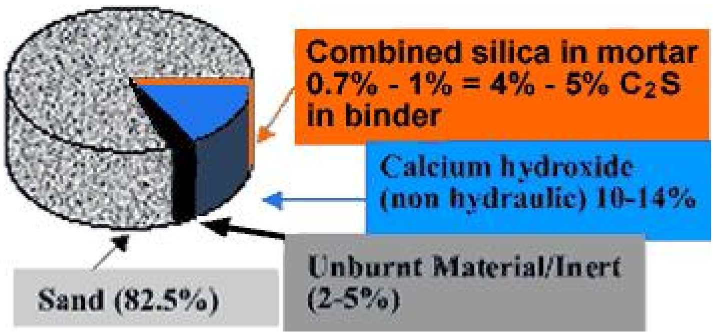
Hydraulicity and Properties of St Astier Natural Hydraulic Lime

Hydraulicity is the property of a binder to harden in contact with water.

Hydraulicity is produced by burning a limestone containing silica, alumina and iron oxides which above certain temperatures combine, totally or partially, with the Calcium Oxide. The resulting silicates, aluminates and ferrites give hydraulic properties to the product. Today as in the past, natural building limes are obtained by burning and slaking limestone and the more or less hydraulic character of the finished product is directly related to the percentage of calcium silicates, aluminates and ferrites formed during burning. The composition of the Earth crust shows the predominance of silica and its presence is almost inevitable in all limestone deposits.

The building limes of the past, if the soluble (combined) silica content is analysed, will almost certainly show some hydraulic property, even if very feeble. The analysis of historical mortars today rarely takes this factor into account and, as sometimes the amount of combined silica in a mortar is minute, a number of findings will not identify the hydraulic component in the mortar.

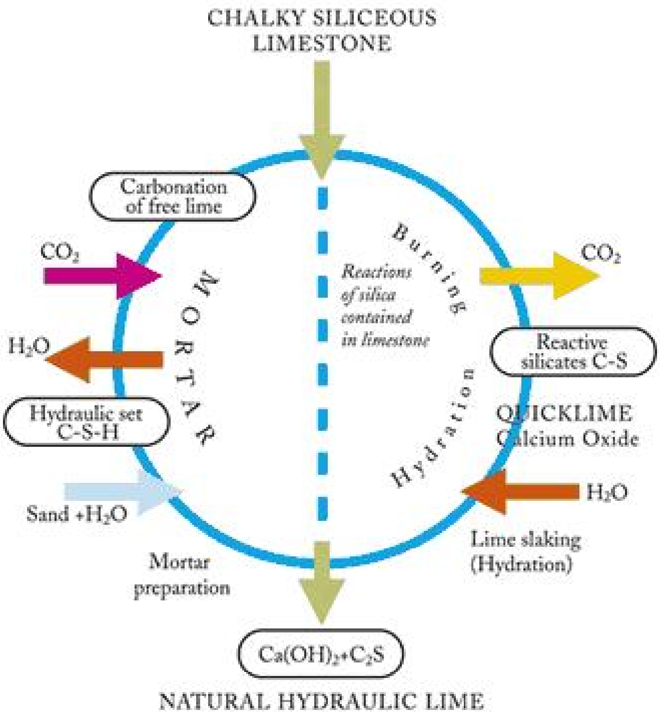
For example: an amount of 4% of combined silica in a binder represents, in a typical mortar with a 17.5% binder content, only about 0.7 % of the total mass of the mortar but still this mortar will be feebly hydraulic. See example below based on an NHL 2 with a binder/sand ratio of 1:2.5



The existence of pure Calcium Carbonate deposits is not common. High Calcium limes are mainly exploited for industrial use (i.e. steel industry), where it is essential to have an almost pure material. Even in metamorphic type calcareous stone such as marble, silica is found. The little amount of Silica required to combine with the CaO during burning makes the production of Hydraulic properties almost inevitable when the raw material is a calcareous stone.

This mortar will be almost certainly classified as non hydraulic by most analysts. If a "match" is required, this might be erroneously made by adopting a non hydraulic high calcium lime instead of a feebly hydraulic lime.

The Making of St Astier Hydraulic Limes and Mortars



The quality of hydraulic limes derives from the mineralogical composition of the raw material and the manufacturer's skill and production control. See: Mineralogy and Chemistry of Raw Materials & Products".
The absence of sulphates in the St. Astier limestone and the low traces of alkali such as Potassium and Sodium cannot result in products which will favour sulphate attack or alkali-silica reactions. The low amount of alumina will produce only very low levels of tricalcium aluminates, so important in avoiding sulphate attack. **Annex 1** clearly shows the potential damaging components in binders which are responsible for many of the long term deterioration and failures in mortars.
The result of an efficient burning and controlled slaking is that St. Astier products have a high percentage of free lime residual very much above the minimum limits required by the Standards for hydraulic limes.

Minimum Free (available) Lime		EN/BS 459	St. Astier
requirements $Ca(OH)_2$ %	NHL 5	3	15-20
	NHL 3.5	9	24-26
	NHL 2	15	over 50

A number of classifications have been put forward. The main ones are listed below, together with their shortcomings:

1. Classification related to setting time.
It is based on the principle that limes with a setting time of over 1 day are not hydraulic.
The relevant tests are conducted on a lime paste and therefore cannot be acceptable as hydraulic limes are used in mortars (lime + aggregates). The setting time in mortars depends not only from the hydraulic properties of the lime but also from the volumetric ratio of the mortar mix and other factors such as water content.

2. The cementation index.
It supposes that there is no unburned residue and that combined silica (SiO_2) is present as C_3S. Although this is correct in Cement it is not so in the case of hydraulic limes where C_2S is the main hydraulic component and there is always an unburned residue.
A high level of C_3S would not allow hydraulic lime mortars to be reworked as, for example, possible with St. Astier limes.

3. - Classification based on colour.
They were dismissed by their own Authors.

4. - Vicat classification
In the early 19th century L. Vicat established that Limestone containing Silica, Alumina and Iron Oxides would produce Hydraulic limes. He attributed the presence of these to "clay" impurities in the limestone and proceeded to classify in relation to the amount of "clay" content in a calcareous stone. He based his Hydraulicity index on the following formula:

$I = (SiO_2 total+Al_2O_3+Fe_2O_3) / (CaO\ total)$

Vicat did not consider, however, that not all the SiO_2 is soluble (some of it is insoluble quartz) and therefore available to combine with the CaO. Furthermore he supposes that all the $CaCO_3$ in the stone is converted in CaO during burning with no residue, which is also incorrect. Vicat formula is perfectly applicable to cement where the high burning temperature ensure that all components are combined in their near totality with the CaO but cannot be today adopted for hydraulic limes. For example, using the Vicat Hydraulicity Index, cement has an Index (I) of 0.42 with a compressive strength of approximately 55 N/mm^2 @ 28 days and an NHL 3.5 would have an Index of 0.37 with a compressive strength of 50 N/mm^2 !

5. - The theory of soluble (combined) Silica

This is by far the most reliable method of classifying hydraulicity.

The principle is simple but indisputable: the silica contained in a calcareous limestone is combinable or inert. The appropriate burning process determines the quantity of silica that will combine. This explains how from a uniform deposit, such as St. Astier quarry, it is possible to obtain different hydraulic characteristics from the same stone. Soluble silica combines with the CaO (ratio of approx. 1:3) during burning at 900°-1,000°C, forming CS (Calcium Silicates) which are responsible for hydraulicity. **See Annex 2.**

The amount of available silica in the stone is the determining factor. Limestone containing less than 4% will not produce hydraulic limes. From 4% and above hydraulicity will be generated in direct proportion to the combined amount between available silica and CaO. **See Annex 3.**

Soluble silica and ancient mortars analysis.

The soluble silica theory is of great value when studying ancient mortars to try and individuate their more or less hydraulic behaviour. Once it is agreed that the soluble silica combines with the CaO to produce reactive Calcium Silicates, by finding the levels of soluble silica in ancient mortars one can establish their degree of hydraulicity and match them if so required. By using this method it will be surprising how many ancient mortars would show hydraulic properties. This is due to the fact that our forebears were making building lime with limestone rarely free of silica, alumina and iron oxides (minerals present in clay, hence the popular definition of "clay contamination"). As said previously, it would be enough for the soluble silica to be as low as 4% to generate hydraulic properties in the lime.

Consideration on pozzolanic additions to achieve setting in mortars not made with hydraulic limes.

Due to the properties of today's Air Limes (putty or hydrated), the use of pozzolans is necessary in the majority of cases to allow the builder to get on with his work but the attention to be paid to the water content in the mix, the variable setting properties, the granulometric and colour requirements, result in unnecessary complication, higher costs and higher potential risk of failure

The use of pozzolans is not needed with St. Astier limes. If the main reason for the use of pozzolanic material is to create an hydraulic effect then the use of the correct grade of natural hydraulic lime will achieve the same or better result in a safe and reliable manner.

The composition of the raw material, the experience of the Manufacturer in the production process and the quality control procedures have made available to the User a range of Natural Hydraulic Limes suitable for all construction requirements.

Annex 4 shows some of the most important performance characteristics of St. Astier NHL mortars compared with blended NHL/Putty mixes and cementitious mixes (1:1:6 and 1:2:9)

Here are some of the reasons why St. Astier NHL limes are widely accepted and appreciated:

Purity - NO ADDITION of any kind is made to the St. Astier NHL products to enhance their performance.

No need for blending - The St. Astier range permits the builder to select the most suitable product for the work at hand without having to add pozzolans, cement, plasticisers, water retainers, waterproofers etc.

Blending introduces considerable risks of errors, added costs and final short and long term results which are uncertain and therefore hazardous.

Compatibility - The availability of a range of pure binders with different performance characteristics ensures the compatibility of St. Astier NHL mortars with existing mortars whatever their age.

Free lime content (available lime). - Responsible for workability and self healing in NHL mortars.

Economy - Generally binders are bought by weight but mixed by volume, their bulk density therefore determines the volume used. The lower the density the less will be the weight of product used when mixing by volume. The low bulk density of all St. Astier NHL products is such that when comparing with cement, lime putties and some other hydraulic limes, with the same weight of material purchased one can obtain a sizeably larger quantity of mortar.

Example: taking the density of NHL 2 at 550 gr/litre versus lime putty (1,350gr/litre), the density of putty is 145% greater than NHL 2, so at the same volume, NHL 2 will produce more mortar.

Versatility of use - Building, rendering and plastering mortars, grouts, injection, concrete, paints are all uses that can be achieved with NHL products.

Motars performance - Mortars made with St. Astier NHL binders achieve:

Elasticity	A factor in building without construction joints. Important in diminishing shrinkage and cracking. Allows for minor movements.
Permeability	Good vapour exchange qualities allow for condensation dispersion. No rot. Great benefits to the living environment.
Resistance to salts	The absence of any potentially damaging addition (i.e. gypsum or cement) make sulphate attack, alkali-silica reactions impossible. Existing salts in the building fabric will pass through and eventually can be washed off. Excellent performance in marine environment
Suitable Compressive Strength	Unlike cement or cementitious mixes (1:1:6 etc..) the compressive strength will be achieved gradually, allowing for movement. The availability of a range will permit the making of mortars with the required strength without having to add or blend.
Resistance to weather	Early setting will provide quicker protection from adverse weather. See "Protecting Lime Mortar".
Self Healing	The available lime provides this quality. A timely light water mist over a minor shrinkage mark will help to heal it.
Resistance to Bacteria and Vegetable growth	The alkalinity of the binder does not favour their development
Insulation	The porosity of the mortar present good insulation values.
Sand colour	The whiteness of the NHL binders will reproduce the colour of the aggregate used
Reworking	All St. Astier mortars can be reworked (8 - 24 hours), reducing wastage and increasing work speed. This is due to the absence of cement, gypsum or pozzolans.
Recycling	Materials built with NHL mortars can be reused.
CO_2 absorption	probably the most Eco friendly contribution of using limes. Damaging CO_2 is re-absorbed during the carbonation of the free lime.

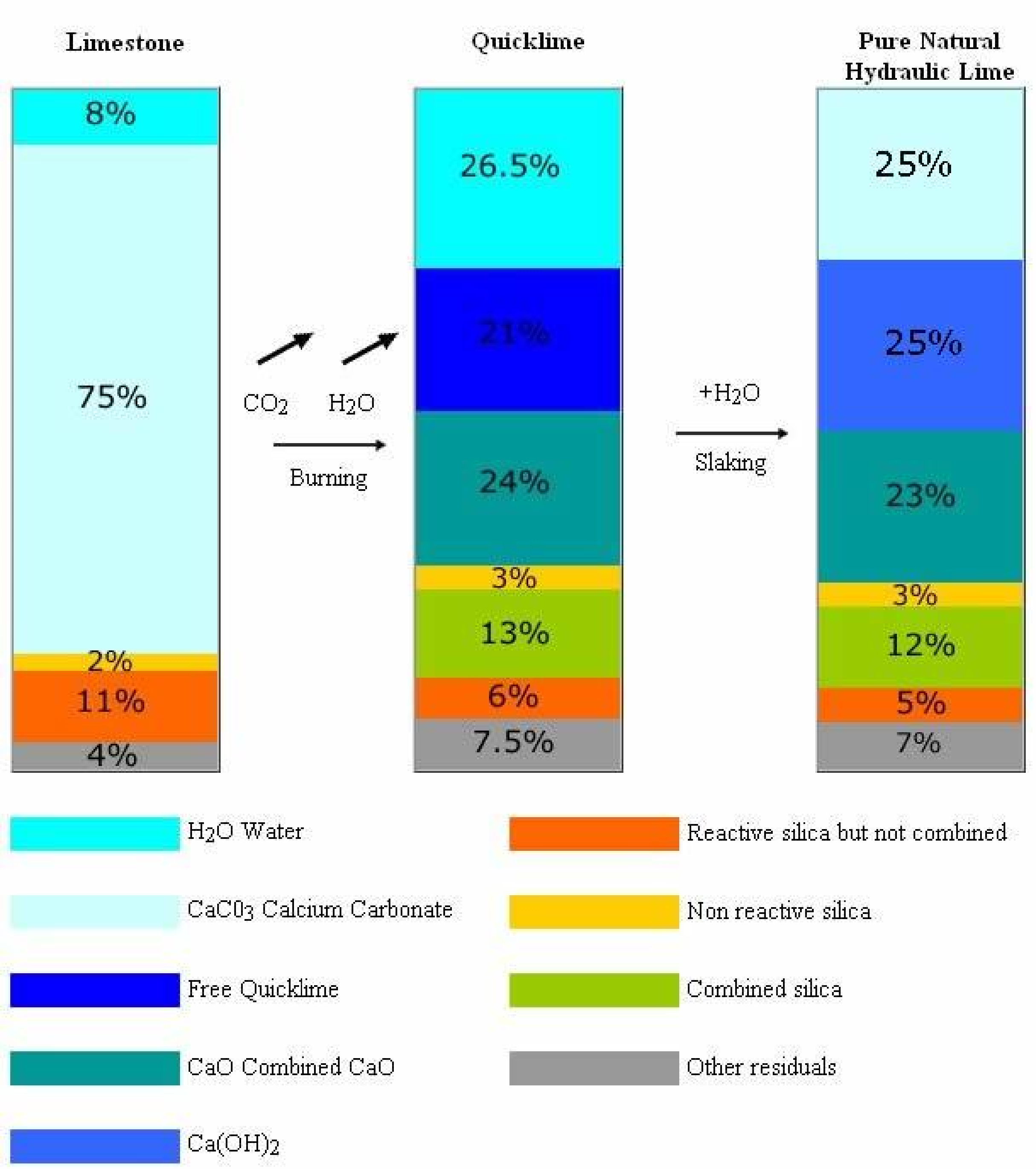
Hydraulicity and Properties - Annex 1

Potentially damaging components in binders

		% content in		
		OPC	NHL	**Potential damaging effect**
Tricalcium Aluminate	C_3A	3 - 10+	<1	Reacts with Sulphates and water producing sulphate attack causing mortar deterioration and eventual failure. Reacts with sea salts. Affects bricks/stones.
Tetracalcium Aluminoferite	C_4AF	8 - 10	NIL	Reacts with Gypsum causing expansion
Sulphates	SO_3	2 - 7	0.4 -0.6	Contributes to sulphate attack
Alkalis	Na_2O/K_2o	1 - 3	>0.1	Reacts with the silicates in cement and sand producing gradual disintegration ALKALI-SILICA REACTION
Gypsum	$CaSO_4$	2 - 9	NIL	Subject to expansion, efluorescence. Deteriorates in contact with sea salt

Note: in marine locations the air contains sea salt which reacts with C_3A in OPC, causing serious damge to cementitious renders.

Hydraulicity and Properties - Annex 2

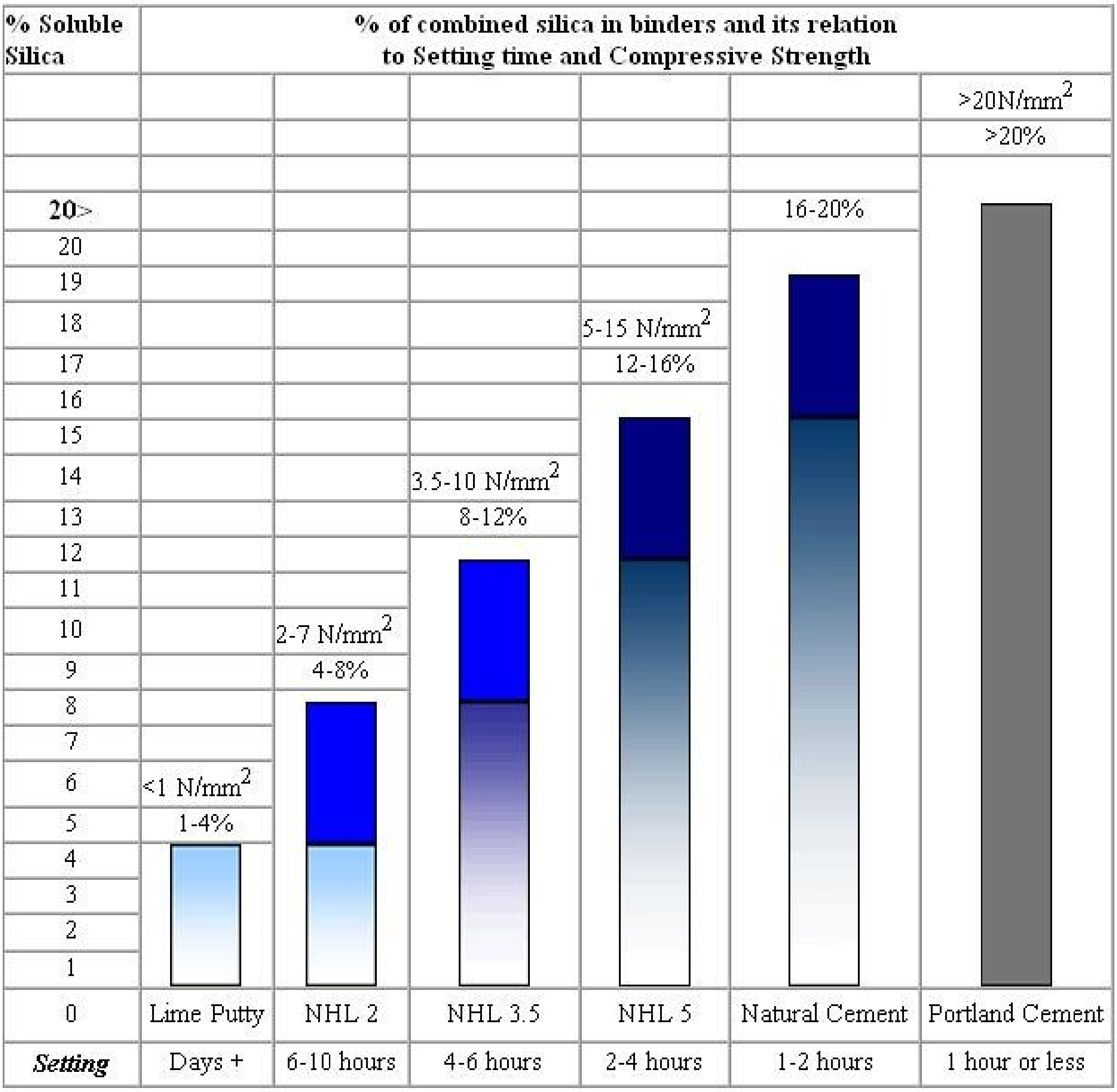


Chemical Process in the Production of Pure and Natural St. Astier Hydraulic Lime:
Limestone - Quicklime - Pure Natural Hydraulic Lime

Hydraulicity and Properties - Annex 3

Hydraulicity: % of soluble silica and relative hydraulic properties

EU Norm 459-1		NHL Classification
NHL 5	5-15	
NHL 3.5	3.5-10	N/mm^2 @ 28 days (mortars prepared with a binder:sand ratio of 1:1.3)
NHL 2	2-7	



Hydraulicity and Properties - Annex 4a

St. Astier NHL mortars characteristics compared with Cement mortars and OPC/CL lime mortars (Putties/hydrated lime) Sand used: well graded sharp sand 3mm - 0.075

			Tests on pure NHL mortars			Tests on cement/ hydrated lime mixes		
			NHL5	NHL3.5	NHL2	OPC/CL(hydrated)		Notes
Volumetric mix (binder/sand)			1 : 2.5	1 : 2.5	1 : 2.5	1:1:6	1:2:9	
Set (beginning) / hours			2-4	4-6	6-9	1.0	1.0	A
Elasticity Moduli	28 days	MPa	11000	9000	9800	16200	15595	B
	6 mths	MPa	17050	13505	12030	22010	19300	B
	12 mths	MPa	17280	13620	12030	22210	19700	
	24 mths	MPa	18020	13785	12000	22150	19650	
Compressive strength	28.days	N/mm^2	2	1.47	1.36	7.7	5.56	C
	6 mths	N/mm^2	5.9	5.30	3.00	8.1	5.75	C
	12 mths	N/mm^2	8.44	5.90	2.90	8.7	6.05	
	24 mths	N/mm^2	8.81	6.00	3.00	8.5	5.95	
Vapour exchange (air $gr/m^2/h/mmHg$)			0.55	0.65	0.71	0.23	0.25	D/E
Shrinkage 28 days mm.m.			0.13	0.44	0.6	0.63	0.42	

The water addition in the shrinkage test was regulated to obtain mortars with the same workability (flow table test 190 +/- 5mm)

N O T E S

A - Mortars containing OPC start setting too quickly.
B - OPC mortars are not as flexible as lime mortars.
C - NHL mortars achieve a good compressive strength gradually, allowing for movements
D - Cementitious mixes will retain moisture
E - At complete carbonation

Hydraulicity and Properties - Annex 4b

St. Astier NHL mortars characteristics compared with Cement mortars and OPC/CL lime mortars (Putties/hydrated lime) Sand used: well graded sharp sand 3mm - 0.075

		Tests NHL/Putty(CL)/Sand Mixes NHL 5/CL				Tests on cement/hydrated lime mixes		
						OPC/CL(hydrated)		Notes
Volumetric mix (binder/sand)			0.9/0.1:3	0.7/0.3:3	0.5/0.5:3	1:1:6	1:2:9	
Set (beginning) / hours			3.5	5.25	9.5	1.0	1.0	A
Elasticity Moduli	28 days	MPa	11000	10020	8000	16200	15595	B
	6 mths	MPa	16000	14000	12030	22010	19300	
	12 mths	MPa	16510	14320	12030	22210	19700	
	24 mths	MPa	16500	13950	13220	22150	19650	
	28days	N/mm^2	1.4	1.1	0.6	7.7	5.56	
	6 mths	N/mm^2	4.8	3.95	2.97	8.1	5.75	
	12 mths	N/mm^2	5.3	4.1	2.8	8.7	6.05	
	24 mths	N/mm^2	5.25	4.31	3.85	8.5	5.95	
Vapour exchange (air gr/m^2/h/mmHg)			0.60	0.59	0.63	0.23	0.25	D/E
Shrinkage 28 days mm.m.			0.25	0.60	0.84	0.63	0.42	

The water addition in the shrinkage test was regulated to obtain mortars with the same workability (flow table test 190 +/- 5mm)

N O T E S

A - Mortars containing OPC start setting too quickly.
B - OPC mortars are not as flexible as lime mortars.
C - NHL/Putty mortars are considerably weaker than NHL mortars.
D - Cementitious mixes will retain moisture
E - At complete carbonation.

Hydraulicity and Properties - Annex 4c

St. Astier NHL mortars characteristics compared with Cement mortars and OPC/CL lime mortars (Putties/hydrated lime) Sand used: well graded sharp sand 3mm - 0.075

		Tests on pure NHL mortars NHL 3.5/CL				Tests on cement/hydrated lime mixes		
						OPC/CL(hydrated)		Notes
Volumetric mix (binder/sand)			0.9/0.1:3	0.7/0.3:3	0.5/0.5:3	1:1:6	1:2:9	
Set (beginning) / hours			6.5	8.5	10.0	1.0	1.0	A
Elasticity Moduli	28 days	MPa	8400	8050	7510	16200	15595	B
	6 mths	MPa	13220	12600	11000	22010	19300	B
	12 mths	MPa	13410	12900	11050	22210	19700	
	24 mths	MPa	14250	13010	10850	22150	19650	
Compressive strength	28days	N/mm^2	1.3	1.1	0.75	7.7	5.56	C
	6 mths	N/mm^2	3.9	3.63	2	8.1	5.75	C
	12 mths	N/mm^2	4.8	4.45	3.75	8.7	6.05	
	24 mths	N/mm^2	4.75	4.55	2.65	8.5	5.95	
Vapour exchange (air $gr/m^2/h/mmHg$)			0.69	0.71	0.68	0.23	0.25	D/E
Shrinkage 28 days mm.m.			0.35	0.67	0.89	0.63	0.42	

The water addition in the shrinkage test was regulated to obtain mortars with the same workability (flow table test 190 +/- 5mm)

N O T E S:

A - Mortars containing OPC start setting too quickly.
B - OPC mortars are not as flexible as lime mortars.
C - NHL/Putty mortars are considerably weaker than NHL mortars.
D - Cementitious mixes will retain moisture
E - At complete carbonation

For further Guidance, contact your St Astier Distributor.