Chemical and physical characterisation of some NHL binders and the correlation with the mechanical properties of conservation mortars

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Introduction

- Natural Hydraulic Lime (NHL) results from the calcination of crushed limestone containing clays (Figure 1 and 2). These are similar to the historic materials in terms of chemical compatibility and therefore adequate to use in conservation works. Different from air lime, NHL binders achieve a faster and stronger set due to the initial hydraulic reactions [1][2].
- Chemical and physical properties of NHL of a given manufacturer can change over time.
- BS EN 459-1:2010 classifies the NHL binders based on standard samples unrepresentative in their nature of the mortars used 'on-site' (Table 1).
- Cementation Index (CI) (Equation 1) and Hydraulicity Index (HI) (Equation 2) were used in the past to classify the NHL raw materials according to their potential hydraulic properties (Table 2) [3],[4].
- Mortars from the same NHL class often exhibit distinct variations in properties, frequently presenting stronger mechanical properties than desired which can be harmful to historic fabric (Table 1)[1].

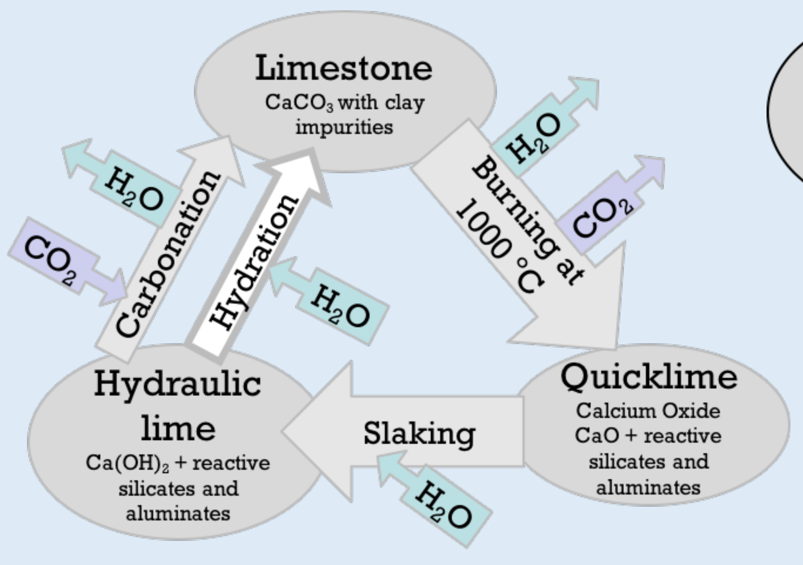

Figure 1: Natural hydraulic lime cycle

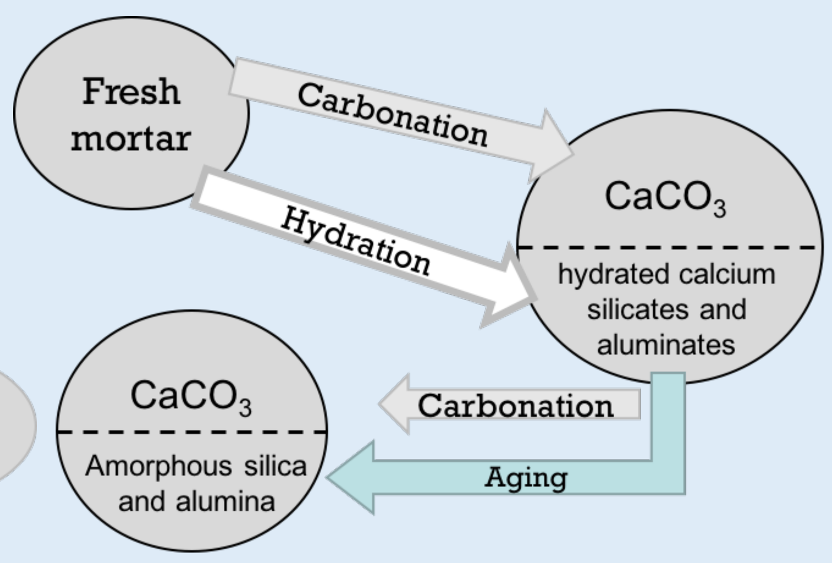

Figure 2: Natural hydraulic lime mortar ageing

Table 2: Cementation index for various types of lime

Lime description	C.I.
Fat limes	close to zero
Slightly (feebly) hydraulic limes	0.3 to 0.5
Moderately hydraulic limes	0.5 to 0.7
Eminently hydraulic limes	0.7 to 1.1

Table 1: Natural hydraulic lime cycle

	Compressive strength at 28 days (MPa)																			
Lime	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
NHL 2																				
NHL 3.5																				
NHL 5																				

$$CI = \frac{2.8SiO_2 + 1.1Al_2O_3 + 0.7Fe_2O_3}{CaO + 1.4MgO} \quad \text{(Eq. 1)}$$

$$HI = \frac{SiO_2 + Al_2O_3}{CaO} \quad \text{(Eq. 2)}$$

Materials

- Three classes of binders from 2 different manufacturers (X and Y) were compared.
- X-ray fluorescence and X-ray diffraction were used to characterise the NHL powders.
- The aggregate used was a common available well graded quartz sand.

Table 3: Lime binder analysed

Manufacturer	NHL 2	NHL 3.5	NHL 5
X	X2	X3.5	X5
Y	Y2	Y3.5	Y5

Table 4: X-ray fluorescence characterisation and CI and HI calculated based Oxides composition

	X2	X3.5	X5	Y2	Y3.5	Y5
Loss on Ignition	17.95	17.23	19.22	22.03	19.75	19.7
MgO	2.37	1.93	2.16	0.44	0.56	0.92
CaO	66.38	65.82	64.23	66.03	61.43	60.72
Al_2O_3	1.63	2.51	2.35	0.38	0.96	0.9
SiO_2	7.8	8.4	7.8	9.35	15.24	15.57
Fe_2O_3	2.1	1.63	1.93	0.38	0.53	0.58
CI	0.36	0.4	0.38	0.4	0.71	0.73
HI	0.14	0.17	0.16	0.15	0.26	0.27

Table 5: X-ray diffraction with the better detected minerals

	$Ca(OH)_2$ Portlandite	$CaCO_3$ Calcite	Ca_2SiO_4 Belite	Ca_3SiO_5 Alite
X2	++	+	+	R
X3.5	++	++	+	R
X5	++	+	+	R
Y2	++	+	+	R
Y3.5	++	++	+	R
Y5	++	++	+	R

++ well detected, + detected, R residual

Mortars

- Mortar prisms were prepared using an horizontal pan mixer and cast in phenolic wood moulds.

Table 6: Formulations parameters

Typical sample type	Prisms 160*40*40 [mm^3]
Curing condition	• Control room (20ºC 60%RH) • Winter • Summer
Spread (flow table)	165 ± 10 [mm]
Mix proportion (by volume binder:aggregate)	1:2

Table 7: Water binder, spread in the flow table and compressive strength at different ages for the mortars considered

	water/binder (mass)	spread (mm)	Compressive strength per days (MPa) 7	14	28	91
X2	0.95	160	0.8	1.3	1.7	2.7
X3.5	1.31	161	0.5	1.1	1.7	2.1
X5	1.18	156	0.5	1.2	1.6	2.0
Y2	1.12	160	0.5	1.1	1.4	1.8
Y3.5	1.19	174	0.7	1.4	2.2	2.2
Y5	0.9	174	1.2	2.1	2.5	3.1

Figure 3: Moulding process

- Flexural and compressive mechanical tests were performed at the different ages.
- Carbonation evaluation was done using phenolphthalein staining test

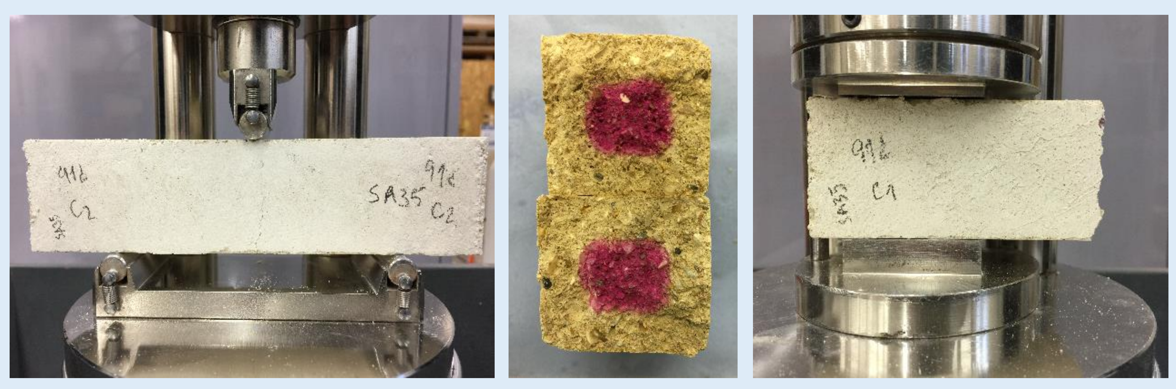

Figure 4: Mechanical strength tests and carbonations with phenolphthalein staining test

- X binders do not show a clear relationship between compressive strength and chemical composition.
- X2, despite being classified as NHL 2, shows similar mechanical strength at 28 days and higher compressive strength at 91 days than the other X binders.
- Y lime shows a relationship between the quantity of SiO_2 and the mechanical strength at 28 days.
- None of the binders achieved the classified mechanical strength at 28 days.

Conclusions

- BS EN 459-1 although useful for manufactures can be inadequate to be used as a guideline for design and specification of conservation mortars
- There is the potential that the chemical and mineral composition can be used to predict mortar properties, but it needs to be correlated with the physical properties of the binder

References

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Acknowledgments

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