PhD project of Rasmus Stenholt-Jacobsen

Mortars for reuse of fired clay bricks

Lime mortar for reuse of fired clay bricks

PhD student at DTU Sustain:

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Period:

15th of August 2023 – 14th August 2027

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DTU Sustain – Competence section: 'Materials and Durability'

Funded by:

The Landowners' Investment Foundation, Realdania and **The Danish Brick and Roof Tile Association**

Scientific support by:

Danish Technological Institute, Weber, Vejle Kalk- og Mørtelværk, DI Byggeri (section for masonry)**, Byggegruppen 3F, Gamle Mursten**

Goal: Ensure bricks can be reused

Either stronger bricks
Or “weaker” mortar

75-80 % bricks and 20-25 % mortar

Photos:
Hempel kollegiet, DTU Lyngby

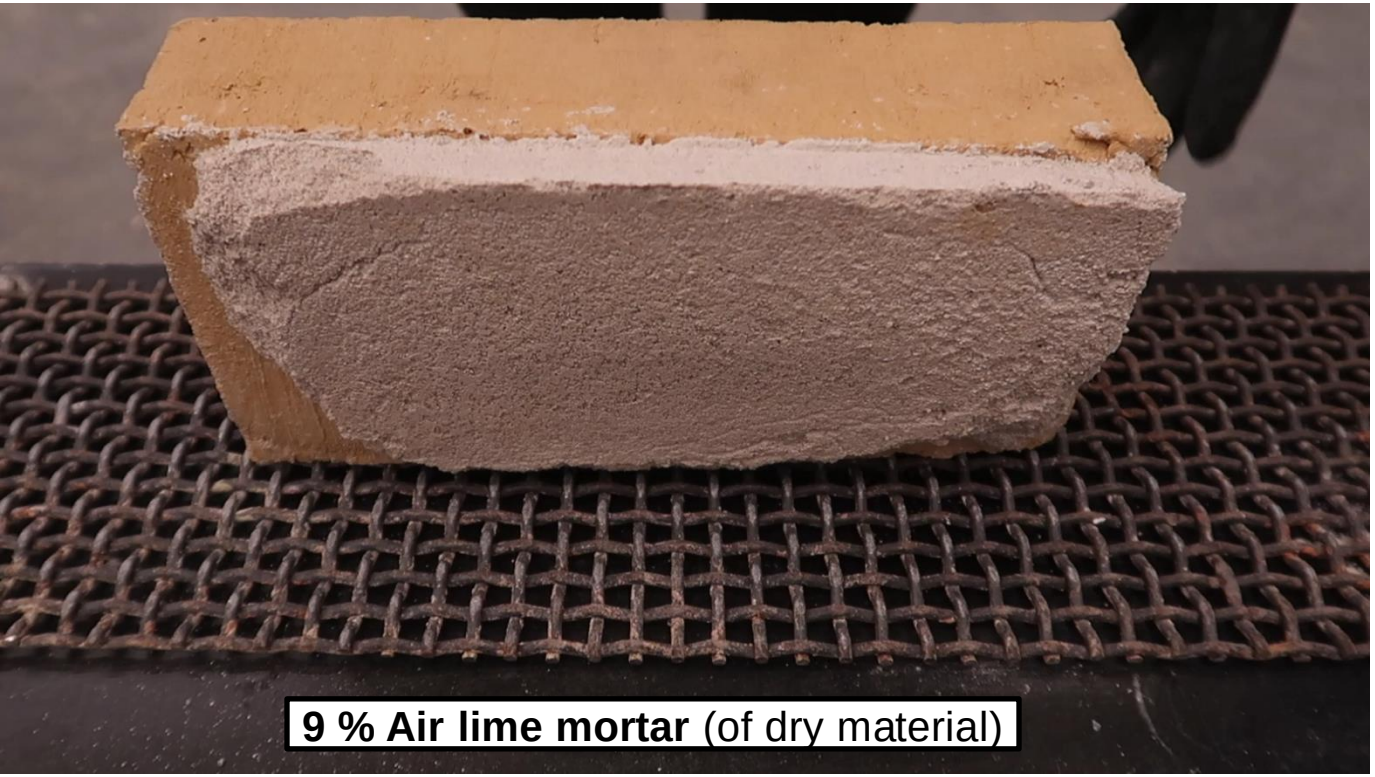
Initial problem: Separation

Photos:
Demolished masonry, Gamle Mursten ApS

Second problem: Cleaning

Raking method

1 year curing (20 °C, 65 % RH)



9 % Air lime mortar (of dry material)

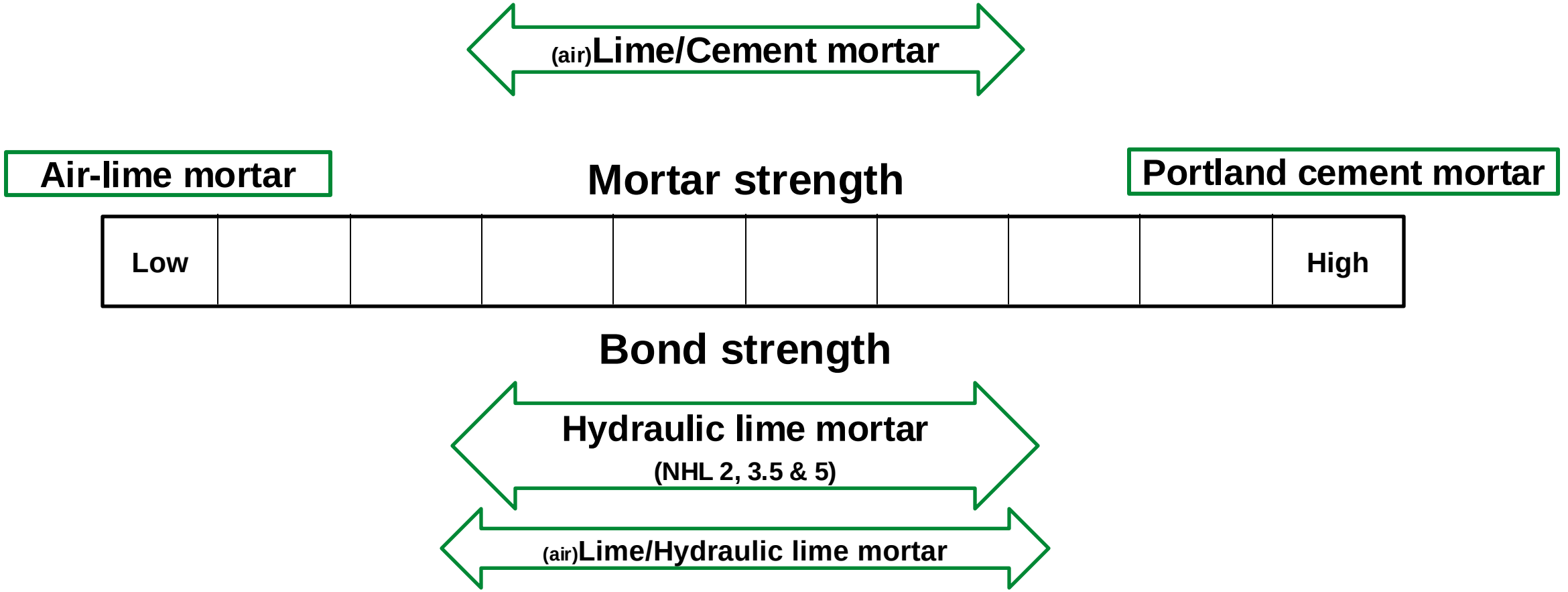
1 year curing (28 days at 20 °C, 95 % RH – then 20 °C, 65 % RH)

Air lime (K) and Porland cement (C) mortar 35/65/650 (K/C/Sand by mass)

Air lime (K) and NHL 5 (Kh) mortar 35/65/500 (K/Kh/Sand by mass)

Specimens from Master' thesis, at DTU Sustain 2022: "Mortars for Reuse of fired clay bricks"

Separation: Binder material



Influence on water content in mortar

Other influences

Separation: Other parameters

Curing time

Humidity and temperature during curing

Conditions of bricks during construction

Initial rate of absorption of bricks

Total water absorption

Pore size distribution of bricks

(air)Lime/Cement mortar

Air-lime mortar

Mortar strength

Portland cement mortar

Bond strength

Workability

Lime and cement type

Dry or wet mortar mix

Shape and grain size distribution of sand

Water retention of mortar

Hydraulic lime mortar

(NHL 2, 3.5 & 5)

(air)Lime/Hydraulic lime mortar

Other relevant parameters

European Standards for: Masonry mortar and clay masonry units

Specification of CE requirements | **Requirements for CE, for masonry mortar** | Indirect requirement through required standard

EN 998-2:2016
Standards for Masonry mortar

Workable life
Shall be declared by manufacturer
Tested following EN 1015-9

EN 1015-9:2002
+ A1:2007
Workable life and correction time

Air content
When relevant
Tested following EN 1015-7
(for mortars with light weight aggregates EN 1015-6 can be used (density))

EN 1015-7:1999
Air content of fresh mortar

EN 1015-6:1999
+ A1:2007
Fresh bulk density

EN 413-2:2016
Masonry cement: Test methods

EN 1015-3:1999
+ A1:2004 + A2:2007
Consistence by flow table

EN 1015-4:1999
Consistence by plunger penetration

EN 1015-2:1999
+ A1:2007
Fresh bulk sampling and preparation

EN 196-1:2016
Cement: Strength determination

Compressive strength
For designed mortars: shall be declared following table 1 (EN 998-2)
Tested following EN 1015-11
Declaration shall include prism method

EN 1015-11:2019
Flexural and compressive strength of hardened mortar

Density (dry hardened)
Shall declare range, when relevant to the use. When tested following EN 1015-10, it shall be within declared range

EN 1015-10:2001
+ A1:2007
Hardened dry bulk density

Water absorption
Shall be declared when used in external elements
Tested following EN 1015-18

EN 1015-18:2003
Capillary water absorption coefficient

Shear bond strength
For designed mortars: Initial she
strength shall be declared for
structural units
Can be declared by tabulated val
or by test following EN 1052-3 w
relevant unit.

Flexural bond strength
For designed mortars: Flexural
strength shall be declared for str
units and when relevant
Note: Declared flexural bond stren
be used in publicly available refe

Characteristic flexural bond st
Following EN 1052-5, tested with
unit
Shall not be less than declared

Characteristic flexural stren
Following EN 1052-2, tested with
unit. Either tested for one plane o
or both (only for blocks, accordin
998-2, table D.1)
Shall not be less than declared

Chloride content
When relevant
Tested following EN 1015
calculation based on chlo
constituents (should not e
0,1 % Cl by dry mas

Thermal conductivi
Shall be declared for ele
subject to thermal require
Either by tabulated valu
testing following EN 1745
table A.12 or sec. 4.2.2 rec

Compressive strength
For designed mortars: shall be declared following table 1 (EN 998-2)
Tested following EN 1015-11
Declaration shall include prism method

EN 1015-11:2019
Flexural and compressive strength of hardened mortar
(Hærdnet bøjnings- og trykstyrke)

Minimum sample volume 1,5 L.
Three specimens shall be made and six halves used for the compressive strength test.

Flow value shall be determined following EN 1015-3 (may also be EN 1015-4 for laboratory prepared mortar)
Laboratory prepared test samples shall be brought to a defined flow value following table 2 in EN 1015-2. Bulk densities above 1200 kg/m^3, should have a flow value of **175 ± 10 mm**
No requirements on how to mix the mortar.

Casting and storage conditions depends on the composition of the binders.
For mortars with mass of **air-lime < 50 %** of binder mass **(7.2.2)**:
Fill moulds in two layers and compact each layer by 25 strokes of the tamper (assumed in each compartment). Skim off excess mortar and store according to 7.3, table 1.

For mortars with mass of **cement < 50 %** of binder mass **(7.2.3)**:
Place frame on a non-absorptive plate with two layers of white cotton gauze. Fill frame in two layers and compact each layer by 25 strokes of the tamper (assumed in each compartment).
Skim off excess mortar, place two layers of white cotton gauze followed by 6 layers of absorbent filter paper. Cover with non-absorptive plate and turn upside down.
Temporarily remove the former bottom plate and place 6 layers of absorbent filter paper on the gauze. Replace plate and flip mould. Store on table with 5 kg load on top for 3 hours, then remove gauze and filter paper.
Store according to 7.3, table 2.

Tamper: Flat square face, 12 ± 1 mm width and 50 ± 1 g mass
White cotton gauze: 4 sheets of ~150x175 mm
Filter paper: ~150x175 mm, 180 - 200 ± g/m^2, water absorption capacity of 160 ± 20 g/m^2 - Sheet number depends on water absorption capacity.
Conditioning chamber: One at RH 95 ± 5 % and one at RH 65 ± 5 %, both at 20 +3/-2 °C
Mould: Metal mould with four compartments of 160x40x40 mm

ive soluble salts content
n intended use is exposed
weather following table 1;
S0, S1 or S2

General specimen requirements are 10 pr. test
(table A.1 and A.2)
All sampling must be in accordance with 771-1 A2

EN 771-1:2011+ A1:2015
Standards for clay masonry units

Dimensions
Shall be declared in l, w, h in mm, with tolerances and when relevant to the use; range

May be a requirement to declare information regarding the unit and their "**configuration**". **(771-1 sec. 5.3.2),** with respect to **772-16, 772-9 and 772-3,** where the mean shall be within declared limit

Plane parallelism (772-16) and **flatness of beds (772-20)** are only relevant for masonry with thin layer mortar

EN 772-16:2011
Dimensions

Initial rate of water absorption
When relevant to the use
Clay masonry unit immersion period of 60 s +/- 2 s

EN 772-11:2011
(coefficient of) **Capillary water absorption for AC$^+$, AAC**, MS^{++}, NS$^-$, along with IRA^{--} for clay masonry units**
(apparently not Calcium silicate)

Gross (brutto) dry density
When relevant to the use
(Acoustics, fire resistance, thermal insulation)

Net dry density
When relevant to the use
Tolerances may be declared: D1: 10 % D2: 5 %, Dm: ? %
as the allowed deviation for test mean from declared value

EN 772-13:2002
Net and gross dry density (not for Natural stones)

EN 772-3:1998
Net Volume & percentage of voids

Water absorption
For external, shall be declared following 772-21
For damp proof courses, shall be declared following 772-7

EN 772-7:1998
Water absorption for damp proof course units

EN 772-21:2011
Water absorption for clay and calcium silicate masonry units

Reaction to fire
Shall be declared for units subject to fire requirements
Notes in EN 771-1 sec. 5.3.11

Durability (freeze/thaw)
Shall be declared as F0, F1, F2
No EN standard currently

Moisture movement
When required in the specific country
No EN standard referenced

Influence on water content in mortar

Other influences

Separation: Other parameters

Curing time

Humidity and temperature during curing

Conditions of bricks during construction

Initial rate of absorption of bricks

Total water absorption

Pore size distribution of bricks

(air)Lime/Cement mortar

Air-lime mortar

Mortar strength

Portland cement mortar

Low									High

Bond strength

Workability

Lime and cement type

Dry or wet mortar mix

Shape and grain size distribution of sand

Water retention of mortar

Hydraulic lime mortar

(NHL 2, 3.5 & 5)

(air)Lime/Hydraulic lime mortar

Other relevant parameters

CEN Standard sand's influence on mortar properties

Prism casting with two different sand types

Result:

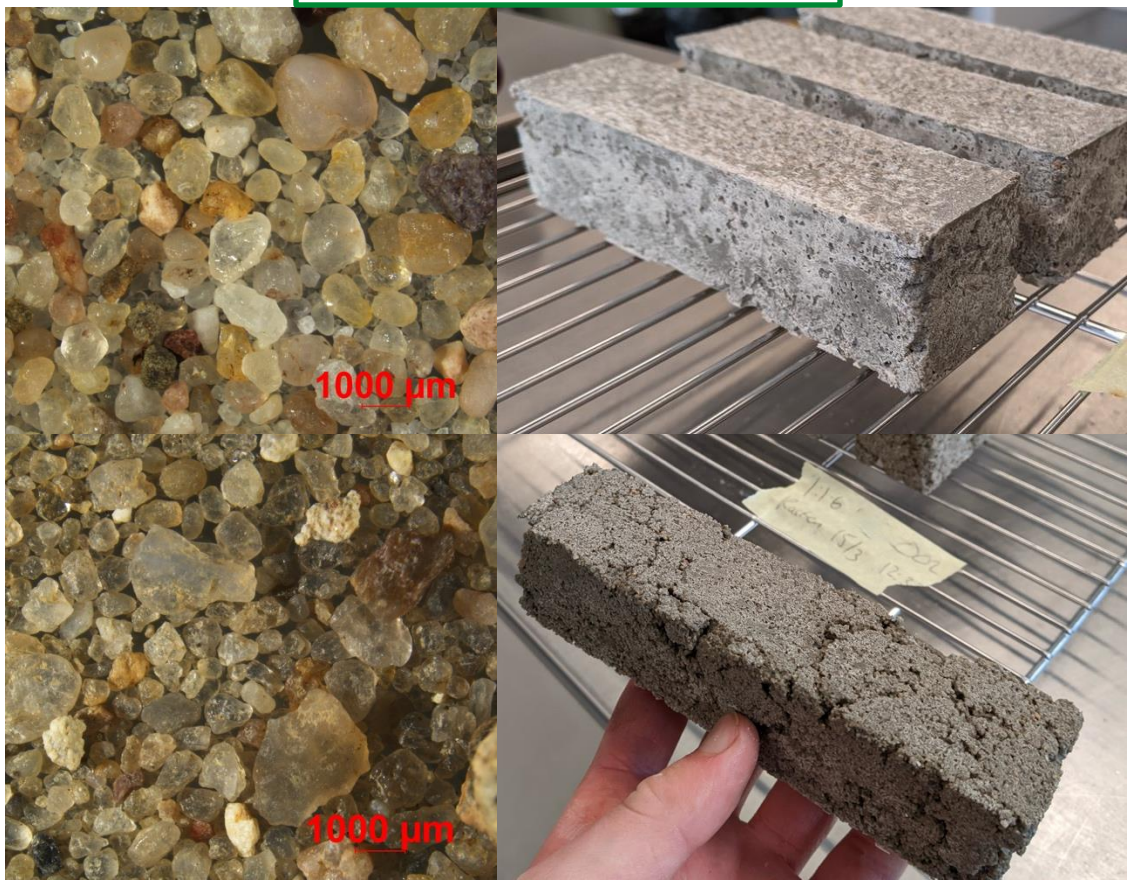
- Sand type heavily effects the water requirement for a specific workability

But:

- The individual mortar mixer influences the water requirement as well

This study is accepted as an extended abstract and will be presented at the international lime mortar conference: SUBLime, in November 2024

CEN Standard sand from Normensand,
In accordance with EN 196-1



Danish pit sand from central Jutland
In accordance with EN 1996-1-1 DK NA:2019

SUBLime
Sustainable Multiphysics
Multiscale Tools for Building
Lime Applications

Controlled variables

Measured variables

Separation: Narrowing down

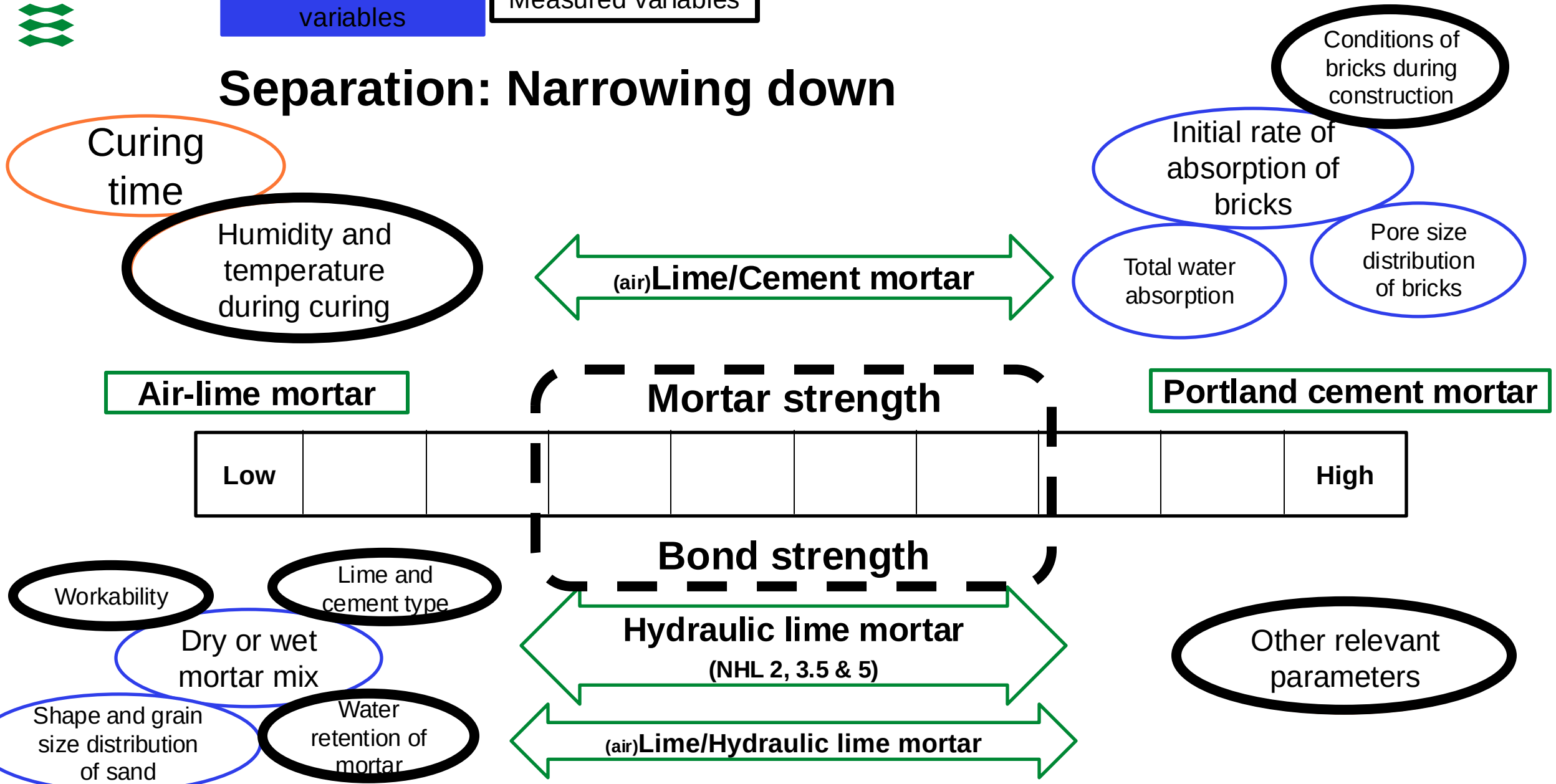


Photo at Vejle Kalk- og Mørtelværk, 27/9 2024

Separation: Field tests

MX1	MX2 + MX3.1	MX3.2	MX4	MX5
5 MPa Designed masonry mortar (DMM)				
”KC 35/65/650” Prescribed masonry mortar (PMM)				
2,5 MPa (DMM)				
”KC 50/50/700” (PMM)				
”KKh 20/80/475” (PMM)				
”KKh 35/65/500” (PMM)				

In accordance with manufacturers declaration and the general overview for prescribed masonry mortar at https://www.mur-tag.dk/udfoerelse/fuger-i-murvaerk/moertelvalg/

- Water struck solid bricks from Egernsund Wienerberger
  - Red bricks: ~ 2,1 ± 0,2 kg/m^2
  - Yellow bricks: ~ 2,5 ± 0,2 kg/m^2
- 2-3 specimen sets of each mortar type
  - Constructed by the same mason
  - Initial 7 days of indoor curing
  - Subsequent outdoors curing until testing
- Material properties are determined in accordance with EN 998-2, EN 771-1 and EN 413-2

Separation: Test methods

On site bond wrench test

Similar to EN 1052-5

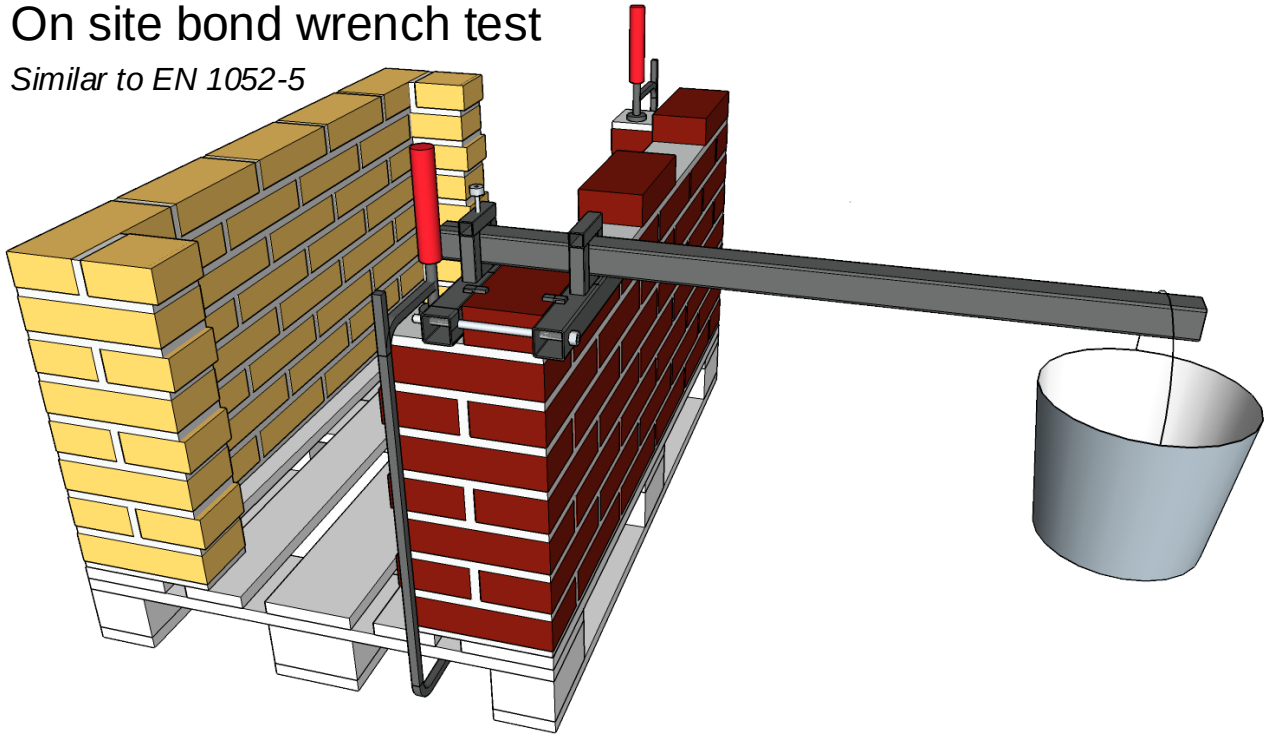


Photo at the Danish Technological Institute 4/5 2024

Internal mortar strength by X-drill test or similar

X-drill test developed by the Danish Technological Institute

Simple demolition

Demolition method inspired by Gamle Mursten ApS report on demolition of wallets (Nedbrydning af mure, 2017)

Demonstration of wallet toppled from a pallet

Mortar test methods

Workability by flow table and plunger penetration

EN 1015-3 & EN 1015-4


Water retention using absorbing paper and bricks

EN 413-2 & Saint-Gobain Weber "VTI" method


Fresh bulk density and air content

EN 413-2 (similar to EN 1015-6 and EN 1015-7)


Casting of 40x40x160 mm mortar prisms

EN 1015-11

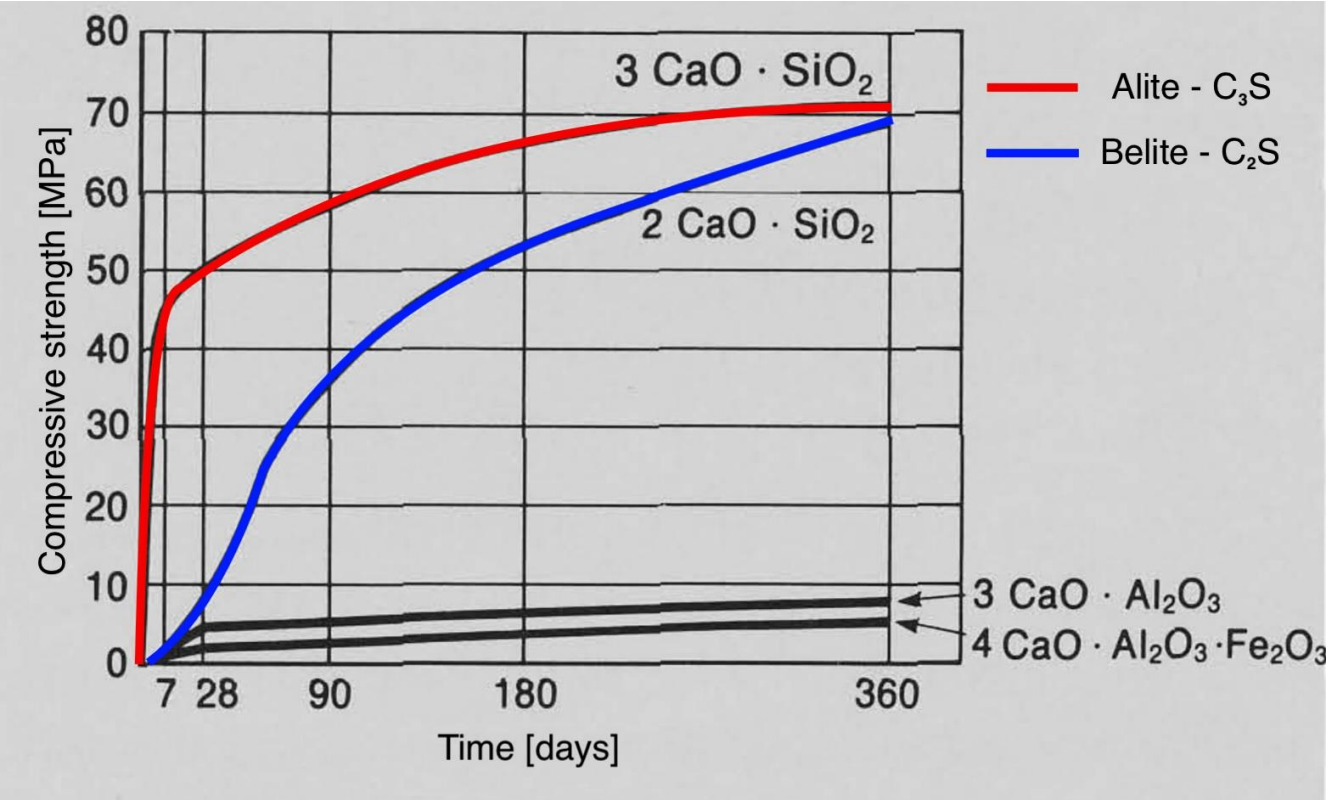

**Casting*

**Demoudling and curing*

Time and Humidity

Expected curing conditions:

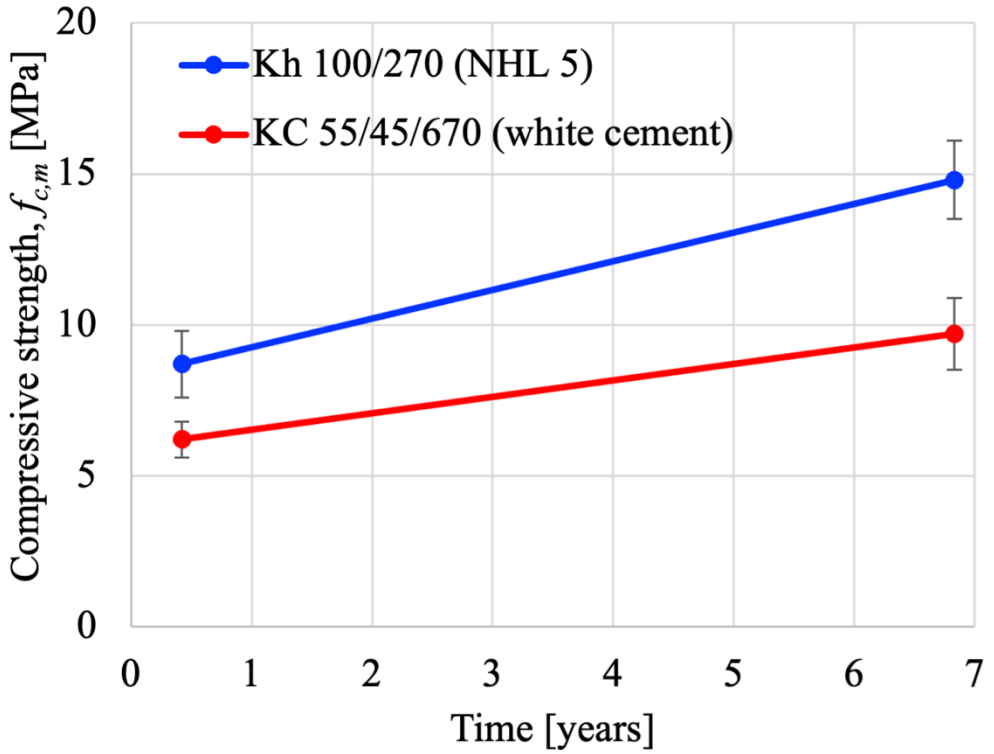
- High humidity (> 85% RH)
- Constant temp ~23 ºC



Betonbogen, 1985, page 276

Curing conditions:

- 85 % RH
- Constant temp ~23 ºC



7-year strength of hydraulic mortars, 2014, Anders Nielsen

Time and Humidity

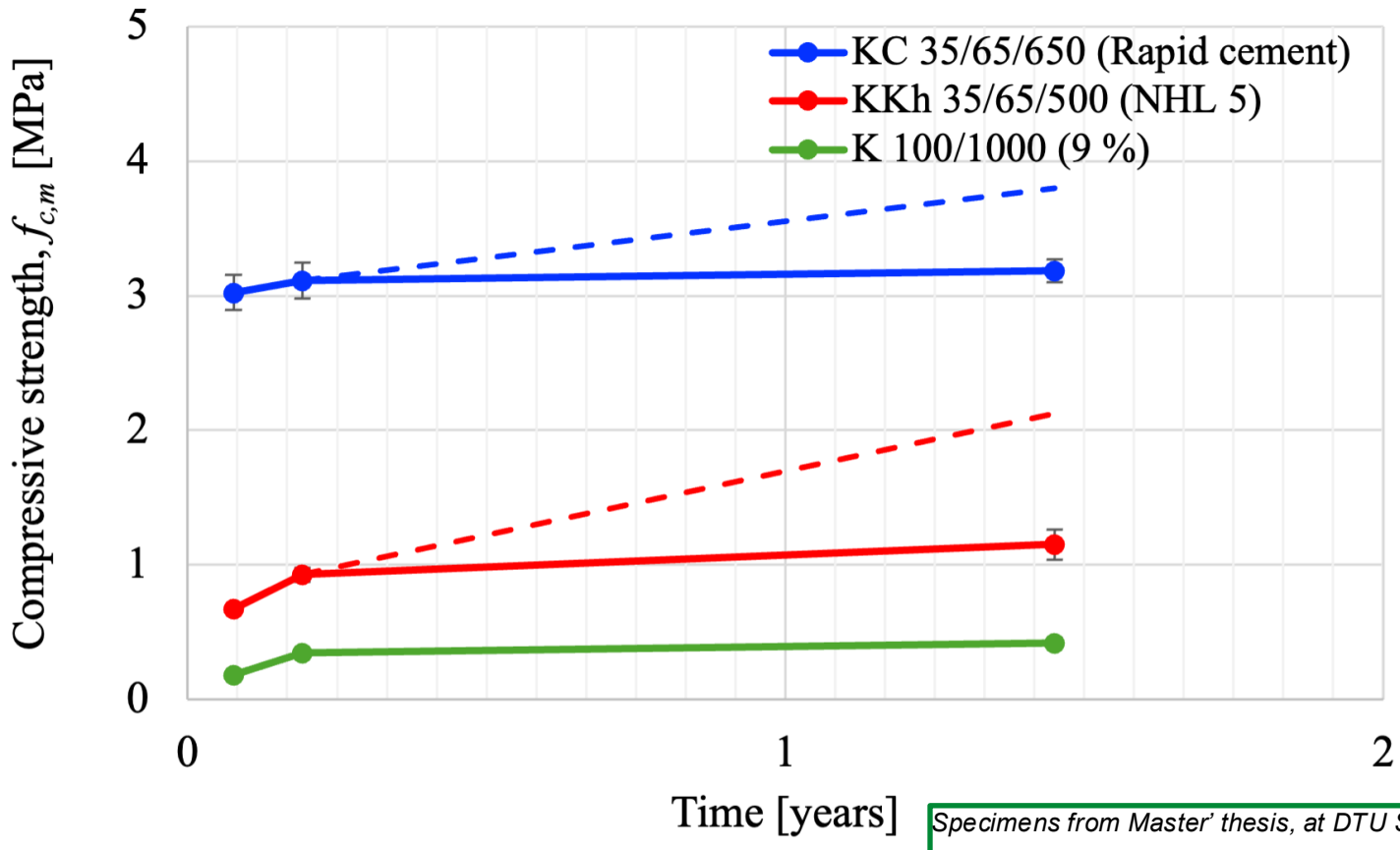
But how are masonry mortars normally tested?

Curing conditions:

- 7 days at 95 % RH
- Then 65 % RH
- Constant temp ~20 ºC

Simple exemplified* extrapolation based on 7 year data at 85 % RH

**the two studies are of cause not directly comparable*



7-year strength of hydraulic mortars, 2014, Anders Nielsen

Specimens from Master' thesis, at DTU Sustain 2022: "Mortars for Reuse of fired clay bricks"

Time and Humidity: Outdoor curing

28 days of curing *(sep-oct)*:
- ~ +7 to +18 ºC
- ~ 70 to 80 % RH

180 days of curing *(oct-mar)*:
- ~ -1 to +7 ºC
- ~ 70 - 90 % RH

365 days of curing *(mar-sep)*:
- ~ +7 to +21 ºC
- ~ 60 - 80 % RH

Curing expectation:

Portland cement: ~20 - 40 % hydration
NHL 5: Little to no hydration
Air-lime: little to no carbonation

Portland cement: ~50 - 60 % hydration
NHL 5: Some hydration
Air-lime: Some carbonation

Portland cement: ~80 % hydration
NHL 5: ~ 50 % hydration
Air-lime: more carbonation

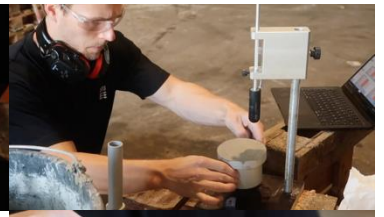
Photo at Vejle Kalk- og Mørtelværk, 27/9 2024

Dansk klimanormal 2011-2020, DMI
Approximate chart of coast and inland humidity in Denmark

Mortar observations

Workability by flow table and plunger penetration

EN 1015-3 & EN 1015-4



Water retention using bricks

Saint-Gobain Weber "VTI" method

Water content and its effect on correction time

Mortar Type	Water content		Workability		Correction time (red bricks: 2,1 kg/m²)	
	Dry mortar [% dry]	Wet mortar [% dry]	Flow table / plunger [mm]	Masons Comment	Water retention [% water loss in 2 min]	Masons comment
2,5 MPa *Designed mortar*		20,4	181 / 35	Good workability	10	Good time for correction and joint finish
	12,5		194 / 35	Good workability	20	Short time for correction and joint finish
KKh 35/65/500 *Prescribed mortar*		20,5	184 / 39	Very good workability	7	Good time for correction and joint finish
	18,3		195 / 37	Very good workability	14	Medium time for correction and joint finish

Calculated from initial water and mixing water

Average of 4 / 3 measurements

Average of 2 measurements

What about the rest of the project period?

Activity	Half year 1.	2.	3.	4.	5.	6.	7.	8.
Participaring in courses								
Teaching and department work at DTU								
Literature study of mortars, bond strength and testing methods								
External stay at a company specializing in mortar identification								
Initial study of bond strength, separation, and cleaning(*)								
Analysis of mortar composition and its influence on separation and cleaning (*)								
Analysis of the brick properties after cleaning - How do they function for reuse? (*)								
Development of identification method for reusability potential in existing masonry (*)								
Writing the Ph.D. thesis								

(*) It is expected that these works will conclude in an article for a conference or a scientific journal