

Mineralogy of binders and the Effects of Free Lime content and Cement addition in Lime Mortars.

This document is meant to assist the user in the evaluation of the composition of various binders and mortars.

I. PREMISE

In Restoration and Conservation, it is of the utmost importance that mortars are compatible, chemically and mechanically, with the existing mortars and with the building materials present. This is especially the case in interventions involving the placing of mortars within a structure (rebuilding, injection, grouting, re-pointing) as potentially damaging chemical or organic components in the binders and the aggregates adopted will cause the deterioration of the structure itself.

The main damaging components are:

Soluble salts (sulphates are the main ones). Represented mainly by SO_3 , SO_4 , $CaSO_4$ (gypsum).

Aluminates. Mainly tricalcium aluminate (C_3A)

The presence of sulphates and aluminates will cause, in a relatively short period, a sulphate attack when these components are exposed to rain water

Alkalis (K and Na). Their presence, even if generally in small percentages, can cause a reaction with the silica content of the sands (Alkali-Silica reaction) with similar effects to a Sulphate attack.

Organic content. It must be below 1% of the binder content. Organic matter is subject to deterioration in time and can also promote biological growth.

Mainly because of the above it is by far preferable to adopt pure lime mortars in the restoration or conservation of our built heritage (vernacular or monumental).

Pure limes are of two categories:

A - calcium/magnesium (dolomitic) limes (Air limes). Their hardening is the result of re-absorption of CO_2 from the air (carbonation), therefore they are classified as Air limes under the current EN/BS 459.1. They are produced from the burning and slaking of calcareous*/dolomitic stone with little or no content of minerals such as silica, alumina and iron oxide.

** a stone is defined as calcareous when it contains more than 50% Calcium carbonate ($CaCO_3$)*

The hardening is slow and can be further impeded by the presence of moisture (dampness or rain) which will not allow the surface of the mortar to absorb CO_2 due to the formation of a "film" on the surface itself. To obtain a set, in these products, addition of cement and possibly pozzolanic materials are made. These materials such as furnace slag, fly ashes, brick dust, residuals from ceramic production and so on are all grouped under the generic term of Pozzolans and their adoption is nearly always justified by the use of a volcanic ash that the Romans adopted. The ash was from Vesuvius and was called Pozzolan because it was quarried in Pozzuoli, near Naples.

B – hydraulic limes. So called because they set in contact with water (secondary hardening also takes place in contact with air due to the presence of air lime in their composition). They are produced from the burning and slaking of calcareous stone containing silica, alumina and sometimes ferrite.* The resulting calcium silicates, aluminates and ferrites constitute the hydraulic component.

** As little as 2% silica content in the stone is sufficient to produce hydraulic characteristics. Silica represents 60% of the earth crust and therefore its presence in stones and clays is quite normal. Alumina and iron oxide content is normally much less than silica.*

The EN/BS 459.1 does not allow any additions to the pure and natural hydraulic limes (NHL). If cement or pozzolans are added in a quantity of up to 20%, the suffix "Z" has to be added and printed on the bag (NHL-Z). If the addition is over 20% or if various products such as cement, air lime, fillers etc. are blended to produce a binder that sets in contact with water (hydraulic), the product is called HL.

II. Mineralogical difference between natural hydraulic lime (NHL) high calcium lime (CL/DL) and grey cement.

The main components of NHLs are:

Hydraulic Elements

- predominantly C_2S (Belite)
- Some C_3S or Alite (derived from possible “high spots” during burning)
- Calcium aluminates (Ca. 2%)
- Ferrites (< 1%)
- Un-combined reactive silica. Portion of SiO_2 which has become reactive (amorphous) due to exposure to heat but has not combined with the CaO to form calcium silicates (CS). See [Annex 1](#) (*Summary of formation and effects of reactive silica*).

Non hydraulic elements:

- Available lime (free lime). $Ca(OH)_2$ or Portlandite

Other Elements:

- Alkalis (Na,K) between 0.04% and 0.07% for Na_2O and 0.10% to 0.25% for K_2O .
- Sulphates (SO_4) derived from the natural clay content in the stone or from the type of fuel or coal used in the furnaces.
As for the Alkalis, the lower the figure the better.
- Unburned residuals. This fraction is inert.

The main components of high calcium limes are:

- Calcium hydroxide – $Ca(OH)_2$ between 70 and 95%
- $CaCO_3$ – limestone residual

The main components grey cement are:

- Predominantly C_3S
- Some C_2S
- Aluminates 10%-15%
- Gypsum / $CaSO_4$: 5% to 10%
- Alkalis (NaK) > 2%
- Fillers

The main differences between NHLs and cement are:

A. Chemical:

A.1 - Ratio between C_2S (Belite) and C_3S (Alite) and correspondent differences in compounds formed during hydration.

The hydration of both compounds produces the group CSH or Calcium Silicate Hydrates resulting in similar mechanical performances but C_3S will produce 3.2 times more Portlandite [$Ca(OH)_2$] than C_2S . See full chemical reaction path in [Annex 2](#).

This Portlandite will be produced as soon as water is added to the mortar and in time, it will crystallise in the pores of the mortar leading to reduced vapour permeability more commonly described as breathability.

The crystallisation of Portlandite will also alter the elasticity moduli of the mortar and stiffens the mortar creating high risk of long term crack formation. The presence in NHLs of amorphous/reactive silica not combined with the CaO is beneficial as it fixes Portlandite, limiting the risk of effluorescence caused by $Ca(OH)_2$ (Portlandite) leaching.

A.2 – Effects of high aluminate content (C₃A) and sulphate (Gypsum) addition to cement.

Aluminates produce delayed ettringite* by reaction with sulphates which are contained in the binder or in the building fabric and rain water. Sulphates addition in cement is necessary to slow the otherwise near instantaneous set. Otherwise known as “**sulphate attack**”, this most common problem causes the deterioration of the mortar. The expansion force of the ettringite salt is much higher than the cohesion force of the mortar (70-240MPa versus 4-6MPa), causing cracks, joints delamination with consequent water ingress etc....For the full chemical reaction path see **Annex 3**.

*Ettringite: calcium hydrate of aluminate trisulphate, also called Candlot salt.

A.3 – Effects of presence of Alkalis

Although the Sodium oxide (Na₂O) and Potassium oxide (K₂O) or alkali content in cement seems little (>2%), their presence can trigger the “alkali-silica” reaction, attacking the sand component in a mortar.

Alkalis are added to cement as flux materials to reduce the fusion temperature. They stay in the cement and can dissolve silica, causing deterioration of the sand used in the mortar.

A.4 CO₂ re-absorption

Cement does not re-absorb any CO₂ emitted during production. As a consequence, blended cement/CL binders and mortars have a lower CO₂ re-absorption value than NHL binders and mortars.

Table 1 - Summary of CO₂ emission

Product	CO ₂ Measured in Kg per Ton of Product		
	Total CO ₂ emission (from fuel+ decarbonation)	CO ₂ re-absorbed during Carbonation	Total CO ₂ not re-absorbed
Cement	819	NIL	819
Hydrated Lime (CL)	872	535	337
St. Astier NHL 5	635	350	415
St. Astier NHL 3.5	606	270	336

*For the complete table see **Annex 4***

The CO₂ emission (CO₂ not re-absorbed) of high calcium limes and NHLs is quite similar. This is due to the higher total emission in the production of CLs.

B Physical

B.1 - Rheology, hardening kinetic

The great advantage of an alitic binder (cement based binder containing ₃S as its main component) is its fast setting and hardening compared to belitic binders (NHL binder containing mainly C₂S or Belite). However, the consequence of achieving high mechanical performance rapidly is higher stress on the support and higher risk of shear. A belitic binder strength gain is more gradual as shown in the following table.

**Table 2. - Comparison of hardening of Belite and Alite
(hardening of pure components expressed in Kg/cm²)**

Hardening Comparison	7 Days	28 Days	180 Days	365 Days
Alite C ₃ S	322	466	512	584
Belite B-C ₂ S	24	42	194	325

From the table above we see that alite long term strength is higher than Belite. However, alitic binders (cement based) are much less elastic and breathable than belitic binders (NHLs) as shown in the paragraphs that follows.

B2. - Elasticity moduli

The crystallisation of Portlandite produced in the hydration of C_3S (as seen in A1) and by adding CL to cement (1:1:6 mixes etc...) has the effect of stiffening the mortar.

A hard mortar will not accept movements. Construction joints are necessary not only in pure cement mortars but in all blended mortars containing cement.

B3. - Permeability to vapour (breathability)

Permeability is extremely important in restoration and conservation as it diminishes condensation and the consequences of damp. The void structure of cement mortars, especially when badly graded sands are used, is poor. The mortar is quite dense.

The capability of a mortar to allow air movement in a structure is quite reduced in cement based mortars. Expressed in grams of air $\times m^2 \times$ hour, concrete will have a value of 0.15 whilst NHL 5 and NHL 3.5 mortars made with ISO 679 standard sand at 1:2 ratio reach 0.55 and 0.64 respectively (up to 4 times better).

B4. – Capillarity and water absorption

Cement mortars have a lower capillarity and water absorption than NHL or CL mortars, but their density and correspondent low permeability will promote moisture accumulation within the structure. High capillarity and water absorption are partly compensated by evaporation when a mortar has a good void structure and high permeability to vapour. This is however not the case in cement mortars with their typical poor void structure.

B5. Bonding strength

The higher bonding strength of cement mortars does not necessarily mean higher durability. Dense mortars can (and do) delaminate if, for any reason such as shrinkage or movement cracks, there is moisture penetration and frost heave. The bonding strength of NHLs is very adequate and the higher permeability and elasticity will result in better durability.

The high bonding strength of cement mortars can also cause damage to the building elements when attempts are made to remove these mortars or when they came off by delamination. The face of the bricks, for example, remains attached to a cement render. If a brick loses the face, its water absorption becomes much greater and the resulting high suction can cause problems even if the cement render is replaced by a lime render.

Masonry elements built or rendered with cement mortars are rarely recyclable (in the sense of being re-usable) as breakages occur when trying to take the cement mortar off.

III. Major characteristics and properties of NHL – NHL/CL and OPC/CL mortars related to free lime content (available lime).

FREE LIME CONTENT – %Ca(OH)₂ – directly influences a number of the properties of mortars such as: plasticity, fineness, water demand, micro fissures, compressive strength, suction, water absorption, capillarity, vapour permeability, carbonation and lime leaching, bonding strength.

Table 3

St. Astier lime mortars at 1:3 volumetric ratio	CL mortars 1 : 3 volumetric ratio	CL + cement blends OPC:CL:sand (binder:sand ratio 1:3)
NHL 5 6.6%	23.1 to 30%	1 : 1 : 6 16.5%
NHL 3.5 8.2%		1 : 2 : 9 21.97%
NHL 2 16.5%		

Water lubricates the binder particles, governing plasticity. Workable site mortars have an average consistency with a flow between 180mm and 210mm (vibrating table - EN/BS 1015-3 test is conducted at 190mm). Flow values below or above these figures will produce, respectively, unworkable or unusable fluid mortars.

CL binders are finer than NHLs (average 10 microns versus 50 microns) so more water is required with CL binders to achieve the necessary plasticity as it has to cover a greater number of particles.

The greater the amount of water the greater the shrinkage and its related higher suction and loss of strength. The simple explanation is that water evaporates, creating voids, resulting in shrinkage stress within the mortar. When this stress is superior to the cohesion strength, micro cracks occur. At the surface these would be barely visible but they are contained mainly within the mortar matrix. CL binders demand more water and its evaporation will increase the shrinkage stress within the mortar resulting in weak mortars, requiring protection against frost for a long period (often up to 1 year, depending on the thickness of the mortar and the exposure zone) as these mortars rarely reach a compressive strength above 2 N.mm².

The induced porosity described also produces higher suction due to the capillary system of the micro cracks, allowing

rain water penetration which not only slows carbonation of the free lime but also frost/thaw heave in cold climates. It is the capillary structure that promotes water permeability (absorption) as the micro cracks on their own represent only a small part of the pore structure of the mortar.

The effect of high free lime content on capillarity and water absorption is quite clear in Table 4 where, for example, an OPC/CL blend has higher capillarity and shrinkage when the free lime content is increased (1:2:9 v 1:1:6) and lower permeability when cement is present due to Portlandite crystallisation within the void structure.

Table 4. - Capillarity/shrinkage/vapour permeability Binder:sand ratio 1:3

Capillarity/shrinkage/vapour permeability	St. Astier mortars			NHL/CL mortars 50/50/3		CL + cement blends OPC:CL:sand	
Capillarity: g.min (@ complete carbonation)	NHL5 4.61	NHL3.5 6.30	NHL2 8.7	NHL 5 12.94	NHL 3.5 13.75	1:1:6 1.08	1:2:9 6.86
Shrinkage mm.m 28 days	0.15	0.25	0.51	0.84	0.89	0.63	0.42
Vapour permeability g.air.m ² .h (@ complete carbonation)	0.52	0.72	0.72	0.63	0.68	0.23	0.25

Pure CL mortars have a higher vapour permeability than NHL and blended mortars which would partly compensate for higher water absorption but they are more susceptible to adverse climatic conditions for a much longer period of time. Their hardening time is prolonged and they need several interventions to prevent high shrinkage.

Carbonation of free lime is directly related to the mortar exposure to air. Simply explained: limestone (CaCO₃) during burning releases CO₂ and becomes CaO. To harden*, it needs to re-absorb CO₂ from the air, returning therefore to CaCO₃. This process is called carbonation. Factors impeding carbonation are surface damp (formation of a surface patina impeding contact with air), surface water (rain), non breathable surface coatings and finishes. Mortars placed within structures (consolidation/grouting mortars) or building/re-pointing thick walls will also have poor or much slower carbonation in the areas not near to the surface of the joints. The presence of un-carbonated free lime causes lime leaching if water is also present because un-carbonated free lime is partly soluble in water at a ratio of 1.6g. per litre (less in presence of other salts).

** Hardening is not to be confused with setting. It takes much longer and is related to carbonation of free lime and, in hydraulic binders, full development of belitic and alitic reactions.*

The bonding strength of mortars, so important in rendering and plastering work, is also related to the free lime content in the binder.

Table 5

St. Astier lime mortars binder:sand ratio 1:3		NHL/CL mortars 50/50/3 binder:sand ratio 1:3		CL + cement blends OPC:CL:sand - binder:sand ratio 1:3	
NHL 5	0.51	NHL5/CL	0.28	1 : 1 : 6	0.7
NHL 3.5	0.46	NHL 3.5/CL	0.22	1 : 2 : 9	0.5
NHL 2	0.36				

The average bonding strength of a pure CL 90 mortar will be much lower than the 50/50 NHL-CL mortars shown in Table 5. It might reach the minimum requirement of 0.3 N.mm² at full carbonation, but this would expose the work to potential weather damage for too long a period if one considers that the carbonation of pure CL is about 5-10mm per year.

Conclusion.

Although the presence of free lime helps the workability of a mortar, the higher the amount of free lime, the higher the water demand, capillarity, water absorption shrinkage, setting and hardening time. The bonding strength and frost resistance are lower.

The higher the free lime content the more careful should be the consideration given to the application season and protection of these mortars, especially in high rain exposure zones and in cold climates.

The addition of pozzolanic materials will enhance the setting properties of mortars with high free lime content but not much is known about the long term complete effect of pozzolanic additions on the other properties and the overall durability of these mortars.

If, to enhance the setting, cement is added as in the case of a number of mortars widely used, there is a detrimental effect due to the composition of cement and the other properties of cementitious mortars as shown earlier in this document.

In conservation and restoration it is essential to achieve compatibility of new materials with the existing ones. In many situations weak mortars or mortars with a high free lime content are required. When looking at the possibility of using these mortars the following considerations should be made:

- Site exposure
- Application season
- Protection and curing
- Condition of the building structure (good or friable etc...) and its detailing
- Walls dampness and causes
- Presence of salts
- Choice of aggregates
- Void structure, vapour permeability and capillarity requirements of the new mortar/s.
- Thickness and depth of the joints (carbonation time of building – pointing mortars) or size and structure of voids (injection and grouting mortars).
- Thickness of the render (thin renders with mortars with high free lime content will carbonate quicker than thick renders).
- Workmanship and ability of the contractor to comply with the specifications issued

When dealing with ancient structures further consideration has to be given to:

- The function of the new mortar in relation to the state of the structure. This issue arises especially in the conservation of ruins where weak mortars might have been used to construct the original structure but the intervention now required is to preserve what is left. A chemically compatible stronger mortar could be the correct choice, especially in very exposed sites.
- The potential loss of binder in the existing mortar
- The correct individuation of the presence of soluble silica (hydraulic element) in the existing mortar.
- The durability requirement in relation to possible future interventions or maintenance (from “sacrificial” to “perennial”).

The responsibility of the specifier is to understand the intervention needed and choose the most suitable mortar/s for the work to be done. The responsibility of the supplier is to provide correct and in depth information to assist the specifier in making the correct choice. The responsibility of the contractor is to provide the necessary skills and follow the correct working practice.

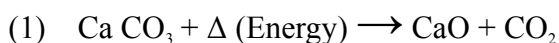
Potential failures are possible if the composition of the binder/s to be used is not known or understood, if additions (cement, pozzolans, additives) are made without knowing their long term effects, if superficial knowledge is mistaken for professional knowledge and if price considerations prevail on technical ones.

Ugo Spano/Laurent Tedeschi
September 2006

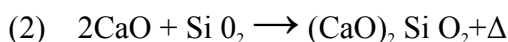
Annex 1

Summary of formation and effects of reactive silica

All natural limes are produced in industries by calcination of calcareous rocks at a temperature ranging from 900°C to 1300°C. Below these temperatures, carbonation (1) yield is not sufficient and at high temperatures, lime crystals will combine back and the resulting quick lime will be hard to slake. For natural limes with hydraulic properties, there is formation of overburned CaO which explains how slaking NHL lime is slower than slaking CLs. The slaking reaction of NHL passes through a maturing phase as described by M LE CHATELIER. In this phase all CXS are preserved.



If calcium oxide or quick lime is in contact with silica, combination will result. This reaction is exothermic



In other words, this reaction gives energy in opposition to decarbonation reaction (1) which is endothermic (takes energy from the system to happen). It is necessary to heat limestone to produce lime but as soon as this lime is produced, it combines exothermically with hydraulic elements present.

Limes are generally produced in vertical kilns so material must stay in solid form through the whole length of the kiln in contrast to cement production where horizontal kilns are used and material is transformed through a liquid state (fusion).

Silica is present in limestone as small inclusion particles (>1 mm) and has only a superficial contact with calcium oxide. Combination reactions are only produced on the surface of silica particles. The internal silica particles do not combine but have been heated and the surface combination reaction is exothermic (2).

Original silica particles in the quartz crystalline state (sand) change to amorphous state (pozzolan, basalt, pumice) by the effect of heat. When these are crushed through grinding, amorphous silica becomes available. This amorphous silica is called "pozzolanic". A very basic (pH ~ 12.5) mixture that brings amorphous silica in solution, as indicated by Boyton, is obtained when lime is mixed with water to prepare a mortar,



It precipitates with free lime to produce :



The "types" of CHS (x, y and z values) obtained after reaction are related to the concentration of the present species but these crystals do not correspond to CSH obtained by belite (C₂S) crystallisation. Theoretically these "types" can be identified but in practice no exhaustive studies have been conducted.

This pozzolanic gain is active or useful since the increase of mechanical performance can only be efficient if there is some hydraulicity in the system which is the case in natural hydraulic limes. For calcium limes, this hydraulicity is introduced by addition of cement or from endogenous activators in crushed pozzolans [Na₂O, K₂O (alkalis) with SiO₂ in pozzolans].

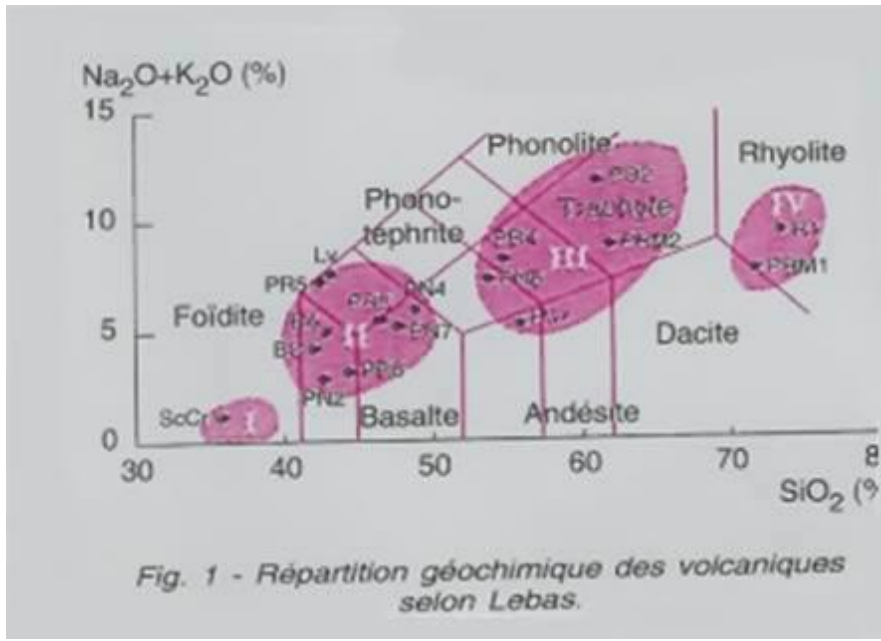


Fig. 1 - Répartition géochimique des volcaniques selon Lebas.

In this table, a mixture of pozzolan is represented with no sand since alkalis would dissolve the sand. To obtain measurable performance increase, C_xS_yH_z must have seeds of CSH to grow, this is the crystalline germination step.

In conclusion: there will be no pozzolanic activity if there was no initial hydraulicity. Addition of amorphous silica to calcium lime will not provide measurable mechanical performance increases whereas additions to NHL2 can result in a very high compressive strength increase.

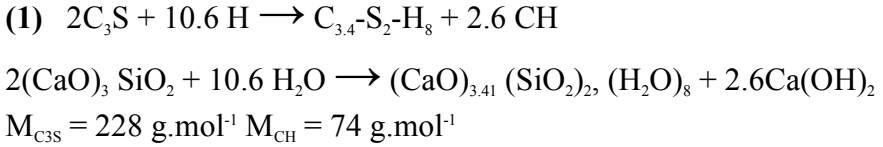
In an NHL mortar, the influence of amorphous silica not initially combined to form calcium silicates but made available through the crushing of some oversized slaked hydraulic lime granules is positive since it fixes the Portlandite [Ca(OH)₂] formed in the hydration of C₂S and limits the risk of surface efflorescence caused by leaching of Ca(OH)₂.

Annex 2

Difference in C₂S v C₃S hydration and Portlandite formation

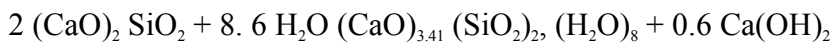
During mortar setting, C_xS (C₂S and C₃S) will hydrate to produce « C-S-H » compounds according to the following equations (1) and (2)

Alite hydration (C₃S) :



1 % in mass of C₃S will produce $74*2.6/228*2 = 0.42\% \text{ mass}$

Belite Hydration (C₂S) :



$$MC_2S = 172 \text{ g.mol}^{-1} \quad MCH = 74 \text{ g.mol}^{-1}$$

1 % in mass of C₂S will produce $74 \cdot 0.6 / 172 \cdot 2 = 0.13\%$ mass

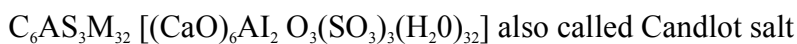
Comparison of equation (1) and (2) leads to the following observations:

C₃S and C₂S will hydrate to form the same CSH resulting in similar mechanical performances but C₃S will produce 3,2 times more Portlandite than C₂S, increasing the risk of lime leaching.

Annex 3

Aluminates and sulphates: sulphate attack.

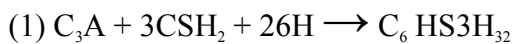
Aluminates can produce “delayed” ettringite by reaction with sulphates that are contained in ancient masonry work (gypsum roughcast, gypsum renders on walls, capillary effect from sulphate water) or coming from urban pollution. Ettringite is a calcium hydrate of aluminate trisulphate with the following formulation:



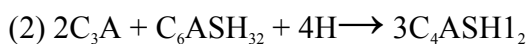
Sulphates are added to cement to control its set time since the aluminates contained in cement have a very rapid set (measured in minutes) which causes a false set.

These sulphates are added in the form of gypsum that is “captured” by the aluminates at the beginning of hydration to form “premature” ettringite. These reactions are harmless towards final quality of the mortar since its initial set has not yet started.

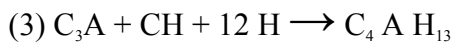
The following reactions are taking place (1)-(2) and (3)



Gypsum has been “consumed” by reaction (1) giving:



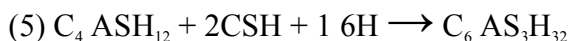
Premature ettringite reacts to give:



These reactions are normal in a cement based component but if sulphates are added to the mortar after it has set, the following reactions occur :



with C₄ASH₁₂ from equation (2) we obtain:



$$M = 623 \text{ g.mol}^{-1}$$

$$d = 1990 \text{ kg.m}^{-3}$$

$$\left. \begin{array}{l} \\ \\ \end{array} \right\} V \text{ mol} = 1240$$

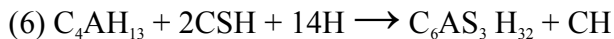
$$M = 1255 \text{ g.mol}^{-1}$$

$$d = 1750 \text{ kg.m}^{-3}$$

$$\left. \begin{array}{l} \\ \\ \end{array} \right\} V \text{ mol} = 2144$$

Crystal volume almost doubled $1240 \rightarrow 2144$

With C_4AH_{13} from equation (3) we get:



$$M = 560 \text{ g.mol}^{-1}$$

$$\left. \begin{array}{l} \\ \\ \\ \end{array} \right\} \begin{array}{l} V_{\text{mol}} = 1148 \\ \\ \\ \end{array} \quad V_{\text{mol}} = 2144$$

$$d = 2050 \text{ kg.m}^{-3}$$

Again, crystal volume almost doubles $1148 \rightarrow 2144$

These expansion reactions take place when the mortar has already set and is no more flexible.

The expansion caused by salt crystallization results in pressure that can be as high as 70 to 240 MPa according to some authors. This stress is considerably higher than the cohesion strength of a mortar, which is in the order of 4 to 6 MPa.

Annex 4

CO₂ EMISSION OF VARIOUS BINDERS

Material - Energy Requirements	Fuel (coal) Kg/Ton	Therms Per Ton	Kilowatts/hour Per ton
Cement	110	900	120
Hydrated CL 90%	84	650	50
NHL 2 with 75% CL	82	634	37
NHL2 with 60% CL	78	605	28
NHL3,5	70	550	25
NHL5	75	650	27

Material	CO ₂ per Kg/Tonne of Binder				
	Emission during burning	Emission from de-carbonation	Total emitted during production	Re-absorbed	Not Re-absorbed
Cement	403	416	819	NIL	819
Hydrated CL 90%	308	564	872	535	337
NHL 2 with 75% CL	300	528	828	445	383
NHL2 with 60% CL	286	430	716	350	366
NHL3,5	256	350	606	270	336
NHL5	275	360	635	220	415

CO2 EMISSION of VARIOUS MORTARS

MORTARS 1 : 2 binder/sand ratio	Weight of binders/ kg per ton of mortar	Total CO2 emission(not re-absorbed) kg per ton of mortar	MORTARS 1 : 3 binder/sand ratio	Weight of binders / kg per ton of mortar	Total CO2 emission(not re-absorbed) kg per ton of mortar
Cement	250	205	Cement	182	149
Cement/CL 1:1:4	133/67	132	Cement/CL 1:1:6	95/47	94
NHL2 with75%CL	135	52	NHL2 with75%CL	96	37
St. AstierNHL 2 with60%CL	143	52	St. Astier NHL 2 with60%CL	100	36.3
St. AstierNHL3.5	166	55	NHL3.5	117	39
St. AstierNHL5	185	77	NHL5	131	54

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