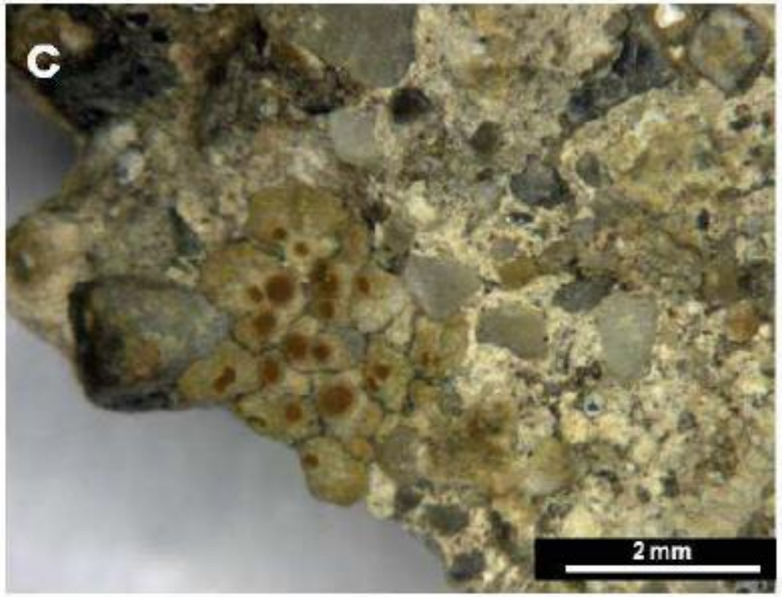
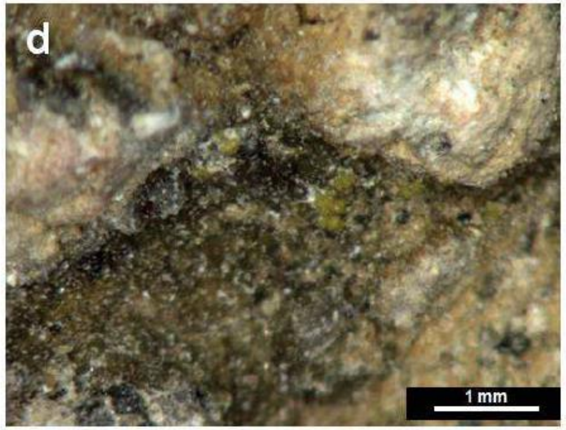
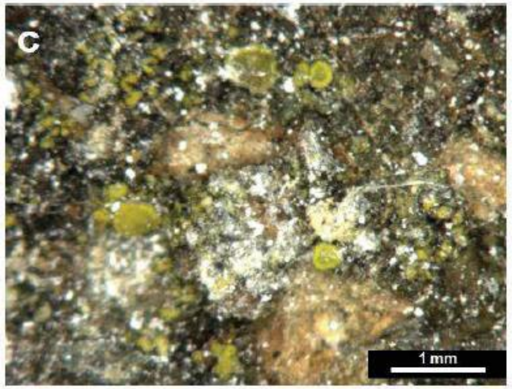
Petrographic characterisation by magnifying loupe (videomicroscope)

- Textural aspects
- Crystalline morphologies
- Porous system
- Presence of alterations
- Treatments







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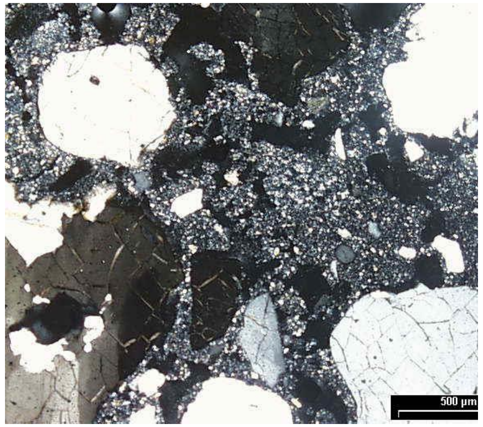
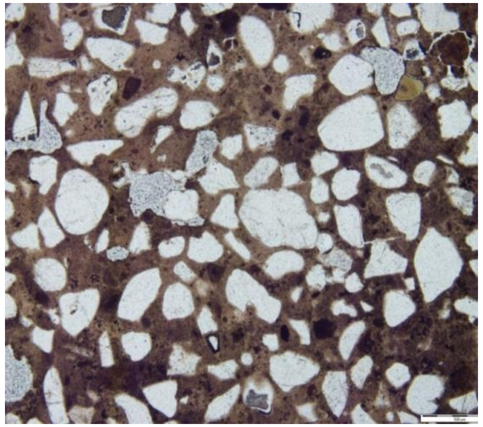
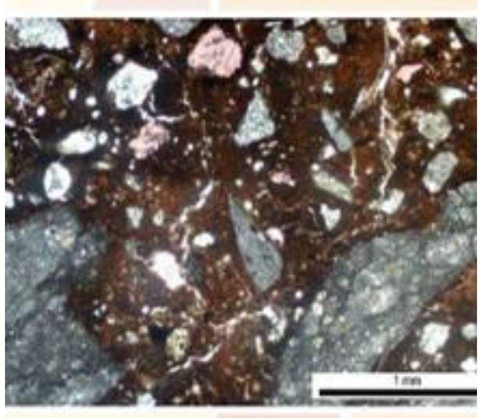
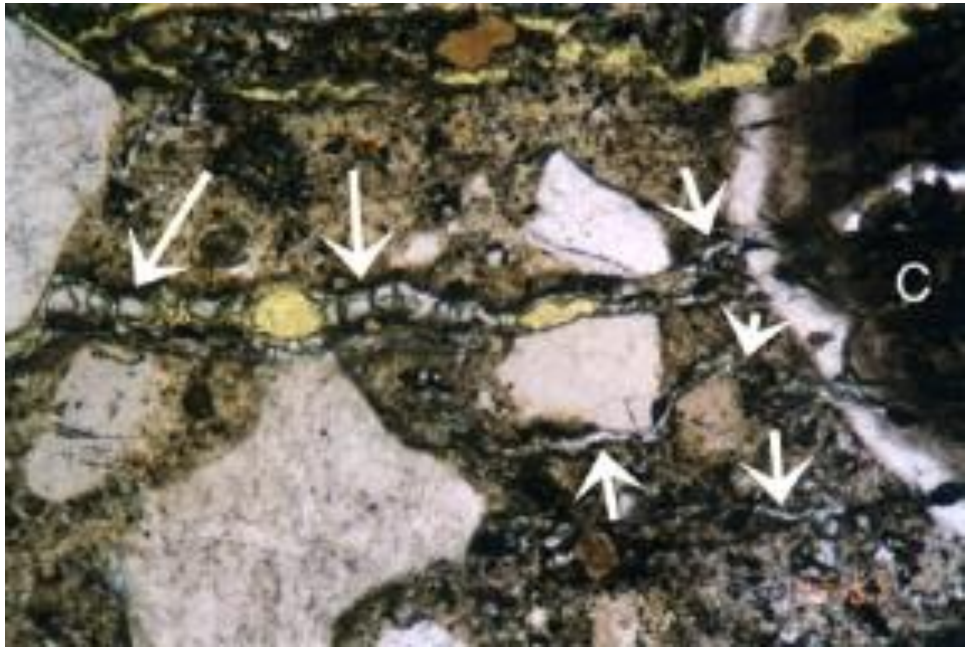
Petrographic characterisation by optical microscopy

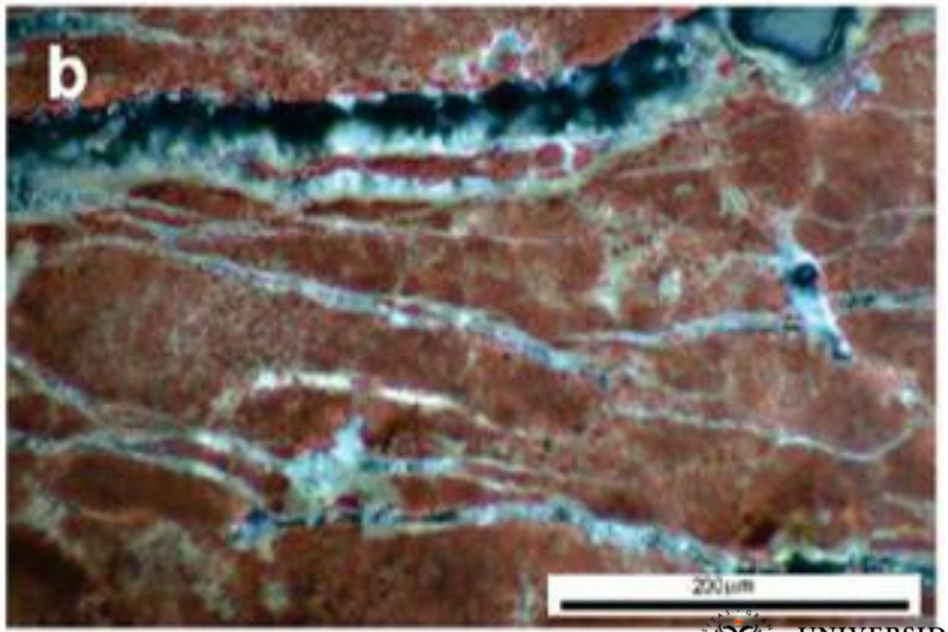
- Identification of mineral phases (by their optical properties)
- Shape, size and particle size distribution of the aggregate
- Porosity (shape and number of pores)
- Shrinkage fissures
- Aggregate:binder dosage
- Alizarin red staining (dolomite/calcite)
- Cement staining with hexacyanoferrate II (hydrated phases of C4AF)
- Identification of lime nodules, charcoal residues, plant fibres, etc.
- Neo-formation phases (crystallisation of salts in fissures)
- Traces of alteration
- Treatments
- Alkali/acid reactivity in cement mortars



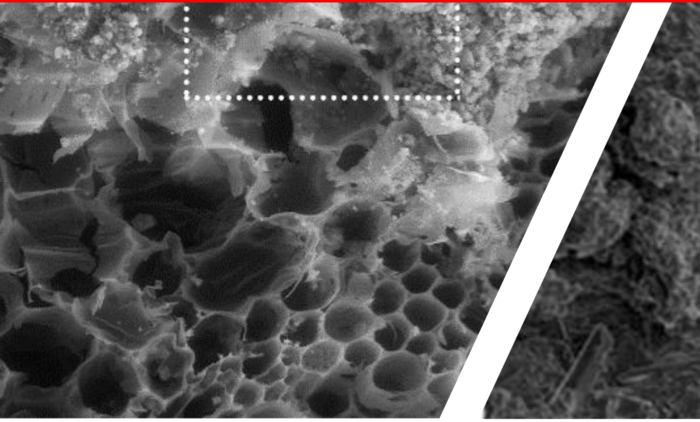


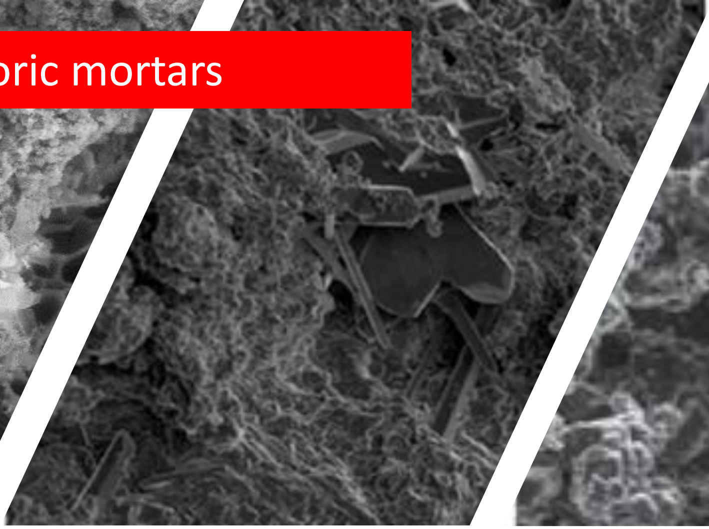


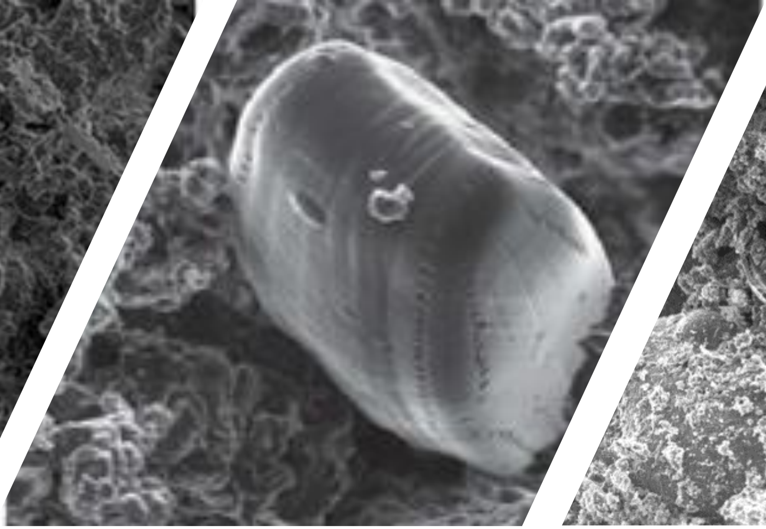


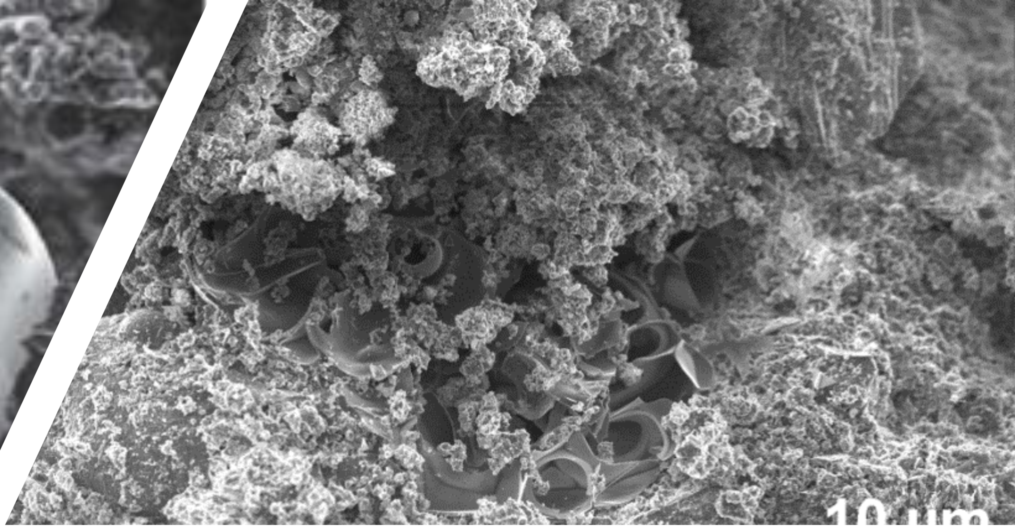


Characterisation of historic mortars



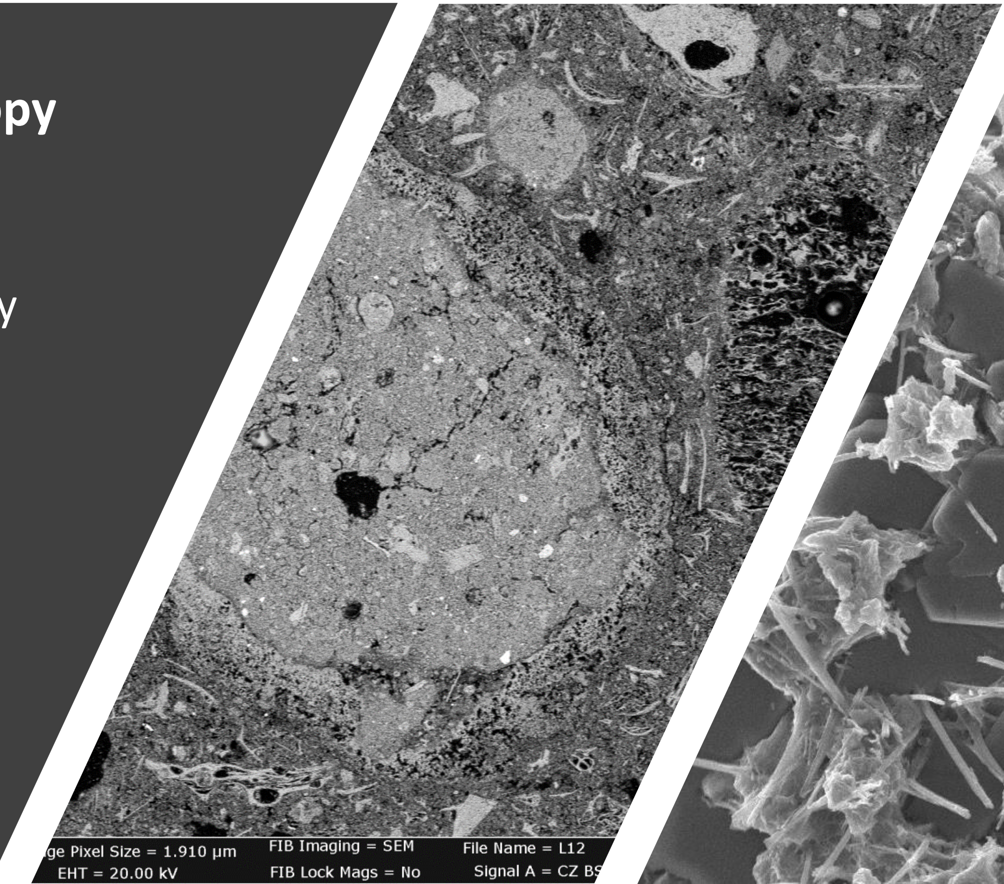


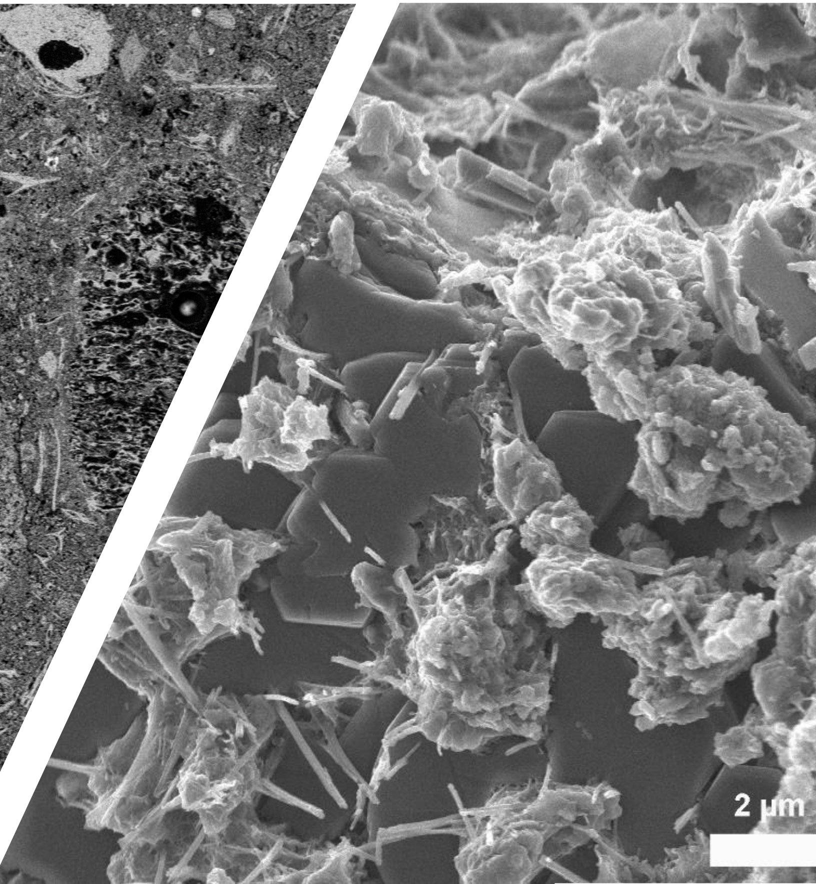




Textural characterisation by electron microscopy (SEM-EDX)

- Identification of mineral phases (by morphology and chemical composition)
- Shrinkage fissures
- Neo-formation phases (crystal growth, crystal morphology and orientation)
- Reaction rings
- Alteration phases (soluble salts)
- Treatments (silica gel, others)





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MORTAR CLASSIFICATION

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REQUIREMENTS FOR RESTORATION MORTARS

DESIGN AND CHARACTERISATION OF RESTORATION MORTARS

Requirements for restoration mortars

- **Compatibility:** The restoration mortar must be compatible with the other masonry elements. This can be ensured by careful selection of mortar components (limes instead of cement; aggregates free of dolomite, chlorides and sulphates; components that do not lead to the formation of soluble salts)
- **Reversibility:** the mortar must be removable if necessary, without damaging existing materials in the factory
- **Durability:** the characteristics of a mortar also depend on the climatic conditions to which it is exposed, so it is necessary to design mortars according to the place where it will be applied, to ensure good durability on site

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Requirements for restoration mortars

"Compatible is defined as: not causing any damage (in a broad sense, ranging from technical to aesthetical and historical) to the existing fabric and being as durable as possible under that condition"
(Van Hees 2010)

Requirements for restoration mortars

- It is necessary to establish the required characteristics of the mortar, depending on its use…

- BUT.. these characteristics may vary once applied, depending on the materials with which the mortar is in contact. For example, the same coating mortar may have different degrees of shrinkage and adhesion if applied on substrates with different water absorption capacity.

Requirements for restoration mortars

"A mortar repair action can be classified by the function of the mortar, constrained by the typology of the masonry itself and influenced by the choice of binder type"
(Hughes 2010)

Requirements for restoration mortars

Restoration mortars must be compatible with the pre-existing structures, as well as effective and durable enough to ensure the long-term stability of the intervention.

RILEM TC REPORT

RILEM TC 277-LHS report: lime-based mortars for restoration–a review on long-term durability aspects and experience from practice

Caspar Groot · Rosario Veiga · Ioanna Papayianni · Rob Van Hees · Michele Secco · José I. Alvarez · Paulina Faria · Maria Stefanidou

Requirements for restoration mortars

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Restoration mortars must be compatible with the pre-existing structures, as well as effective and durable enough to ensure the long-term stability of the intervention.

For conservation interventions on lime-based masonry walls, there are a limited number of mortar solutions, such as:

i) pure aerial lime mortars

ii) air lime mortars-pozzolan mortars

iii) natural hydraulic lime (NHL) mortars

Solutions (i) and (ii) are the closest to the original ones.

The main reason is that their hydraulic and mechanical behaviour (strength and ductility) is easily adapted to most of the existing historical masonry.

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LIME vs CEMENT

Characteristics and properties	LIME MORTAR	CEMENT MORTAR
Burning T (ºC) of the raw material	800-1200	>1400
Setting / Hardening	slow	quick
Shrinkage	Medium to high	high
Water vapour permeability	high	Low/none
Stifness	Low/none	high
Soluble salts	none	Ettringite, thaumasite, etc.
Reversibility	YES	NOT

NOT SUITABLE FOR RESTORATION!!

Lime-based mortars for restoration

Although the basic suitability of lime-based mortars for restoration is undisputed, there are also some drawbacks in the application of these mortars, which must be taken into account to avoid problems.

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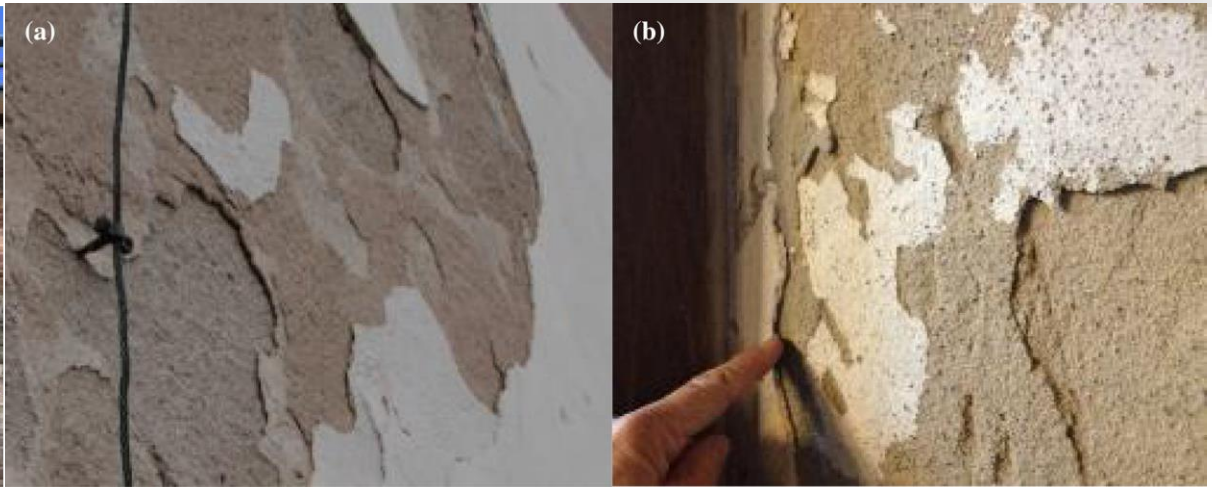

Lime-based mortars for restoration

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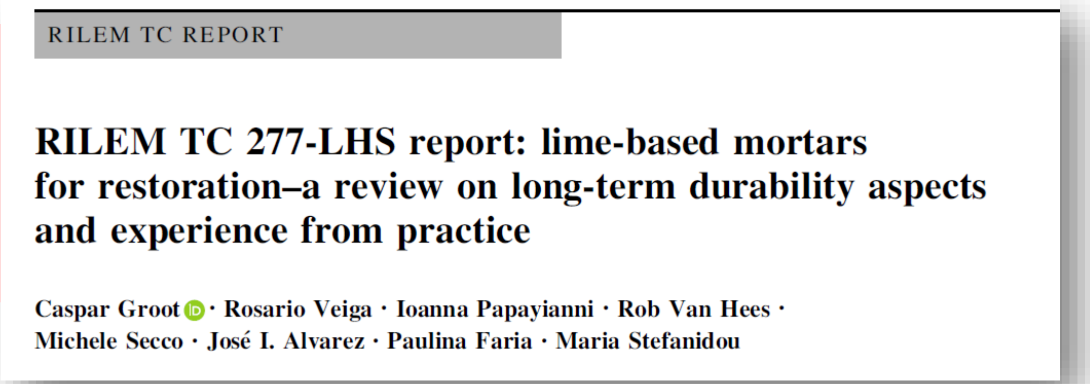
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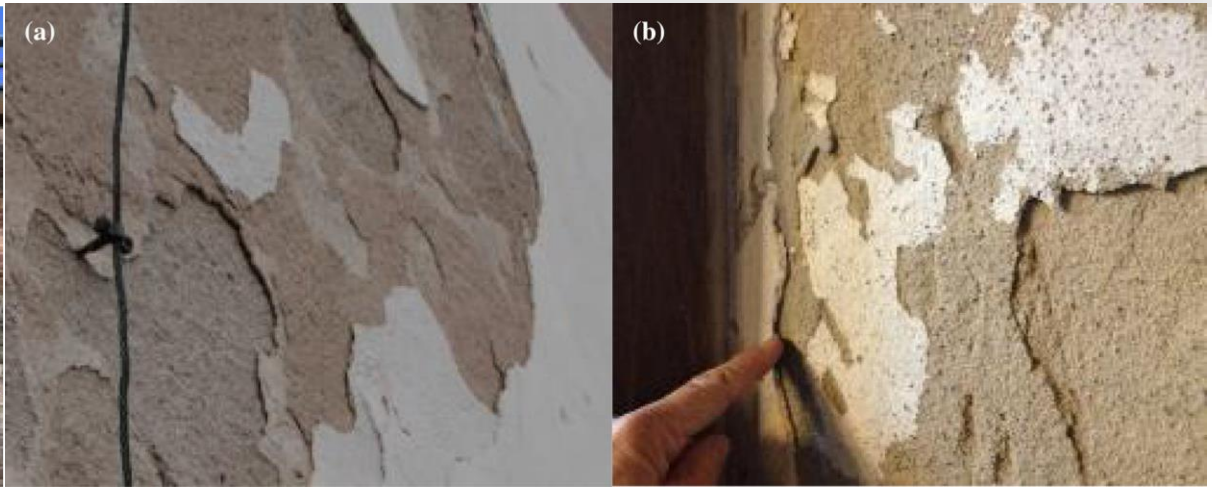

Most of the above mentioned drawbacks and points of attention can be addressed by assessing the performance of lime-based mortars in relation to the expected exposure conditions and testing their suitability, preferably using in-situ test panels. In addition, adverse application conditions should be avoided.

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1
- MORTAR IN THE FRESH STATE

2
- MORTAR DURING SETTING

3
- MORTAR ONCE HARDENED

Design and characterisation of restoration mortars

FRESH

DURING SETTING

HARDENED

This is the phase in which the mortar is mixed with water, forming a plastic and workable mass, which allows it to be used on site. The duration of this phase depends on:

- Composition
- Dosages
- Amount of mixing water
- Temperature and humidity conditions

The properties of the mortar that need to be controlled during this stage are:

- Workability time (period of time during which the mixture is workable and can be applied)
- **Consistency**
- Adhesion
- Water-retaining capacity

Design and characterisation of restoration mortars

FRESH

DURING SETTING

HARDENED

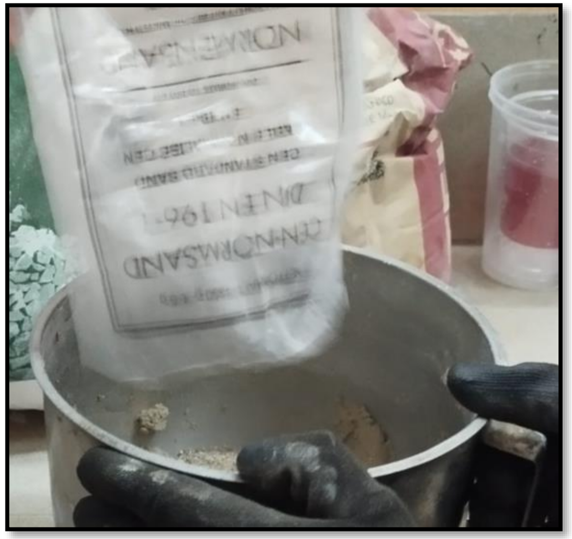
This is the phase in which the mortar loses water (drying) and sets until it hardens. During the setting and hardening processes, the properties of the mortar are constantly changing. The properties of mortars that need to be monitored are:

- **Shrinkage**
- **Mineralogical changes**
- **Micro-structural changes**
- **Physical-mechanical evolution**

3.1.10
Hardening (en)
durcissement (fr)
Erhärten (de)
verharden (nl)
indurimento (it)
σκλήρυνση (gr)
hårdnande (se)
strength development that follows the setting of the mortar

3.1.8
setting (en)
prise (fr)
abbinden (de)
zetten (nl)
presa (it)
πήξη (gr)
bindning (se)
process through which the mortar changes from a workable plastic state to an unworkable stiffer state with very slight measurable strength

Laboratory manufacture of mortar specimens according to EN 196-1 2018



EUROPEAN STANDARD
NORME EUROPÉENNE
EUROPÄISCHE NORM

EN 196-1

April 2016

ICS 91.100.10

Supersedes EN 196-1:2005

English Version

Methods of testing cement - Part 1: Determination of strength

Méthodes d'essais des ciments - Partie 1: Détermination des résistances

Prüfverfahren für Zement - Teil 1: Bestimmung der Festigkeit

EN 196-1:2016 (E)

1 Scope

This part of EN 196 describes the method for the determination of the compressive and, optionally, the flexural strength of cement mortar. The method applies to common cements and to other cements and materials, the standards for which call up this method. It may not apply to other cement types that have, for example, a very short initial setting time.

The method is used for assessing whether the compressive strength of cement is in conformity with its specification and for validation testing of a CEN Standard sand, EN 196-1, or alternative compaction equipment.

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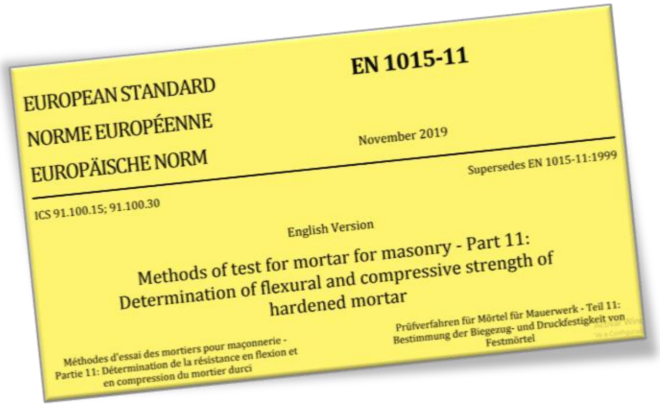
Inconsistencies in European regulations



✓Curing time (5 or 7 days?)

✓ Curing conditions inside and outside the mould (RH?)

Tabla 1
Preparación y condiciones de conservación de las probetas

Tipo de mortero	Preparación	Duración de la conservación a una temperatura de 20 °C ± 2 °C, en días		
		Humedad relativa		
		95% ± 5% o en una bolsa de polietileno		65% ± 5%
		En el molde	Una vez que se ha retirado el molde	Una vez que se ha retirado el molde
Morteros de cal aérea	7.2.3	5	2	21
Morteros de cal aérea/cemento en los que la masa de cemento no es superior al 50% de la masa total de conglomerante	7.2.3	5	2	21
Morteros de cemento y de cal aérea/cemento en los que la masa de cal aérea no es superior al 50% de la masa total de conglomerante	7.2.2	2	5	21
Morteros con otros conglomerantes hidráulicos	7.2.2	2	5	21
Morteros retardados	7.2.2	5	2	21

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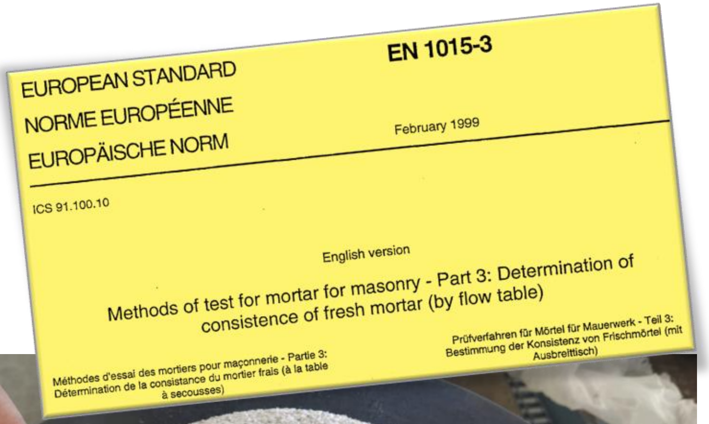
Laboratory manufacture of mortar specimens according to EN 1015-3

Mortar consistency

- It can be determined by standard methods (Abram's cone; flow table) and non-standard methods (estimated from rheological measurements on the binder)
- The **FLOW TABLE TEST** (EN 1015-3) enables establishing the amount of water necessary to obtain a workable mix
- It is difficult to establish the most suitable flow range for mortars, as this characteristic depends on the components and dosage of the mortar



EUROPEAN STANDARD
NORME EUROPÉENNE
EUROPÄISCHE NORM

EN 1015-3

February 1999

ICS 91.100.10

English version

Methods of test for mortar for masonry - Part 3: Determination of consistence of fresh mortar (by flow table)

Méthodes d'essai des mortiers pour maçonnerie - Partie 3: Détermination de la consistance du mortier frais (à la table à secousses)

Prüfverfahren für Mörtel für Mauerwerk - Teil 3: Bestimmung der Konsistenz von Frischmörtel (mit Ausbreittisch)

Introduction

Fresh mortar is brought to a defined level of consistence as measured using the flow table prior to the assessment of those properties which are used to characterise it.

Consistence is a measure of the fluidity and/or wetness of the fresh mortar and gives a measure of the deformability of the fresh mortar when subjected to a certain type of stress. The consistence however is not directly associated with the manner in which the fresh mortar handles when used by a craftsman.

Normally there will be a linear correlation between flow value, measured in accordance with this test method, and the plunger penetration value measured in accordance with EN 1015-4, for the same type of mortar with increasing water content, but the slope will differ with different type of mortars.

1 Scope

This European Standard specifies a method for determining the consistence of freshly mixed mortars (in the following briefly referred to as fresh mortars) including those containing mineral binders and both normal weight and lightweight aggregates, which is by means of the flow value.

Inconsistencies in European regulations

Uncertainty about the most appropriate flow range for lime mortars:

EUROPEAN STANDARD
NORME EUROPÉENNE
EUROPÄISCHE NORM

EN 1015-2

October 1998

ICS 91.100.10

Descriptors: masonry work, mortars: materials, sampling, preparation, batching, packing, certification

English version

Methods of test for mortar for masonry - Part 2: Bulk sampling of mortars and preparation of test mortars

Méthodes d'essai des mortiers pour maçonnerie - Partie 2: Echantillonnage global des mortiers et préparation des mortiers d'essai

Prüfverfahren für Mörtel für Mauerwerk - Teil 2: Probenahme von Mörteln und Herstellung von Prüfmörteln

- EN 1015-3: for any type of mortar, the flow is defined as a function of the bulk density of the mixture when fresh (**110-185 mm**);

- AFAM report, 2003: describes three types of mortars:

1. dry (flow<140 mm)
2. plastic (**140<flow<200 mm**)
3. liquid (flow>200 mm)

- Possibility of air entrapment in the mortar paste

6.2 Mixing the mortar

6.2.1 General

Fresh mortar used for the purpose of testing and preparing specimens for tests shall, as far as possible, have the consistence appropriate for its use. Unless otherwise specified, bring the fresh mortar sample to a defined flow value as specified in table 2, and determined in accordance with prEN 1015-3. The water content needed to achieve this consistence is determined by the use of trial mixes.

Table 2: Defined flow value for various types of mortar related to the bulk density of fresh mortar

Bulk density of fresh mortar (kg/m^3)	Flow value (mm)
> 1 200	175 ± 10
>600 to ≤1 200	160 ± 10
>300 to ≤ 600	140 ± 10
≤300	120 ± 10

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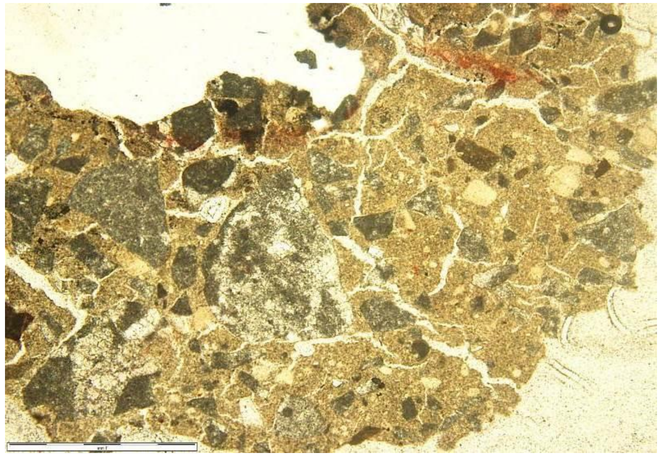
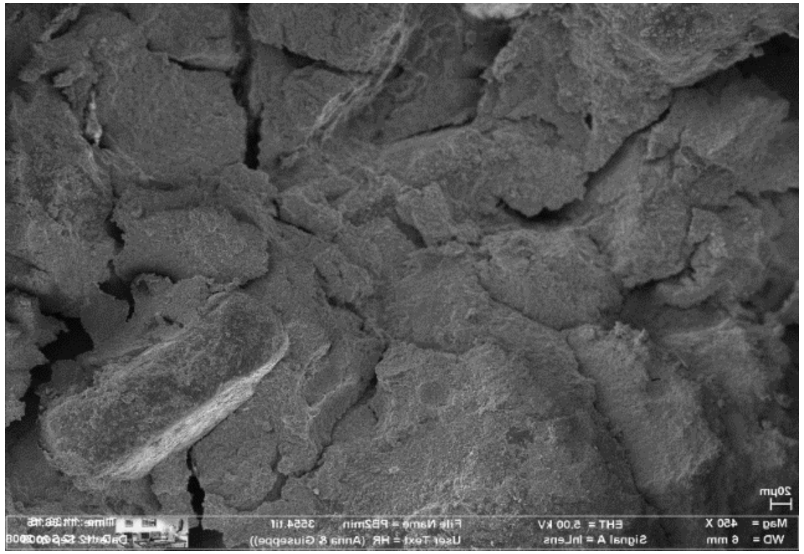
Shrinkage of mortars





Contraction due to a decrease in volume during the setting process and the beginning of hardening, caused by the rapid evaporation of water

It is identified by the characteristic erratic fissures appearing on the surface of the mortar

If it is very pronounced, it can affect the waterproofing by leaving open water penetration routes. Shrinkage increases the higher the amount of lime, water and fines in the mortar

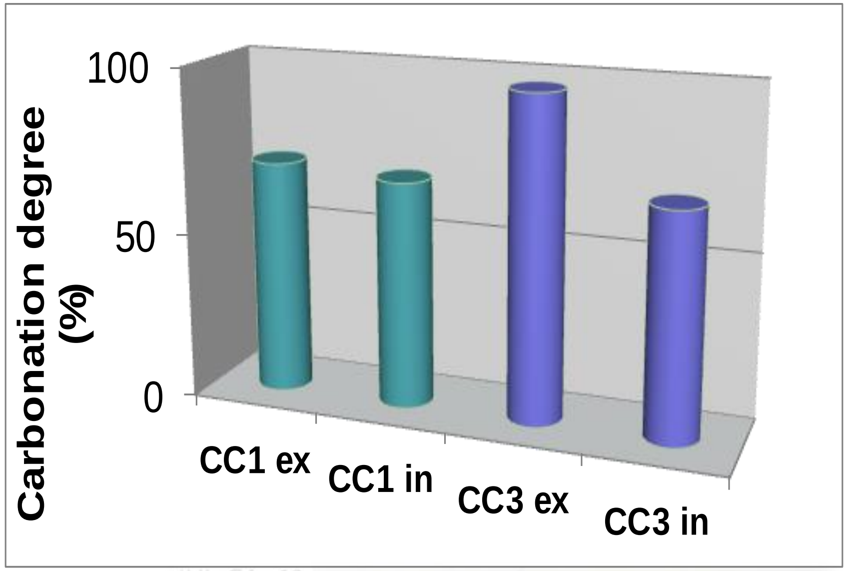
Mortar evolution during hardening

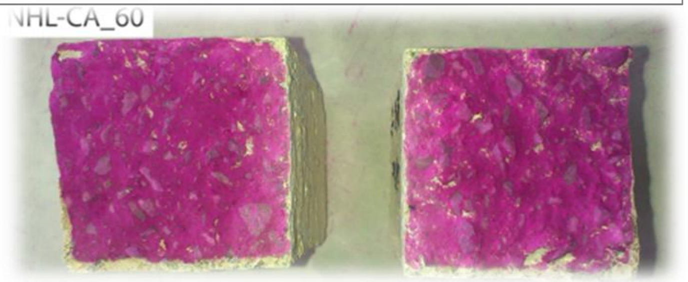
Mineralogical study by XRD and TGA

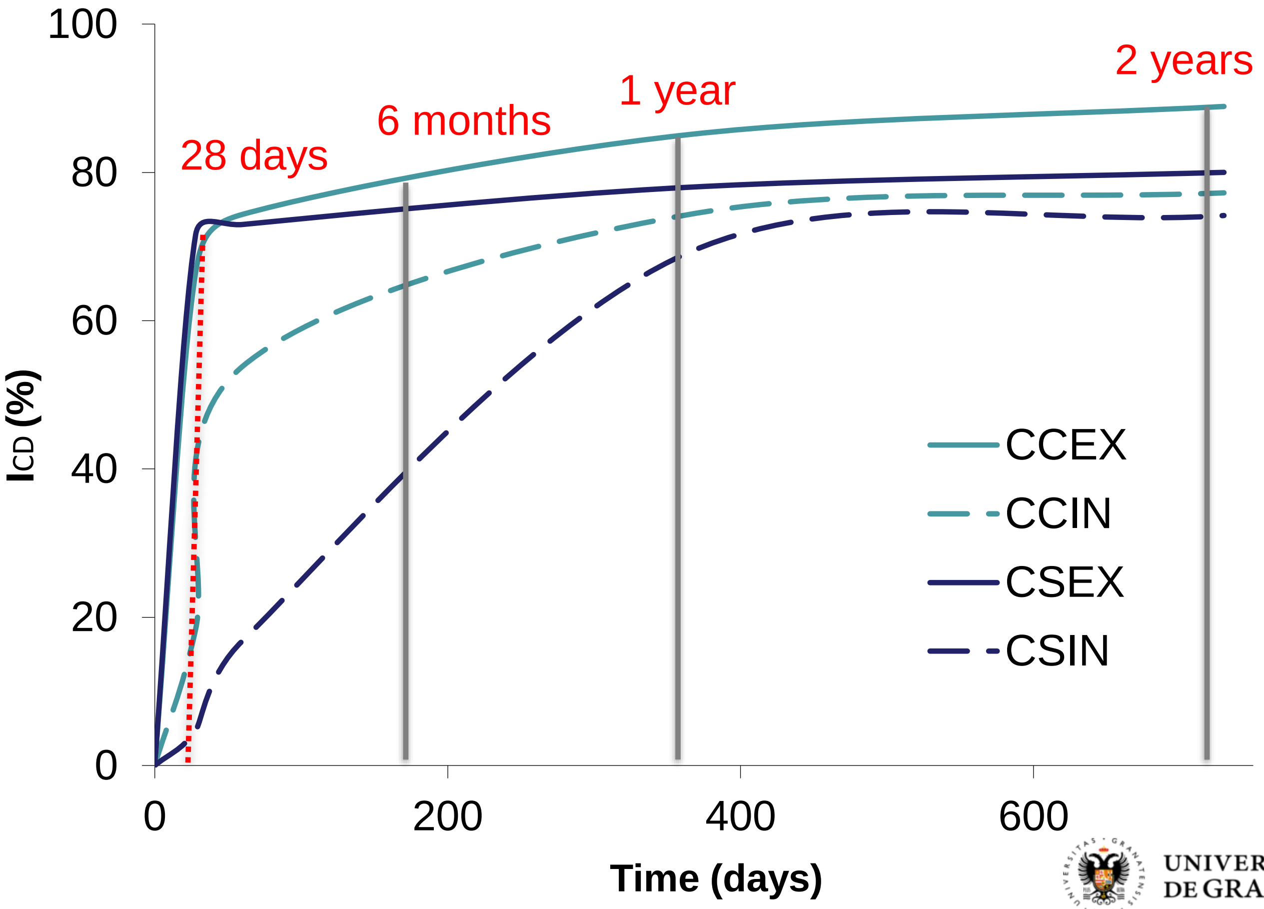
The degree of carbonation (I_{CD}, in %) of a mortar is measured by considering the decrease of the portlandite content (which is transformed into calcite), according to the ratio:

$$I_{CD} = \frac{CH_0 - CH_x}{CH_0} \times 100$$

Arizzi & Cultrone 2013







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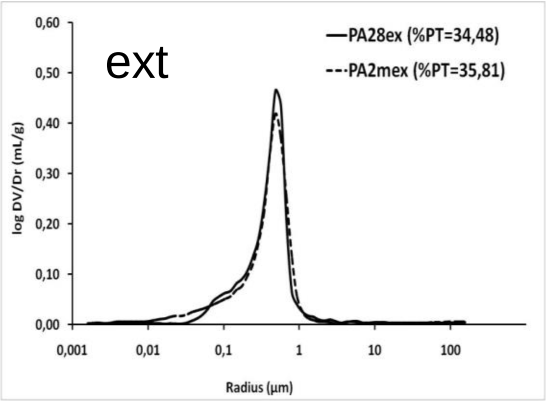
Mortar evolution during hardening

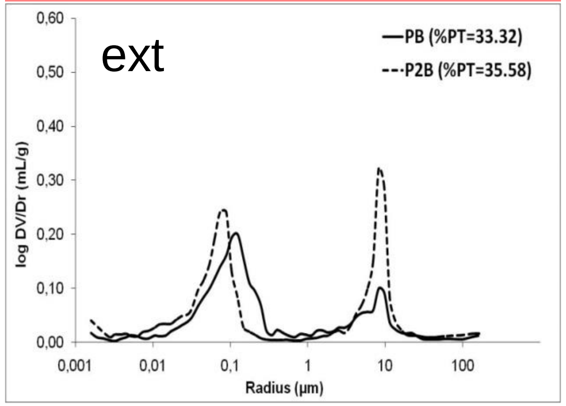
Porosity study by MIP

The porosity (Po, in %) and pore size distribution (PSD) varies according to the composition and dosage of the mortar:

Calcitic lime mortar

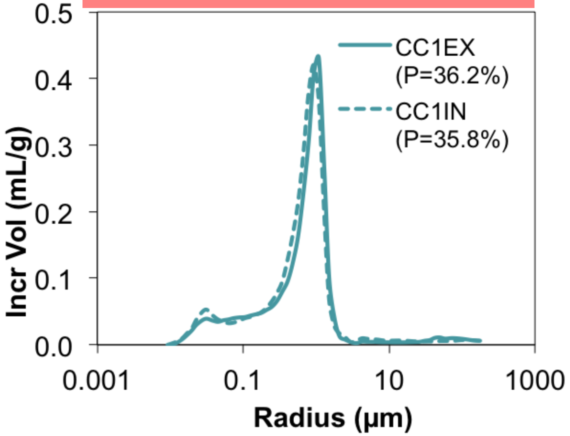


Dolomitic lime mortar

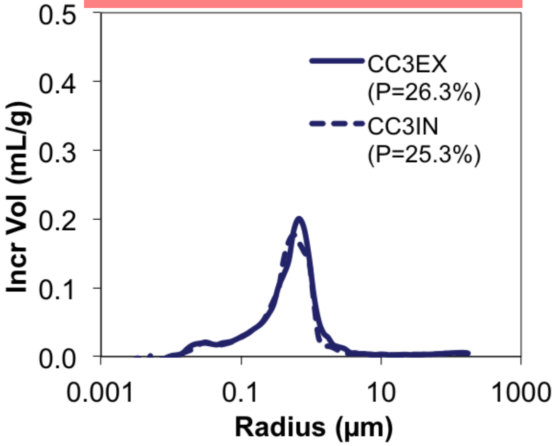


Arizzi & *Cultrone* 2012

1:1 lime:sand



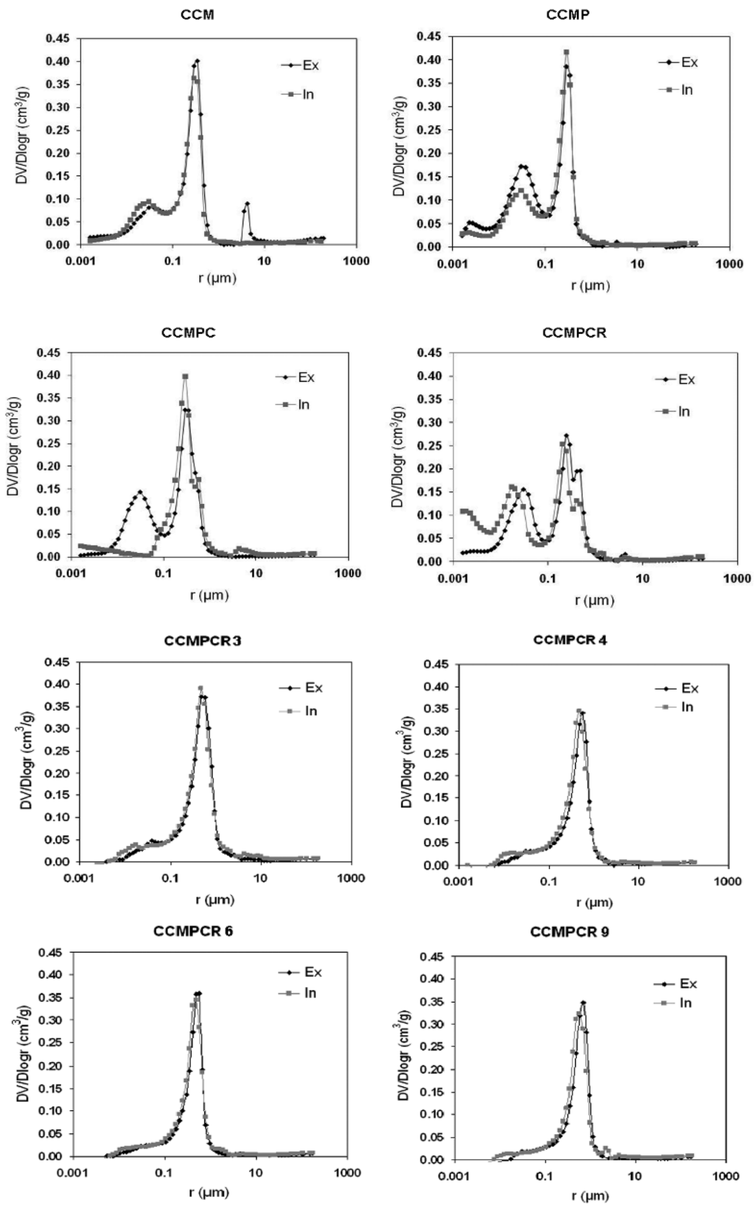
1:3 lime:sand



Arizzi & *Cultrone* 2014

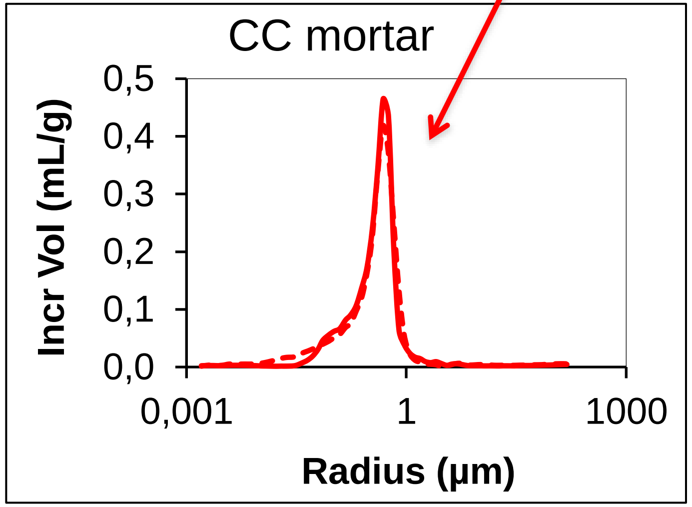
Mortar evolution during hardening

Modification of the pore system of lime mortars with metakaolin



Lime mortars with 20% of MK

Lime mortars with 10% of MK



Arizzi & Cultrone 2012

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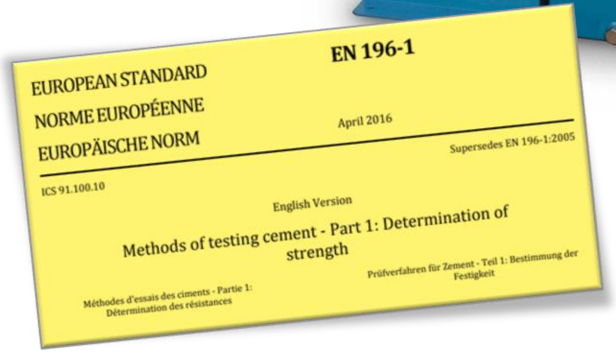
Mortar evolution during hardening

Mechanical study

The factors influencing the mechanical properties of mortars are:

- Type of binder (aerial or hydraulic)
- Dosage (lime:water and lime:sand)
- Setting time



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April 2016

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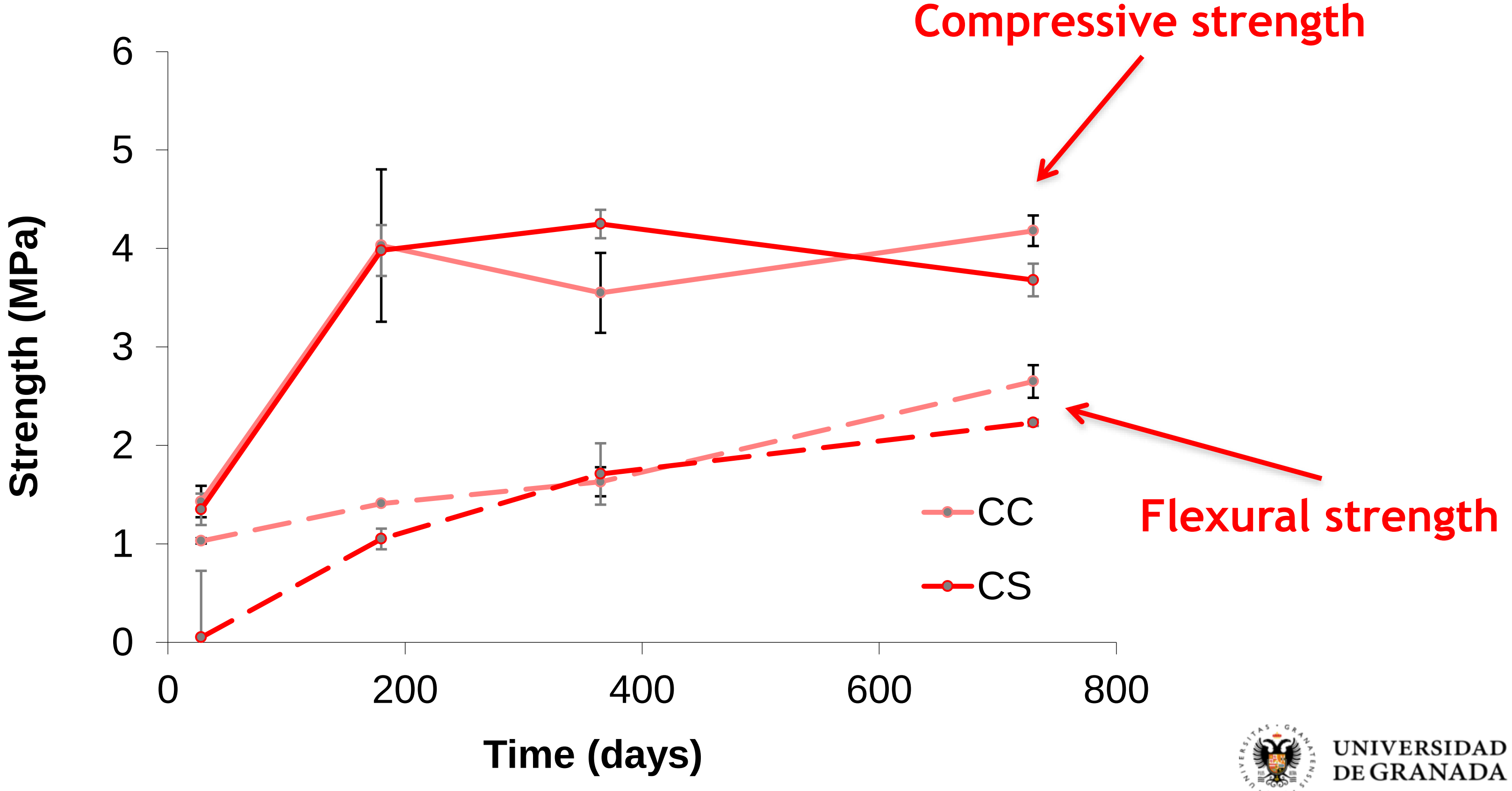

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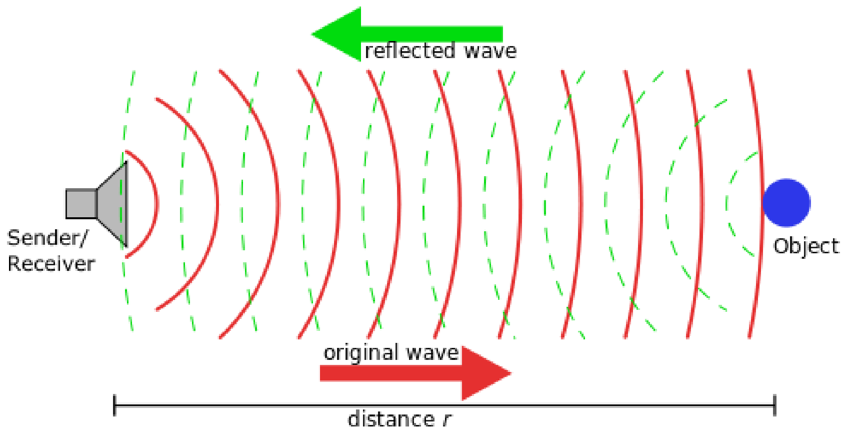
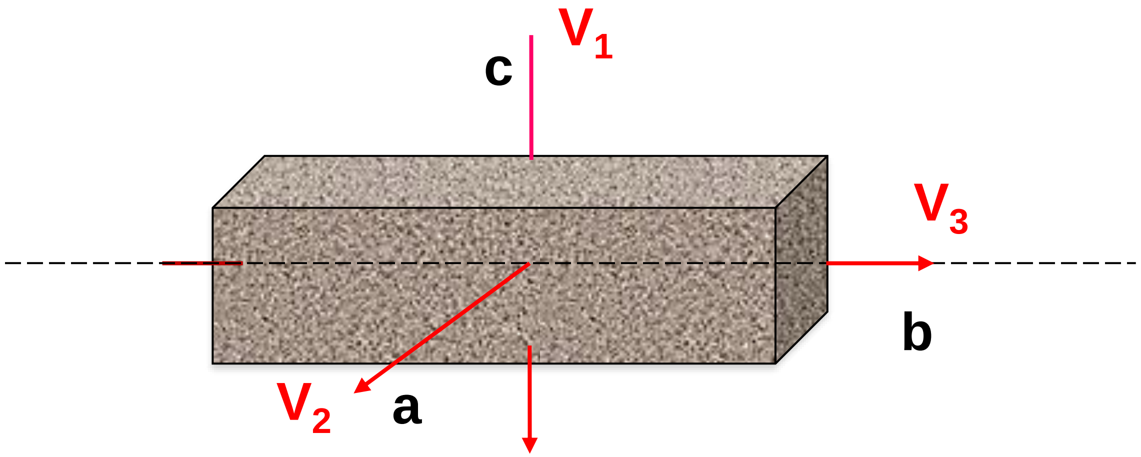
Ultrasounds velocity measurements

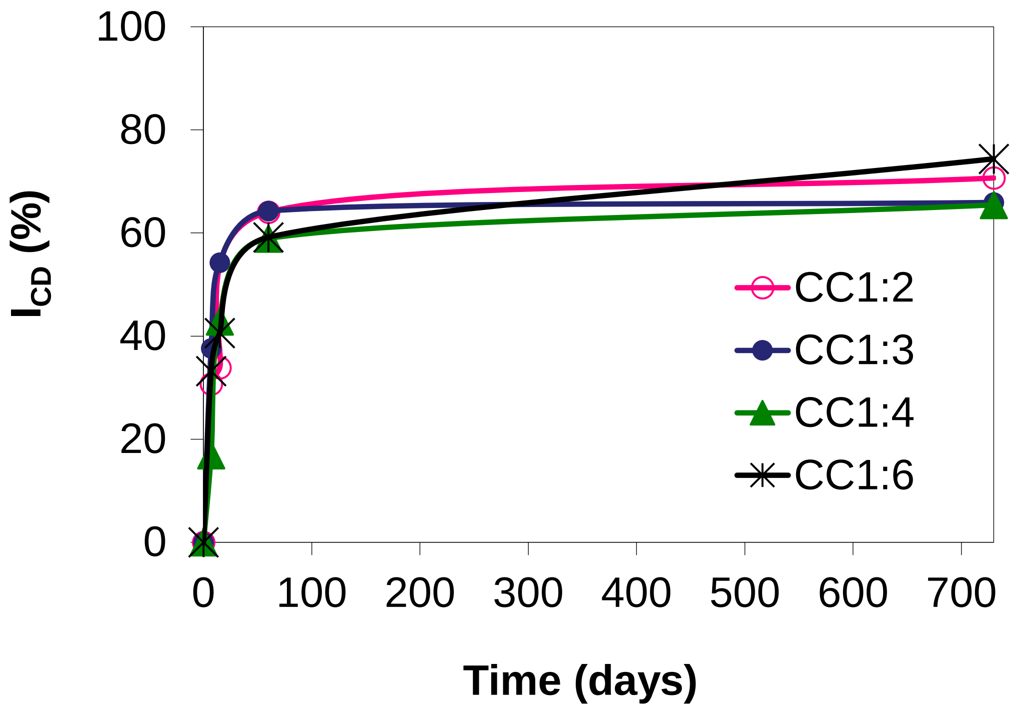
It is a non-destructive test to evaluate the increase in density and mechanical strength of mortars during setting. The factors influencing the speed of ultrasonic propagation through a mortar are both extrinsic and intrinsic to the material:

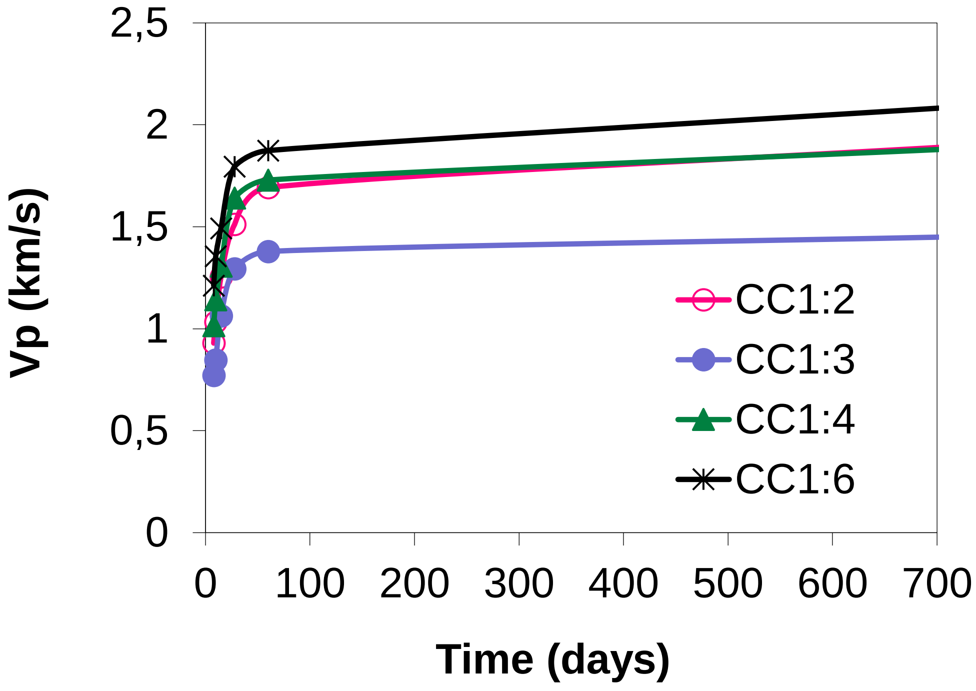
- density
- porosity
- mineralogy
- texture
- moisture





Increase of Vp during carbonation of aerial lime mortars





Hydric properties

Factors influencing the water behaviour of mortars are:

- characteristics of the pore system (open porosity, pore size and shape, connectivity between pores)
- setting time
- environmental conditions

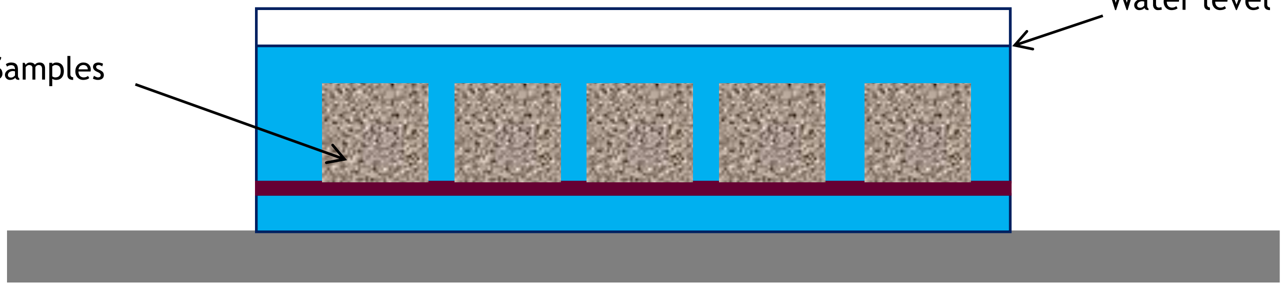
The most commonly applied standards for the study of the hydric properties of mortars are:

RILEM: refer to construction materials for historic buildings.

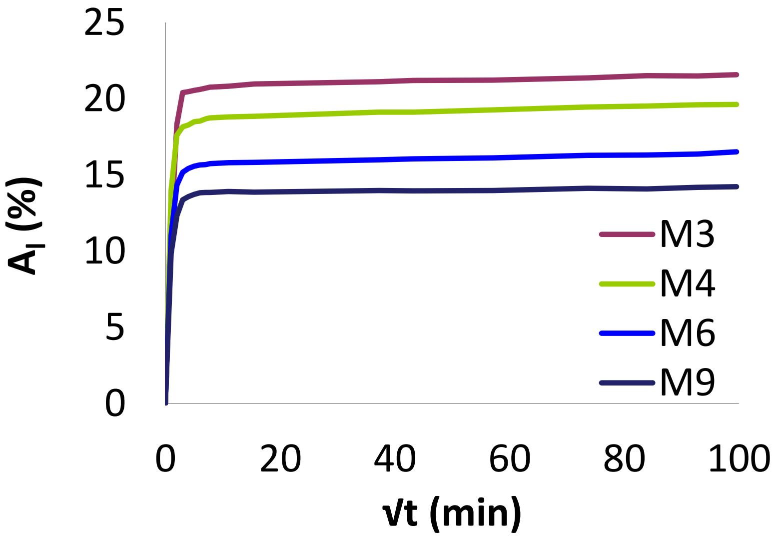
NORMAL: defined for materials constituting works of art (stone)

EN and ASTM: European and American standards. They regulate all types of materials. In the case of mortars, they refer mainly to cement mortars.

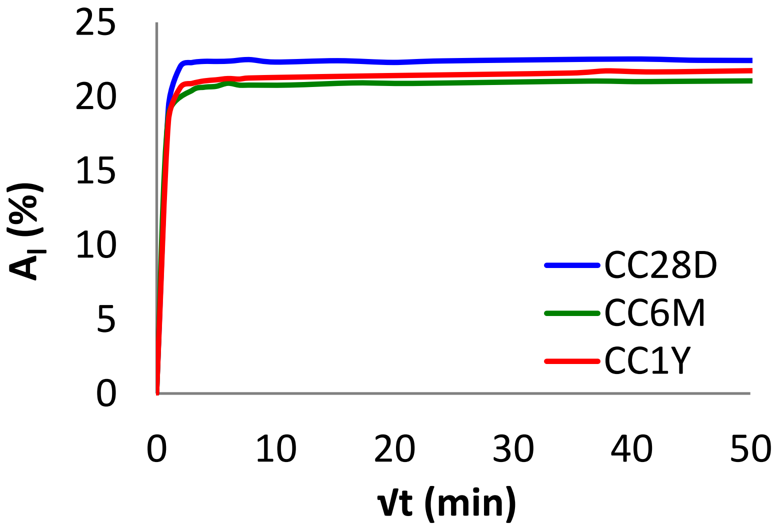
Water absorption by free immersion



Influence of dosage



Influence of carbonation



$$A_l = \frac{M_X - M_0}{M_0} \times 100$$

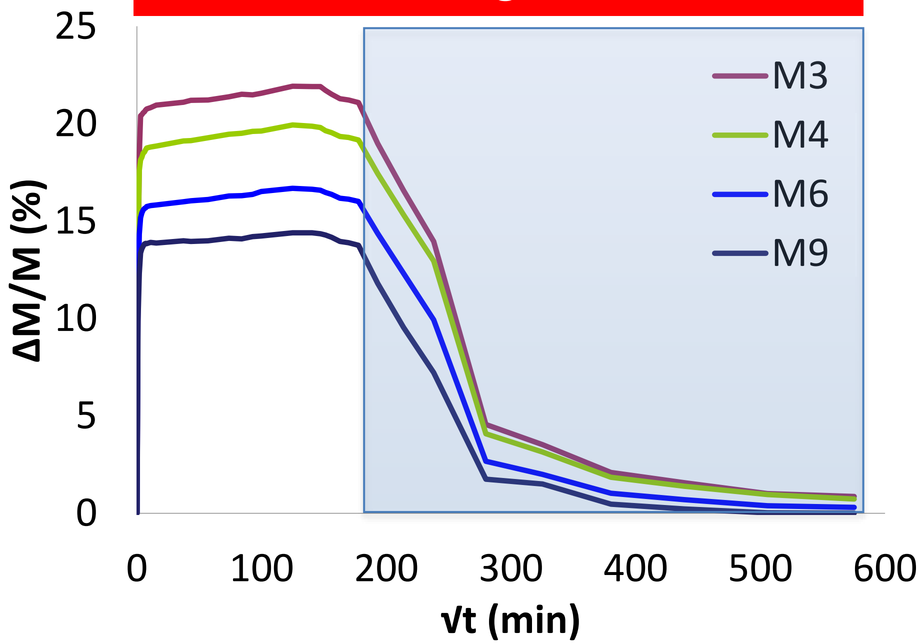
Mortar evolution during hardening

Drying

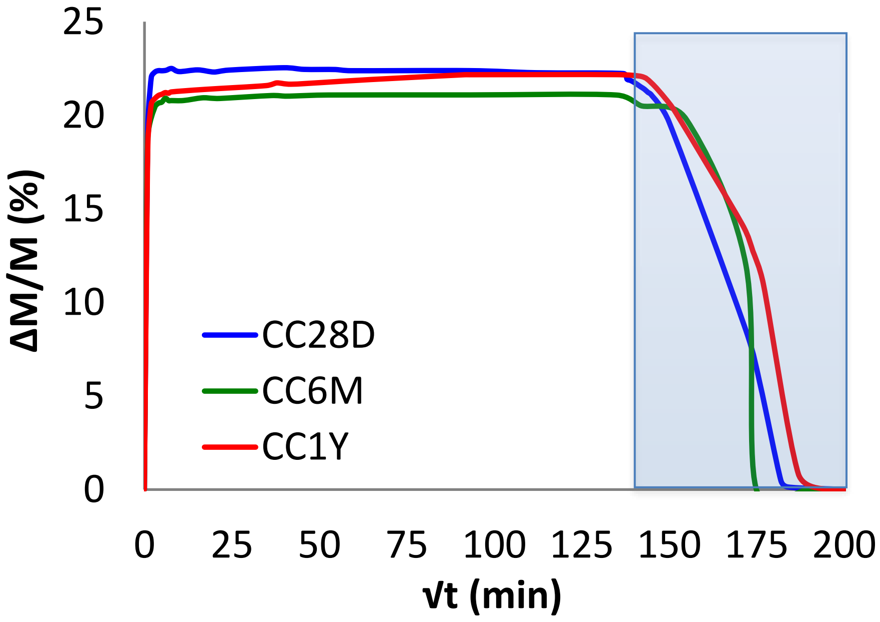
NORMAL 29-88 1988

$$D = \frac{M_D - M_0}{M_0} \times 100$$

Influence of dosage



Influence of carbonation



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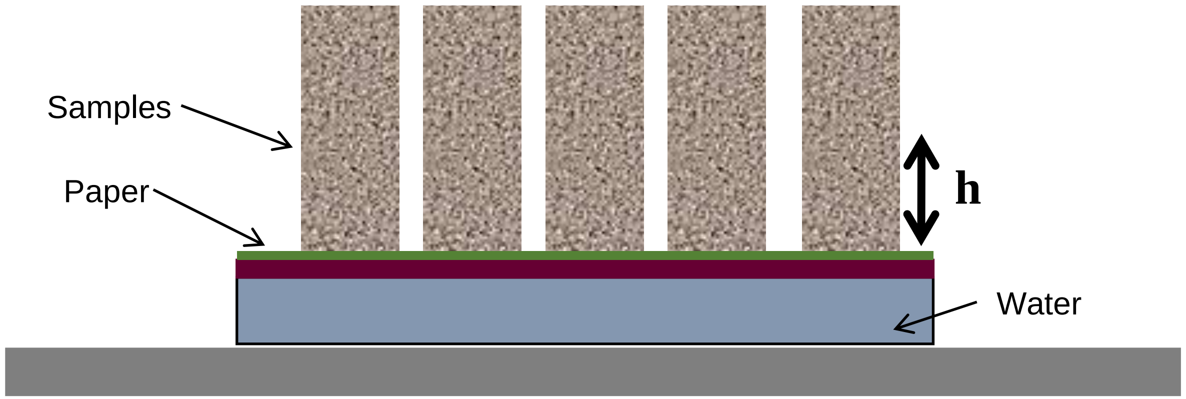
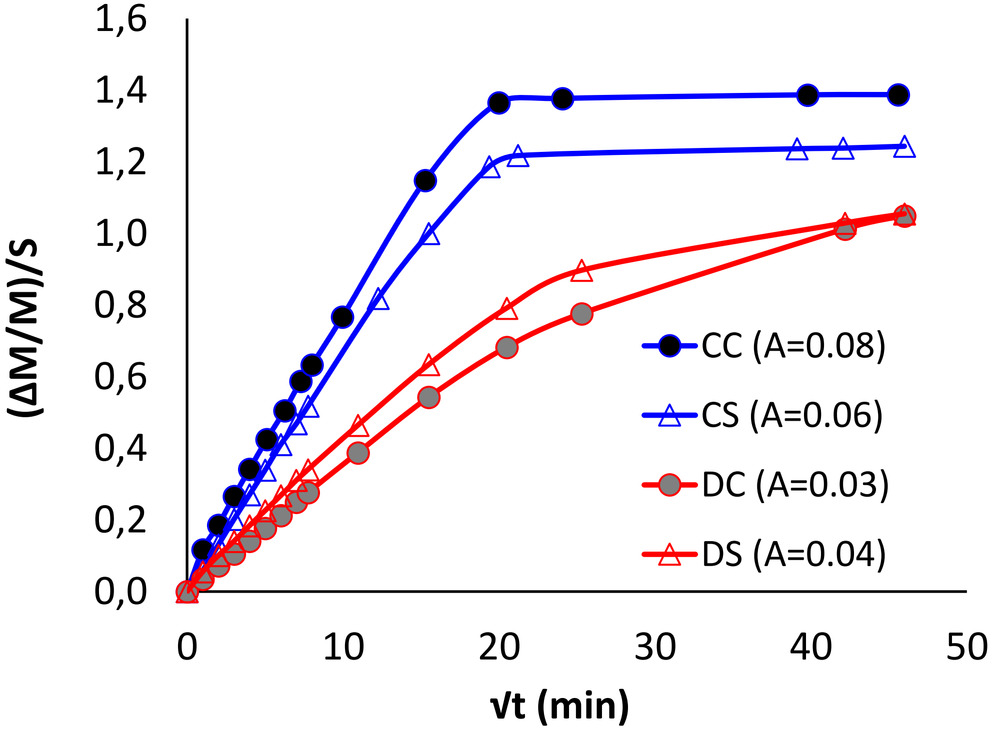
Mortar evolution during hardening

Capillary uptake



$$C = \frac{M_C - M_0}{M_0 S} \times 100$$

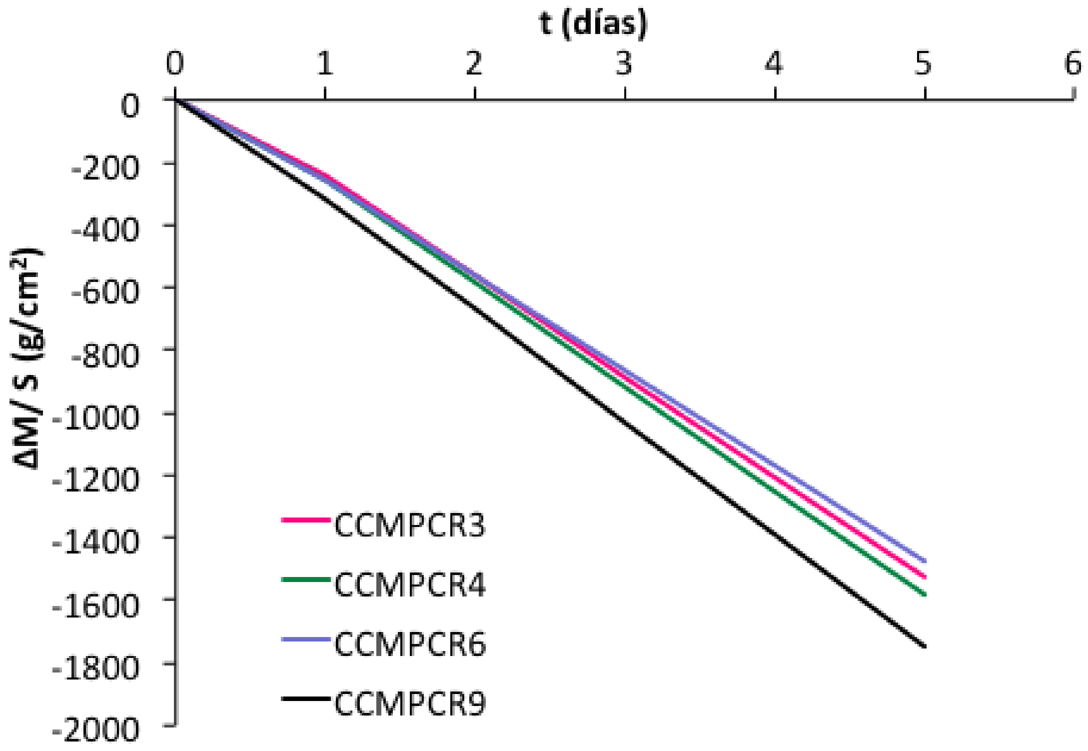
Influence of composition

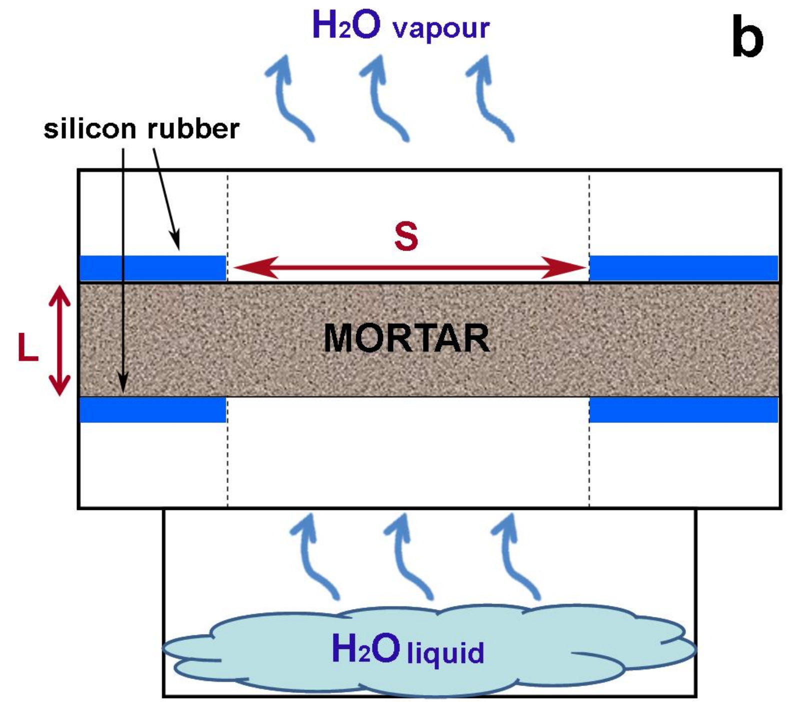


Water vapour permeability

NORMAL 21/85 1985

Influence of dosage





$$K_v = \frac{Q \times L}{D_P \times S}$$

Durability study

Aptitude or capacity of a material to resist the aggressive action of environmental deterioration agents (T, RH, rain, wind) and pollutants (salts, gases, etc.).

The experimental method for estimating the durability of a mortar consists of carrying out laboratory tests in which the mortar is subjected to:

- **Accelerated ageing tests (standard):**

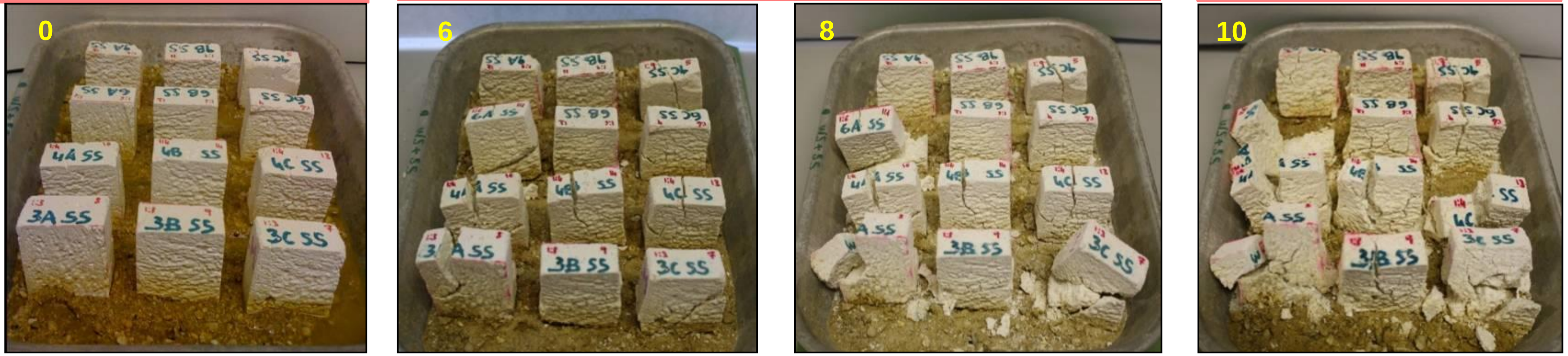
Moisture-dry cycles
Freeze-thaw cycles
Salt crystallisation cycles

- **Deterioration simulations in climatic chamber (non-standard):**

T and RH variations
Rain simulation
Salt attack simulation (salt spray or absorption)

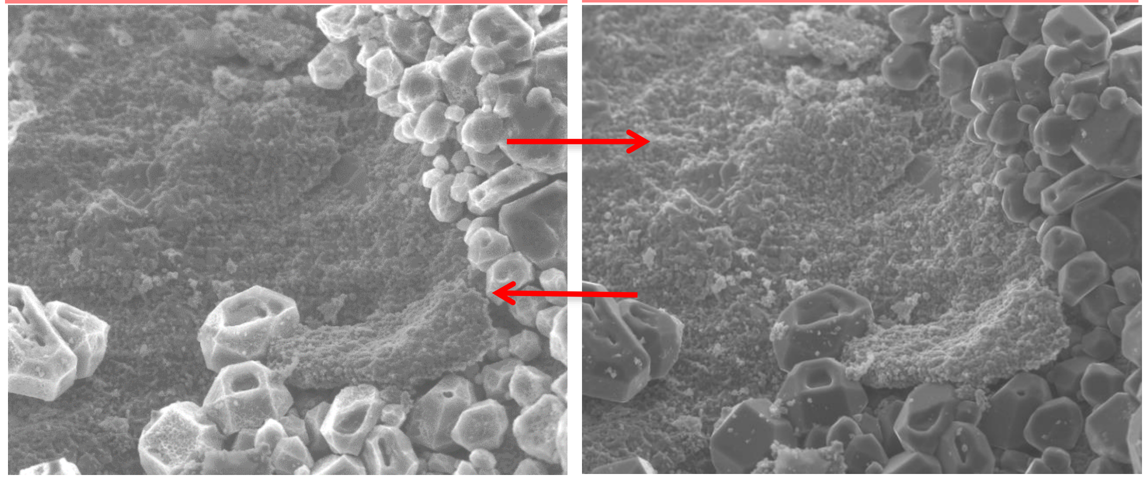
Simulation of salt absorption

SALT EFFLORESCENCES → FISSURES FORMATION → CRACKING



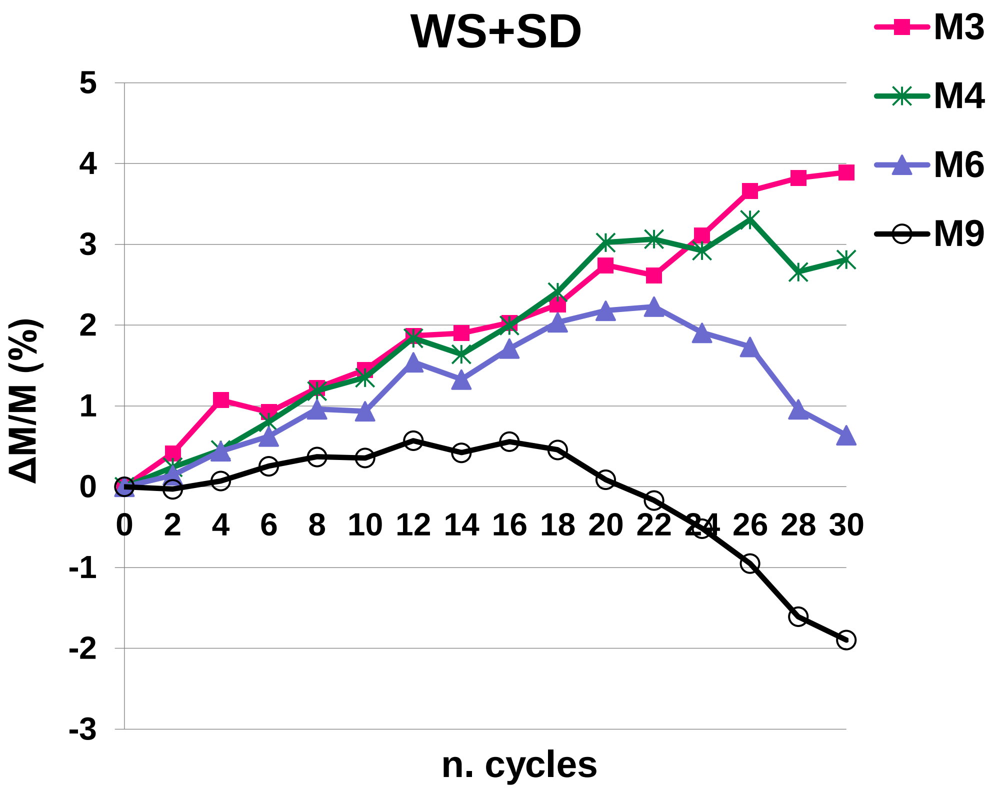
THENARDITE
Na_2SO_4

MIRABILITE
$Na_2SO_4 \cdot 10\ H_2O$

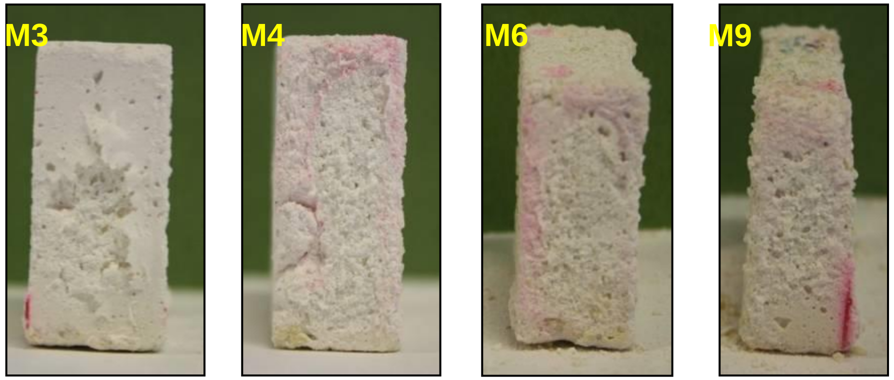


Mortar durability

Simulation of salt spraying

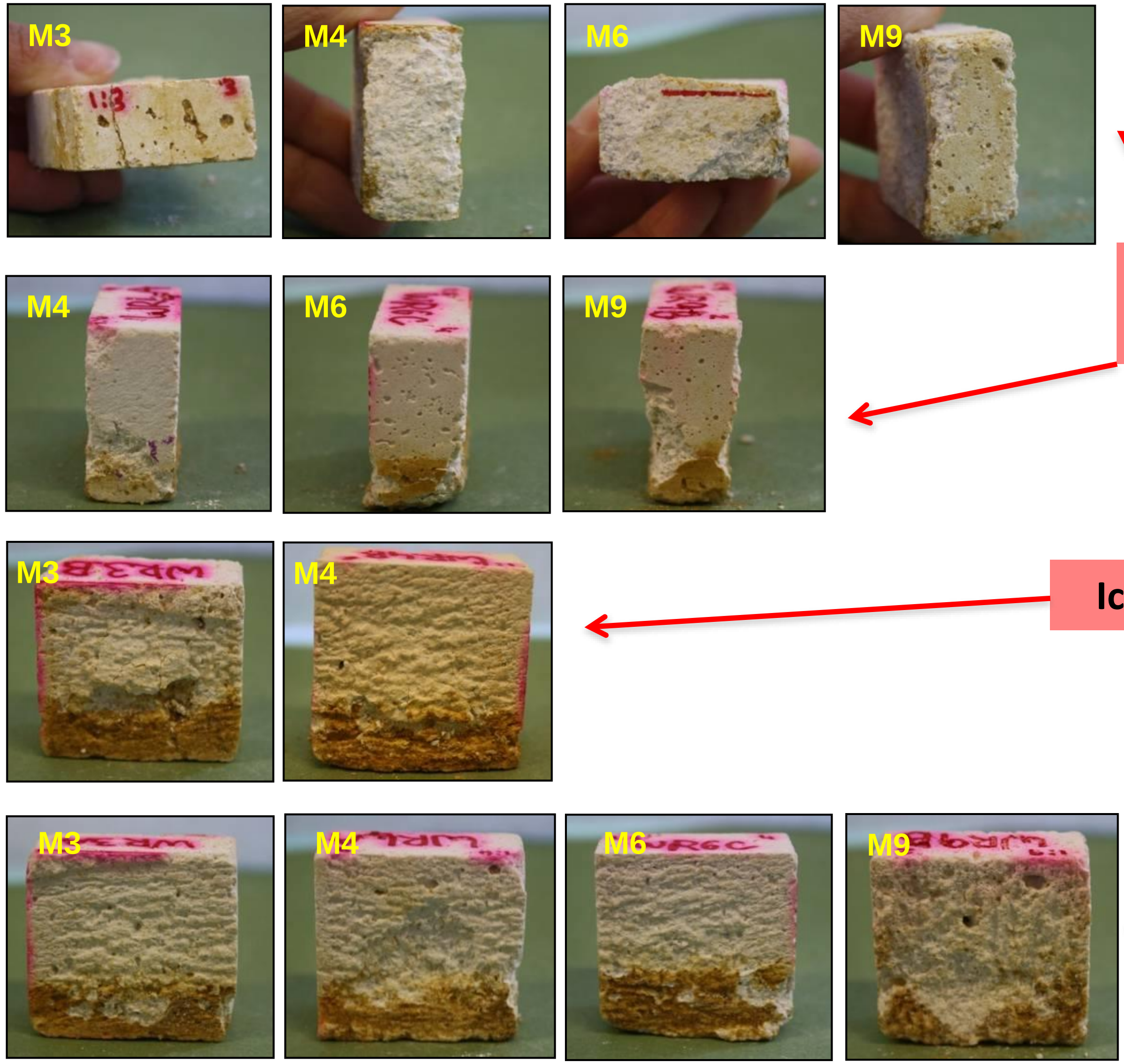


Loss of cohesion between matrix and sand grains



Mortar durability

Simulation of frost damages in mortars



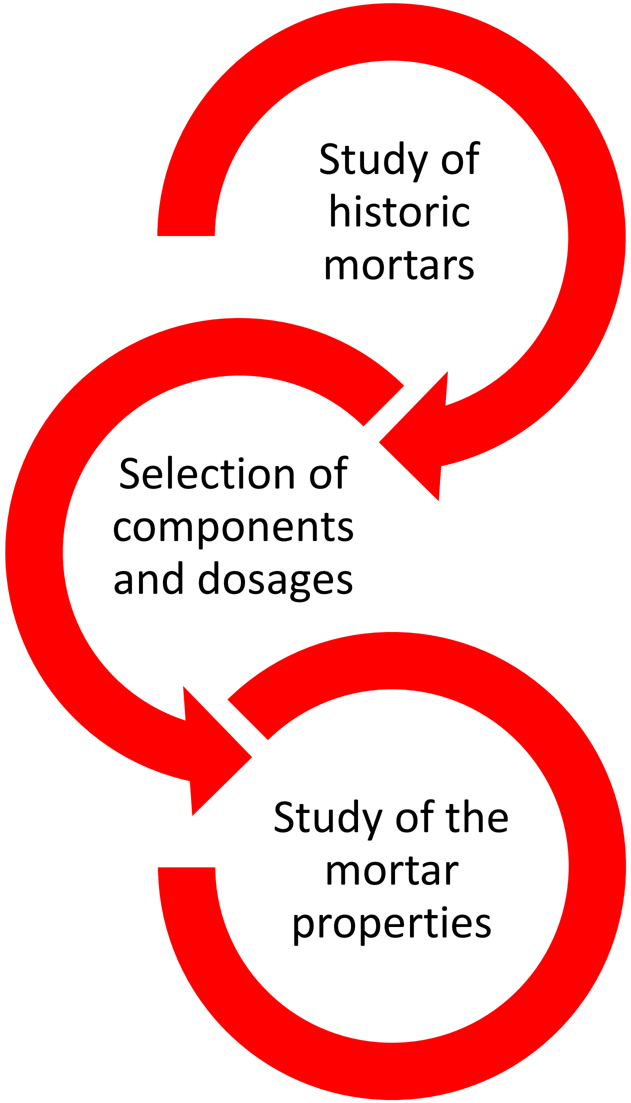
Fragment los due to contact with water

Ice formation inside the pores

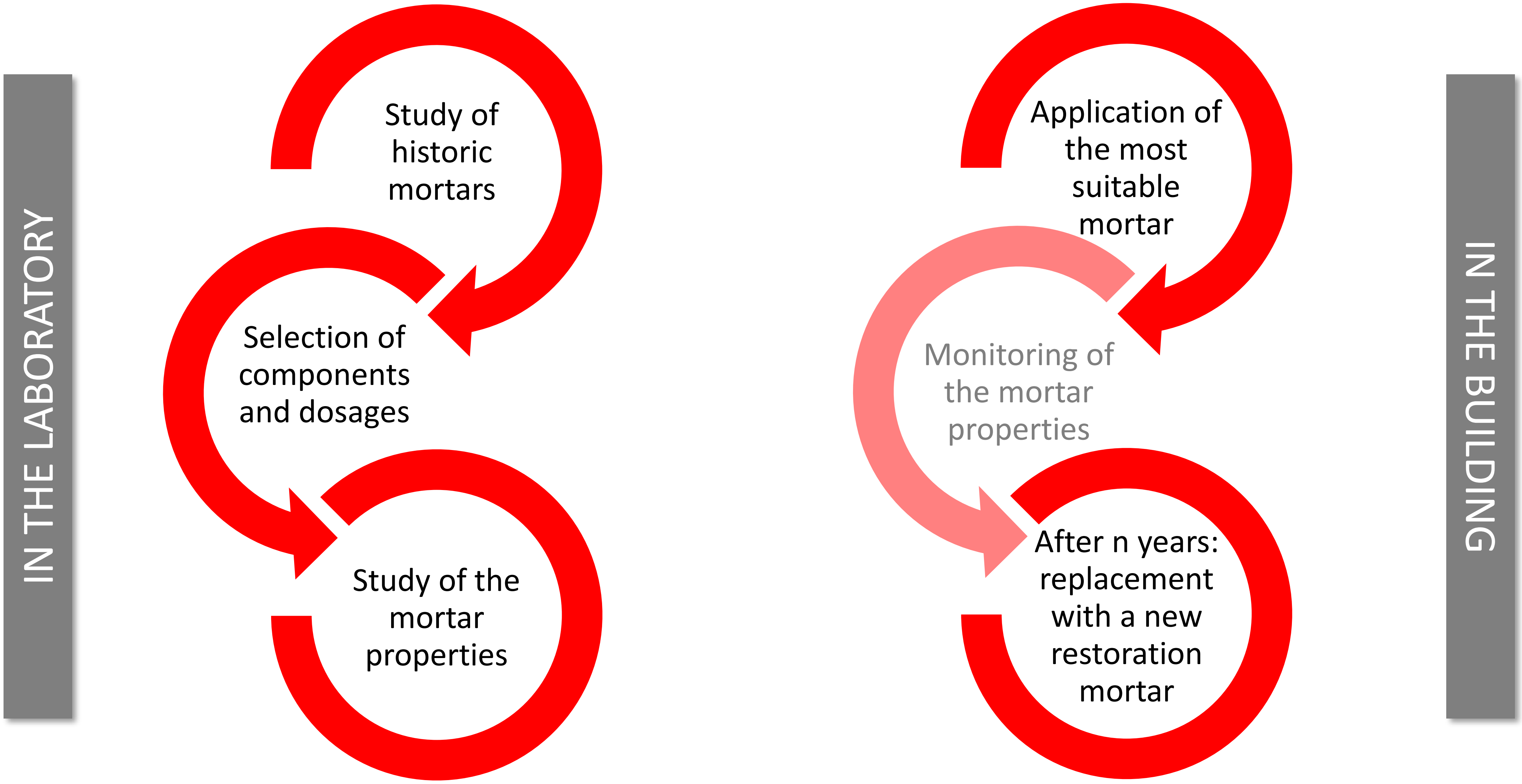
Cohesion los on the surface

Summary of the recommended phases for a correct restoration with mortars

IN THE LABORATORY



Summary of the recommended phases for a correct restoration with mortars



"Building conservation is an attitude of mind, a philosophical approach, that seeks first to understand what people value about a historic building or place beyond its practical utility, and then to use that understanding to ensure that any work undertaken does as little harm as possible to the characteristics that hold or express those values".

"Conservation, An Evolving Concept"

By Paul Drury

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"Conservation, An Evolving Concept"

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Thank you

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