THE LOUIS VICAT TECHNICAL CENTER
MATERIALS and MICROSTRUCTURES LABORATORY
Special Binders Section

TECHNICAL SPECIFICATIONS

USE OF PROMPT NATURAL CEMENT IN MIXES WITH NATURAL HYDRAULIC LIMES

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CONTENTS

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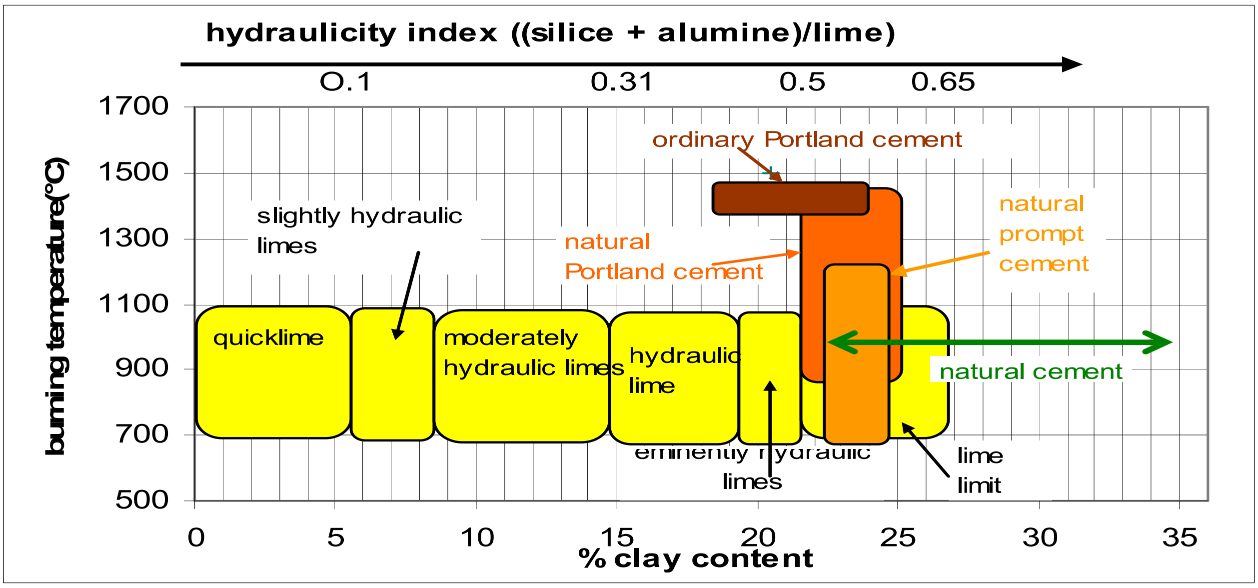
1) THE PROMPT NATURAL CEMENT AND HYDRAULIC LIME

1.1 A common history

At the beginning of the 19th century throughout all of Europe, a substitute was created to replace the then-widespread lime and pozzolan mixes dating back to Roman times. Pozzolan, imported from Italy, was expensive and highly inconsistent in quality. In keeping with the spirit of the 18th century and for reasons of economics, as well as national independence and the pursuit of technical advances to enhance hydraulicity, a good number of lime kiln operators turned to firing limestone with greater impurities using empirical formulations with widely varying results.

In 1818, Louis-Joseph Vicat developed for the first time the theory of hydraulicity (i.e. the property of binders to harden when exposed to water) by scientifically demonstrating the influence of clay content found in the limestone of that period. By focusing on the clay/lime ratio, he defined the "hydraulicity index", which allowed classifying the lime and natural cements being produced at the time (see Fig. 1) and inventing artificial cements by recomposing the lime and clay mixes.

Figure 1: THE CLASSIFICATION DERIVED BY L. VICAT



This same foresight led L. Vicat to oversee the first industrial fabrication of PROMPT NATURAL CEMENT in 1842 at the same Grenoble site where lime was being quarried from a clayey limestone outcropping he found in 1827. His son Joseph would continue producing this natural cement in the nearby Chartreuse region at the "Perelle" site, where to this day operations are ongoing. Due to the intrinsic attributes of the raw material input, the VICAT PROMPT NATURAL CEMENT has become today's only natural cement produced in industrial-scale quantities throughout the world. At the time however, natural cements, also called "Roman cements" or "Roman lime" or simply "hydraulic lime", were being produced all over using limestone with variable clay contents from one deposit to the next and even in some instances within the same deposit.

The natural cement produced by Vicat can be distinguished from commercially-labeled "Roman cements" by its raw materials, a clayey limestone with an outstanding and unique composition featuring the double characteristic of:

- a constant chemical composition, yielding cement of a consistent quality; and
- an ideal mineralogical composition, thanks to optimal clay content, making the cement resistant to higher-temperature firing, given that at the time it was possible to produce, using the same parent rock, a high-quality natural Portland cement. As such, this material was a precursor of today's artificial Portland cements.

1.2 Joint production process

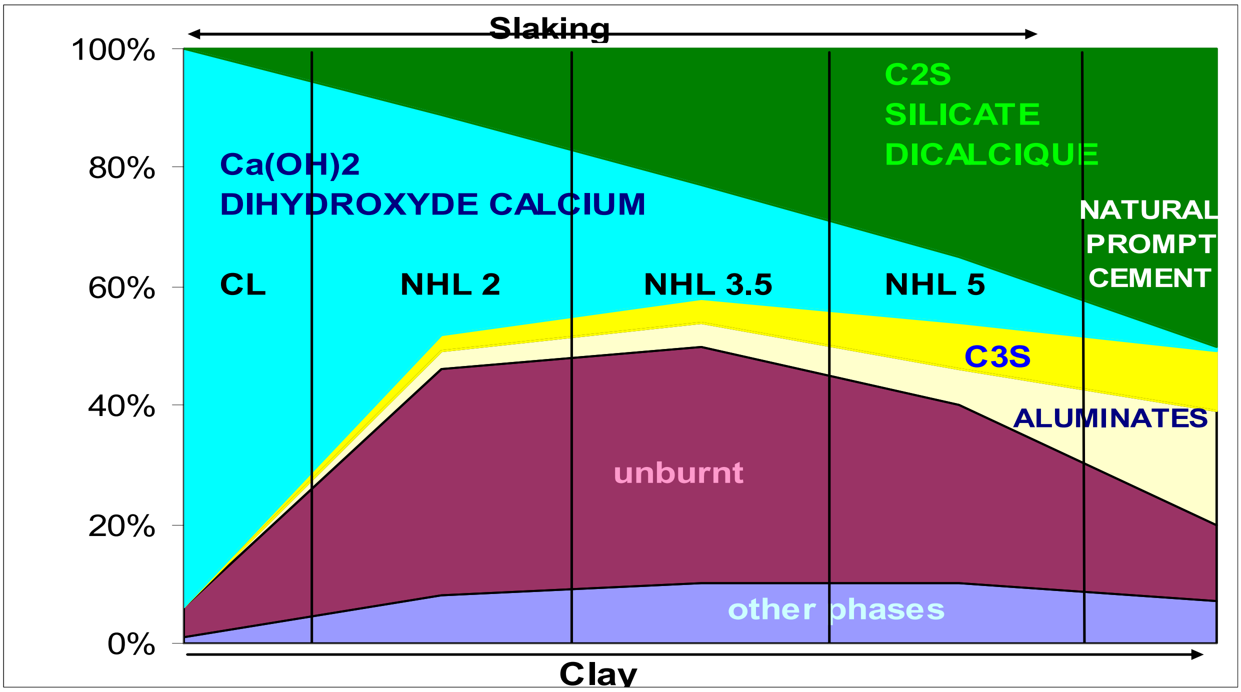
At present, while furnace technology has considerably progressed, the firing process for PROMPT NATURAL CEMENT (PNC) is still extremely close to that employed for producing lime.
PNC thus shares a large number of attributes with lime, in particular with NATURAL HYDRAULIC LIMES (NHL), i.e.:

- No admixture is used, just a single and unique stone is fired, hence use of the qualifier "natural".
- Raw materials are selected from very specific geological beds in order to obtain an optimal and consistent chemical composition; NHL stem from either siliceous or clayey limestone, while PNC are derived from a clayey limestone with a slightly-greater clay content.
- Firing procedures are identical, i.e. same temperatures of less than 1.200°C, in a shaft kiln.

1.3 Overlapping mineralogy

As shown in the diagram in Figure 2, PROMPT NATURAL CEMENTS contain the same mineral composition as NATURAL HYDRAULIC LIME, yet in different proportions:

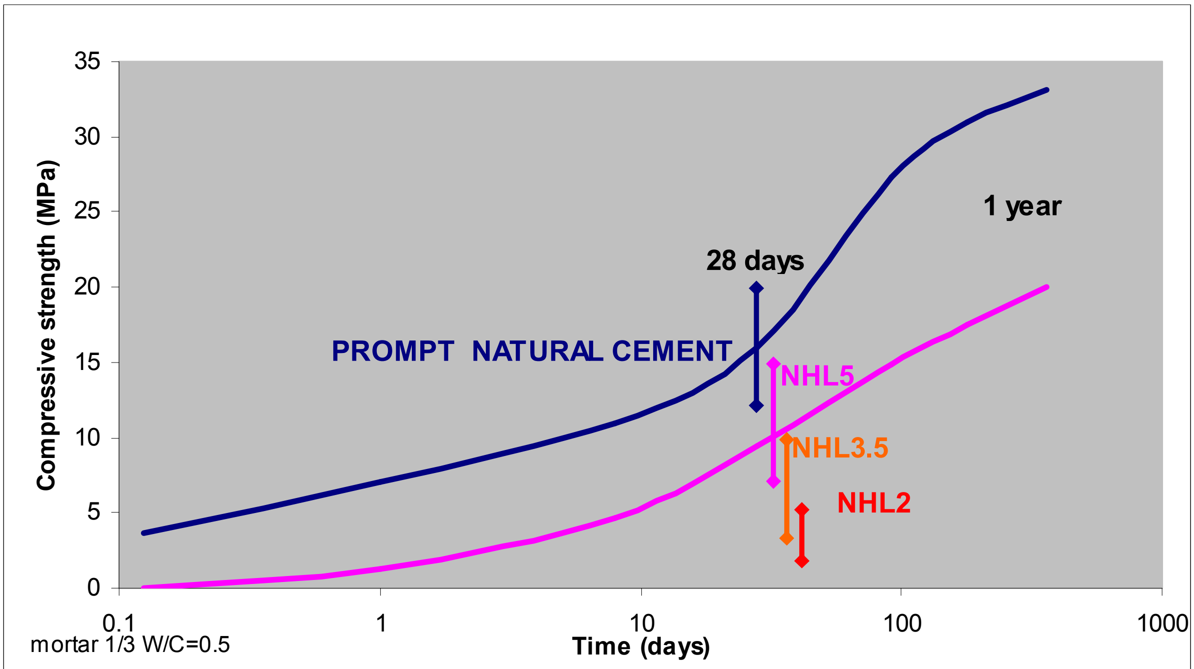
Figure 2: DIAGRAM OF LIME MINERALOGICAL COMPOSITION VS. RAW MATERIAL CLAY CONTENT



- The low-temperature and wide heat-range firing process results in a portion of the stone remaining "unfired".
- Dicalcic silicate (C2S) or belite content is substantial in any event and depends upon both the silica input from the raw material and the firing temperature. This mineral adds hydraulicity to the lime. At low solubility, its hydration will be slow and last several months, which serves to explain the slow rise in NHL strength.
- Tricalcic silicate (C3S) is present in small quantities; this mineral stems from partial and localized melting at the hottest points of the kiln. Its hydration is rapid, taking just a few weeks to be just about complete.
- Aluminates, more heavily present in PNC than in NHL, cause either a loss in workability at low concentrations in NHL or quick PNC setting and hardening.
- Calcium hydroxide or portlandite ($Ca(OH)_2$) gets set into the mixture with the airborne CO_2; practically the sole component of calcic limes (CL), it can reach very high levels in NHL. Generated in the form of CaO during firing, $Ca(OH)_2$ needs to be hydrated (the slaking phenomenon) for lime to be potentially useful. Nearly absent in natural cements as a result of combination with silicates and aluminates, this component is not required to undergo slaking, hence the validity of the term "cement".

1.4 Rise in parallel strength
Figure 3 shows that the PNC and NHL strength increase curves are parallel. This relationship demonstrates the long-term behavioral similarity between these two binders due to C2S hydration and, in part, to the carbonation of Portlandite in NHL. The normative 28-day strength values of all three NHL overlap in this figure. Using the same mode of operations as for NHL, PNC strengths at 28 days also converge with those of NHL5 and wind up only slightly higher. If PNC were categorized according to the standard operating mode for lime (EN 459-1), it would be equivalent in strength to an NHL12 given its range variation between 12 and 20 MPa.

Figure 3: HARDENING KINETICS OF BOTH PNC AND NHL



1.5 Summary table of properties shared among binders

	Lime		Cement	
Binder	CL	NHL	Natural cements	Portland cement (CEM)
Hydraulicity	no	yes	yes	yes
Slaking	yes	yes	no	no
Firing temp.	< 1200°C	< 1200°C	< 1200°C	1450°C
Quenching	weak	weak	weak	strong
Primary mineral	Ca(OH)2	C2S + Ca(OH)2	C2S	C3S
Raw material	A single "natural"	A single "natural"	A single "natural"	A mix of several "artificial"
Color	White	White to light gray	Ochre yellow to brown	Gray or white

Natural cements, such as natural hydraulic lime, are highly distinct from Portland cements, since only the hydraulicity property is shared. In contrast, NHL features five parameters in common with natural cements, and just lime slaking (abundant in NHL) serves to draw the distinction. As such, an impure NHL-PNC mix that respects NHL mineralogical characteristics is by far more compatible than an NHL-CEM mix, and more compatible than using NHL(Z).

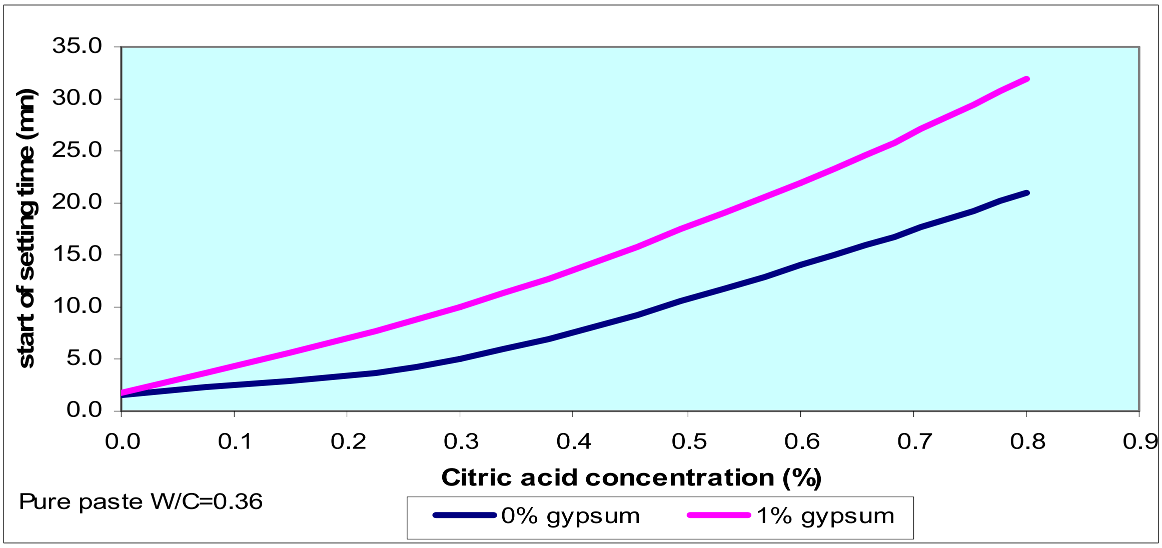
2. PNC PROPERTIES AS SEEN FROM THE STANDPOINT OF LIME

2.1 Setting time

Many applications require a long enough setting time to ensure installation under appropriate conditions. Given these requirements, PNC setting may be adjusted by adding special retardants such as trisodic citrate and citric acid. Adding a bit of gypsum serves to reinforce this phenomenon, as depicted in Figure 4.

A setting time of at least one hour is possible while maintaining 30-minute workability thanks to the PNC-NHL mix, in which case adding a retardant always proves essential during hot weather periods in order to avoid rapid loss of workability.

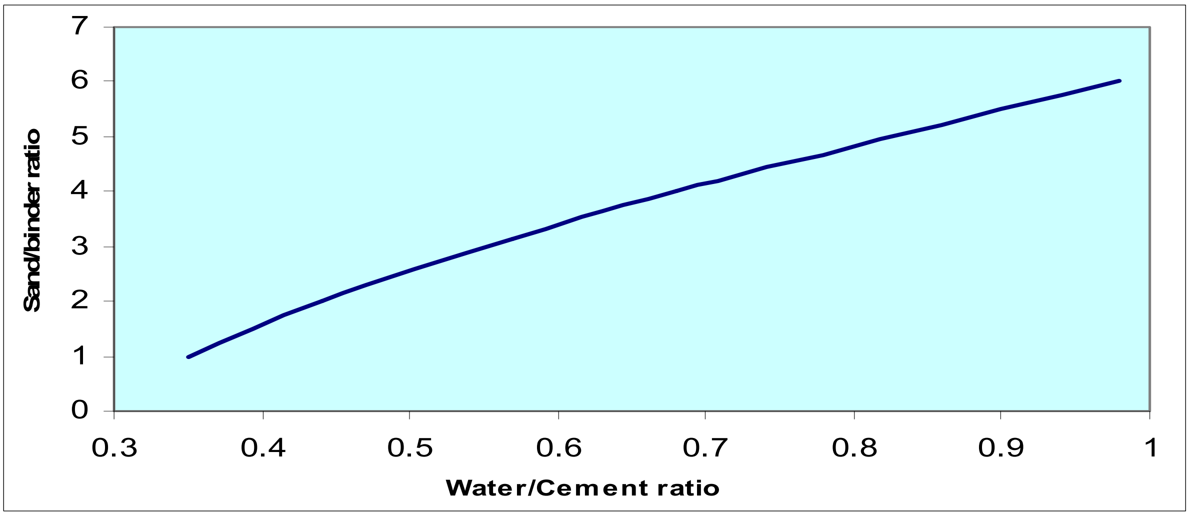
Figure 4: ADJUSTMENT OF PNC SETTING TIME



<u>Experimental conditions:</u>

All of the following tests were performed on mortars by varying the water/cement ratio. <u>In order to maintain constant workability, binder concentration was modulated as follows:</u> ***as the W/C ratio rises, binder concentration is lowered****. Figure 5 reveals that the relationship between W/C ratio and sand/binder (S/B) ratio is nearly linear.*

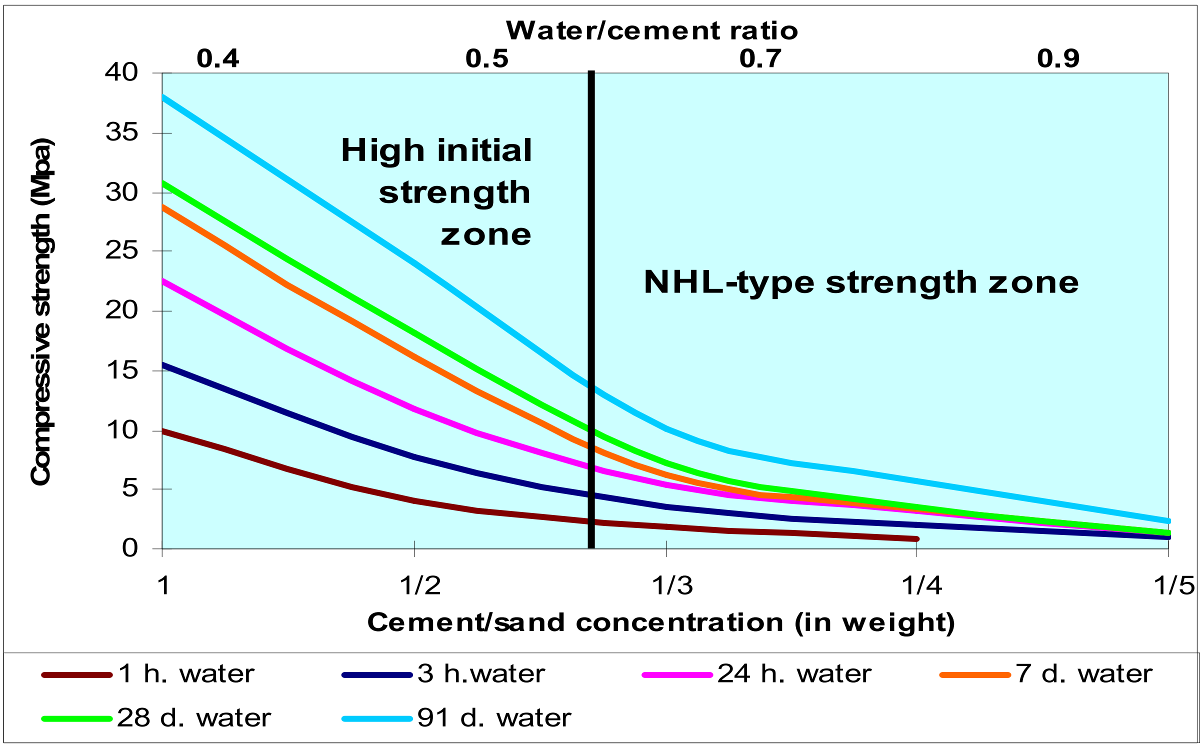
Figure 5: CORRELATION OF WATER CONCENTRATION WITH BINDER CONCENTRATION AT CONSTANT WORKABILITY



2.2 Strength relationships

Figure 6 shows the rise in strength vs. W/C ratio and concentration according to the function defined in Figure 5.
All mix designs based on PROMPT NATURAL CEMENT must take into account not only the advantage provided by early-age strength but also the rise in strength extended over the next several years, well beyond the standard 28-day period.

Figure 6: HARDENING KINETICS VS. CONCENTRATION AND W/C RATIO



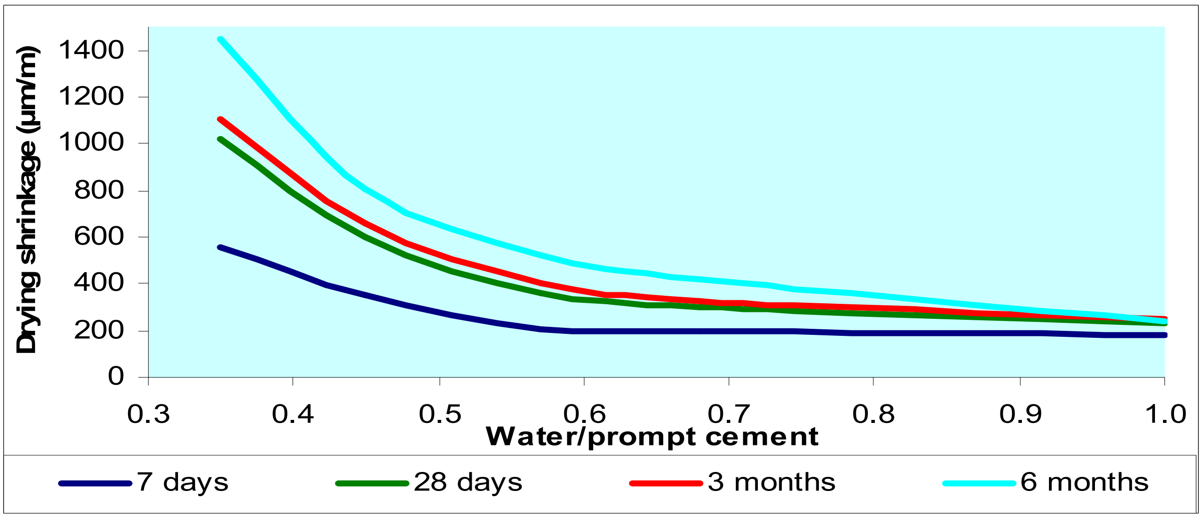
Whether with respect to the W/C ratio or concentration, PNC strength values can be categorized into two zones:

- Initial high-strength zone with a W/C of less than 0.55 and a cement/sand ratio of above 1/2.5; applications of sealant, waterproofing and impermeability treatment are to be included herein. By virtue of a performance that allows resisting structural forces, this zone lies closer to artificial Portland cements.
- The zone where strengths approximate those of NHL, the W/C ratio is greater than 0.5 and concentrations are closer to those when using lime. This zone is targeted by the present set of technical specifications since its long-term behavior is similar to that of NHL (see Fig. 3).

2.3 Shrinkage

The shrinkage of PROMPT NATURAL CEMENT is limited for W/C ratios in excess of 0.5 and S/B ratios of above 2, hence for mixtures with low concentrations. Shrinkage becomes more significant at lower W/C ratios and with an S/B ratio of less than 2 (see Fig. 7 below).

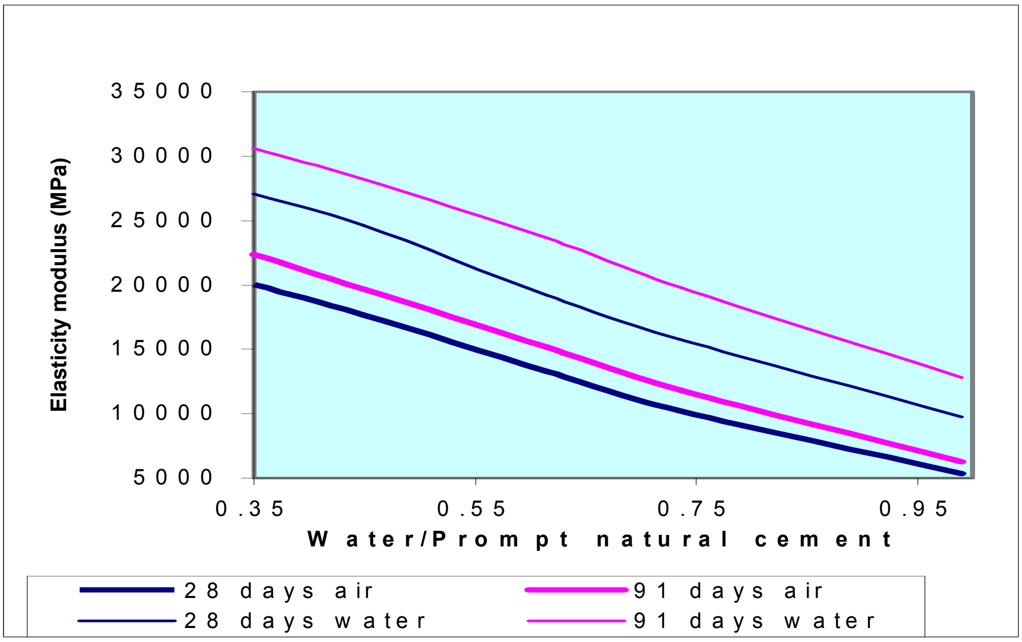
Figure 7: SHRINKAGE VS. W/C RATIO



2.4 Elasticity modulus

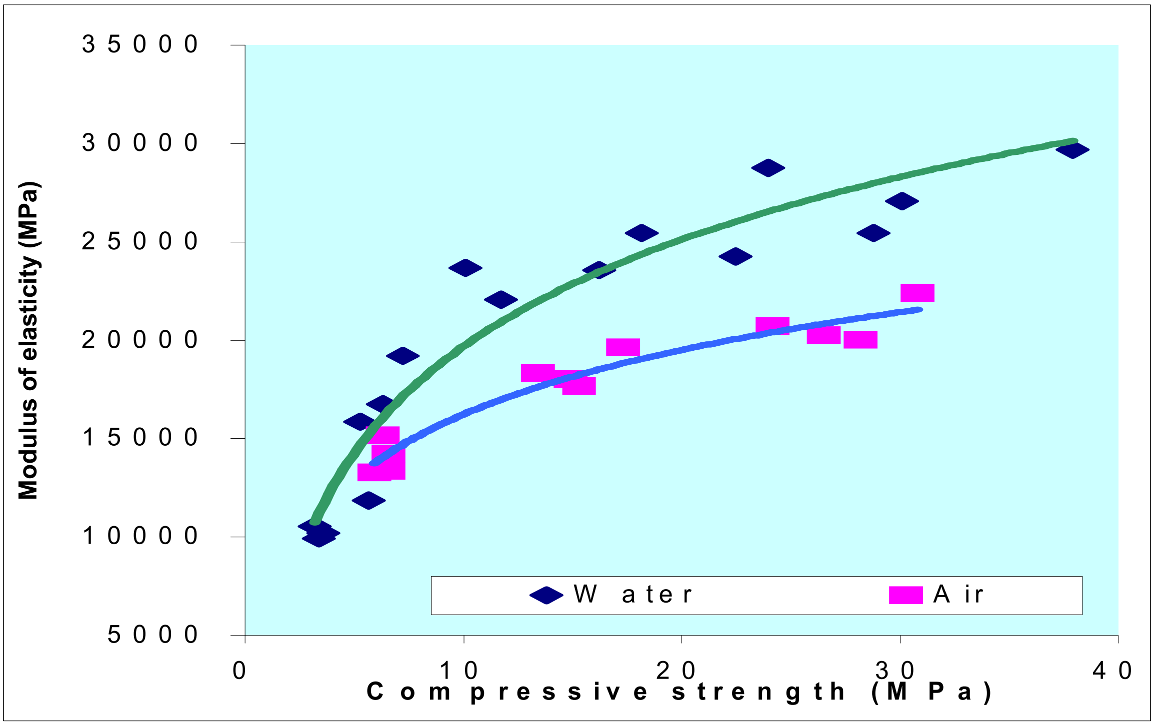
The elasticity modulus of PROMPT NATURAL CEMENT varies linearly with respect to the W/C and S/B ratios. At high W/C ratios, the modulus value lies close to that of NHL mixes.
Figure 8 shows the trend in elasticity modulus of PNC mortar after curing in both water and air.

Figure 8: ELASTICITY MODULUS VS. W/C RATIO



For purposes of illustration, the correlation between elasticity modulus and compressive strength has been given in Figure 9.

Figure 9: ELASTICITY MODULUS VS. COMPRESSIVE STRENGTH



3. APPLICATIONS OF PNC-NHL MIXES

3.1 COATINGS

Natural hydraulic lime is preferred for rendering mortars due to its efficiency, as demonstrated over the centuries in fulfilling the functions required to restore older buildings. To ensure its protective role, coatings need to perform two functions:

1. discharge the humidity in the supporting soil while providing protection from runoff water. The permeance effect enables measuring this humidity transfer in the form of vapor; and
2. protect the existing masonry, provided the coating is able to display an effective bonding. Two factors prove essential to this bonding property: elasticity modulus, since the coating must not be too stiff to withstand without breaking the sizable dimensional variations imposed by the former support (in many cases heterogeneous and soft); and drying shrinkage, which must be as low as possible to avoid adding more constraints that could lead to cracking and delamination.

We have already mentioned above that PROMPT NATURAL CEMENT mixed using the same water/cement ratio exhibits ultimate characteristics near those of lime. Moreover, PNC decreases the time of sustained workability; on the other hand, it adds "liveliness" at an early age, thereby providing the lime with new properties to allow:

- compressing the waiting period between layer applications;
- limiting shrinkage cracking, especially at early age;
- curbing the excessive dehydration of early-age coatings;
- applying excess coating (greater thickness) during a single run;
- strengthening the points that feature natural vulnerability: edges, jambs;
- working during cold weather periods.

Three types of mixes will be presented herein: a "fat" (high concentration) mortar for the base coat, a medium mortar for manual applications, and a low-concentration material for an applicator device used on the plaster layer.

3.1.1 Base coat

The sole purpose of this sublayer is to hold the coating onto its support. Its interface position requires a strong level of bonding and a rough surface finish, in addition to a high concentration level. This tack layer is no longer deemed necessary in cases where coatings are mechanically projected.

<u>Mix concentrations:</u>

In weight terms:

PNC	NHL 3.5	Sand 0-4R
200 kg	160 kg	1 M^3

In volume terms:

PNC	NHL 3.5	Sand 0-4R	Water
3 liters	3 liters	15 liters[3]	5 liters

<u>Preparation and onsite implementation techniques:</u>

Mixing steps at the concrete plant in the following order:

1. half the mixing water, then
2. sand,
3. lime,
4. the other half of the mixing water along with the Tempo retardant, as needed (1 shimmed plug per liter of PNC),
5. prompt natural cement,
6. a mixing time of less than 5 minutes,
7. the mortar is stored in small quantities at the time of use in order to avoid excessively fast setting due to the mass effect,
8. the mortar is not to be tempered; once its workability is no longer sufficient for normal implementation, the mortar must be discarded,
9. application will be conducted manually or using the applicator device.

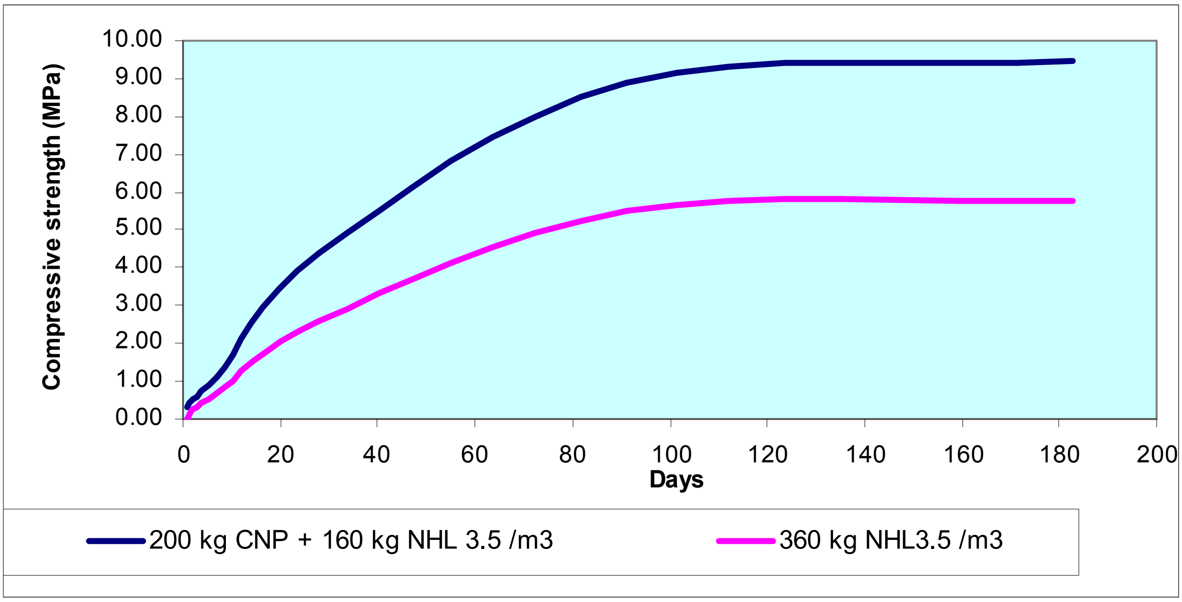
Mix characteristics:

This mortar loses workability after around twenty minutes and its setting lasts nearly 40 minutes at a temperature of 20°C.

Its permeance (which indicates the permeability to water vapor as per the M.O. specifications published by the CSTB industry association, 08/1993) is 0.60 g/m^2.h.mmHg for 0.57 on the NHL 3.5 control mix at the same concentration level. The mix is thus as permeable to water vapor as is the control mortar with an all-NHL base.

During hot weather, it is advised to add a retardant in order to sustain adequate workability.

Figure 10: COMPRESSIVE STRENGTH OF THE 360-KG MIX



Although compressive strengths (Fig. 10) are higher with our mix than with the control mix, nearly the same elasticity modulus (Fig. 11) and a sharply lower drying shrinkage (Fig. 12) lend the present mix all sorts of durability guarantees as regards both bonding and cracking.

Figure 11: ELASTICITY MODULUS OF THE 360-KG MIX

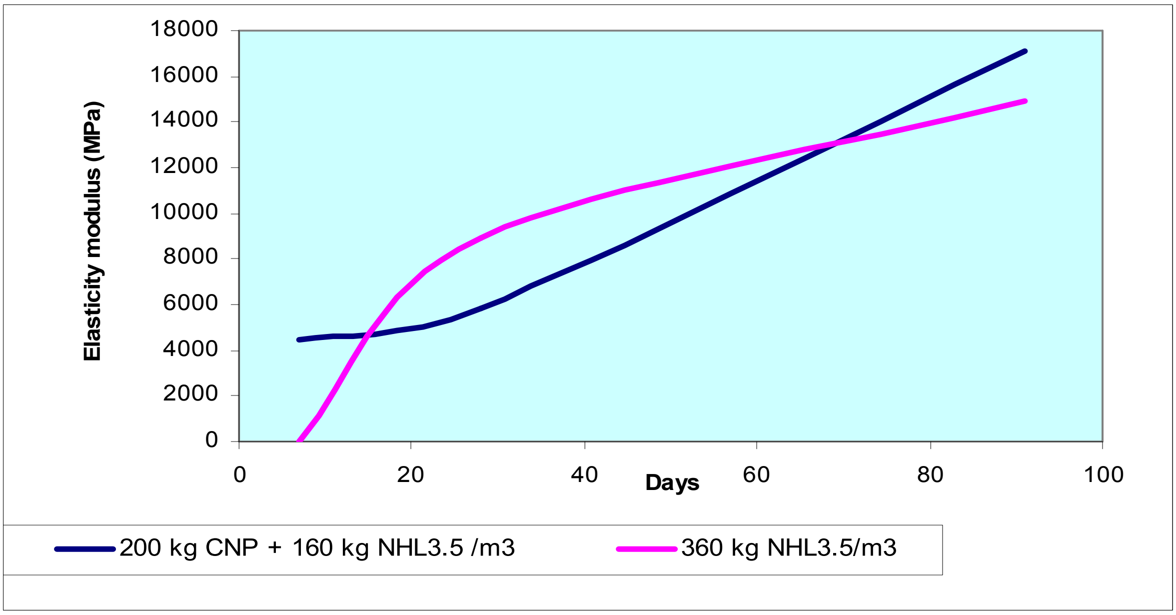


Figure 12: DRYING SHRINKAGE OF THE 360-KG MIX

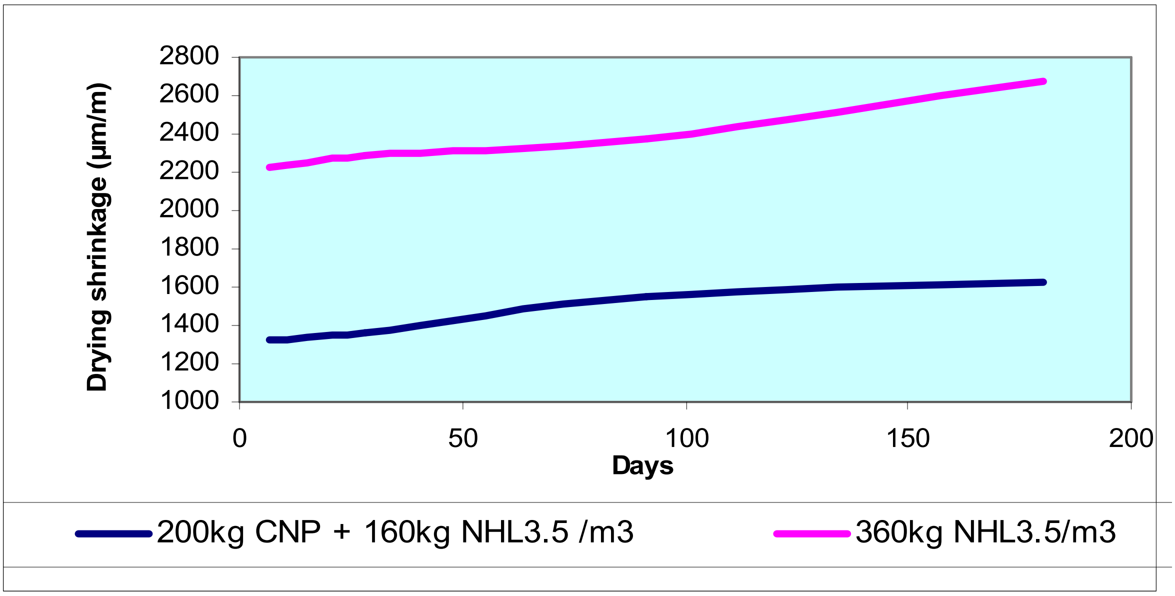
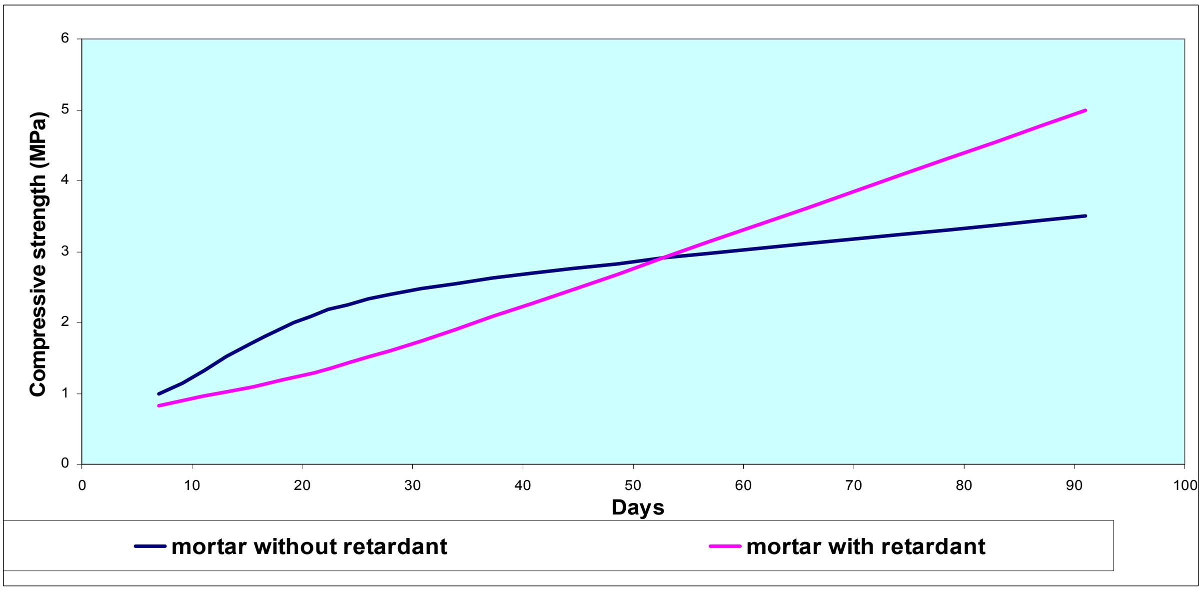


Figure 13: INFLUENCE DUE TO ADDING A RETARDANT



<u>Influence due to adding a retardant on medium-term performance:</u>

Figure 13 above shows the influence of adding a retardant (Tempo) to the recommended concentration levels on a "fat" mortar with a heavy PNC concentration, i.e. a composition of: 2 parts PNC, 2 parts NHL 3.5, 10 parts 0/3R sand, Tempo, and 3.75 parts water. The retardant slightly lowers the 28-day strengths and then increases them, although just as mildly, at 91 days. Durability therefore is not altered.

3.1.2 The plaster base or intermediate rendering

This layer serves to coat both the facing and the support protection; consequently, it must be compatible with such protection.

Two concentrations were tested: medium at 340 kg/m^3 for a manual application, and lean at 280 kg/m^3 for an applicator device:

Concentrations, in weight:

	PNC	NHL 3.5	Sand 0-4R
Lean mortar	70 kg	210 kg	1 m^3
Medium mortar	100 kg	240 kg	1 m^3

Concentrations, in volume:

	PNC	NHL 3.5	Sand 0-4R	Water
Lean mortar	2 liters	8 liters	30 liters	9.5 liters
Medium mortar	1.5 liter	4.5 liters	15 litres[3]	5 liters

Preparation and onsite implementation techniques:
The same as those previously defined for the base coat.
The coating will be applied with the striker or by "floating" depending on the desired finishing.

Mix characteristics:
At a temperature of 20°C, the loss in workability of these two mortars will occur after around 20 to 25 minutes, with mortar setting on the wall taking 30 to 60 minutes depending on support absorption. During hot weather, it is advised to add a retardant; one shimmed plug of Tempo per liter of PNC, in order to sustain sufficient workability.

The permeance (which indicates the permeability to water vapor as per the M.O. specifications published by the CSTB industry association, 08/1993) is 0.92 g/m^2.h.mmHg for the lean mortar and 0.78 g/m^2.h.mmHg for the medium mortar; the NHL-based references at the same concentration levels yield 0.76 and 0.73, respectively. These values enable an effective transfer of humidity in the form of vapor from the inside of the support to the outside by passing through the coating.

The medium mortar mix displays the highest strengths (see Fig. 14). The lean mortar mix and the two control mortars are similar.

Elasticity modulus values (Fig. 15) for the four mortars extend from 13,000 to 16,000 MPa, i.e. over the same value range. Just like for NHL mortars, the PNC-NHL mortar mixes tend to be quite "elastic" by virtue of resisting the variations in support lengths.

The low drying shrinkage of our mixes in comparison with the control lime mixes (Fig. 16) makes it possible to avoid a maximum shear stress at the level of the support interface; bonding is thus improved and the risk of cracking reduced. The drying shrinkage curves are all parallel, the PNC-NHL mix exhibits very low values as of the first measurement. By helping stiffen the lime mortar as of the very early hours, PROMPT NATURAL CEMENT enables a better resistance to drying stresses at early age.

Figure 14: RISE IN STRENGTH OF BOTH THE LEAN AND MEDIUM MORTARS

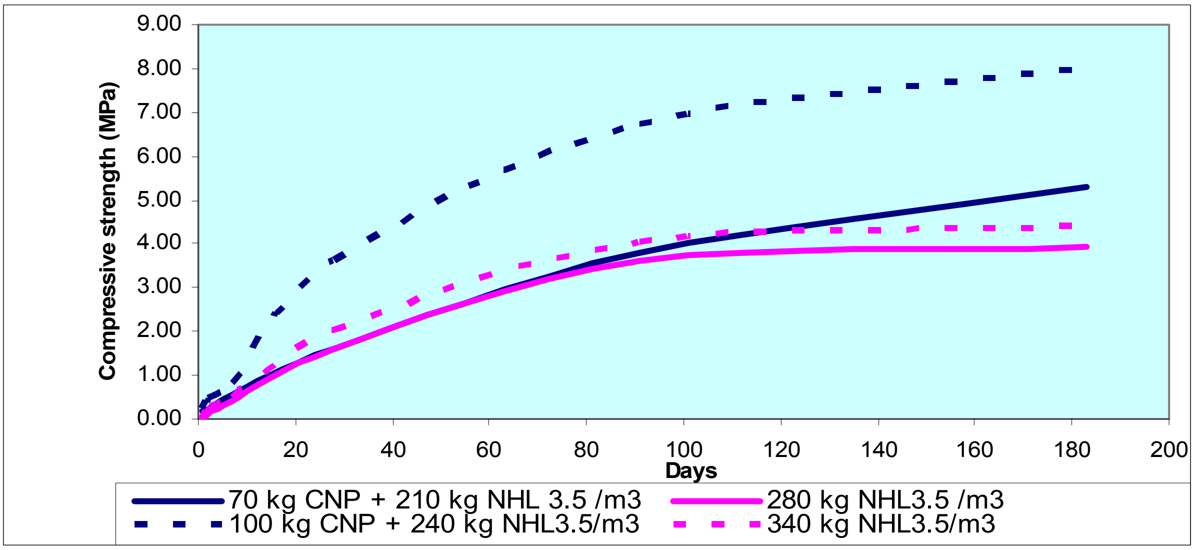


Figure 15: ELASTICITY MODULUS OF THE LEAN AND MEDIUM MORTARS

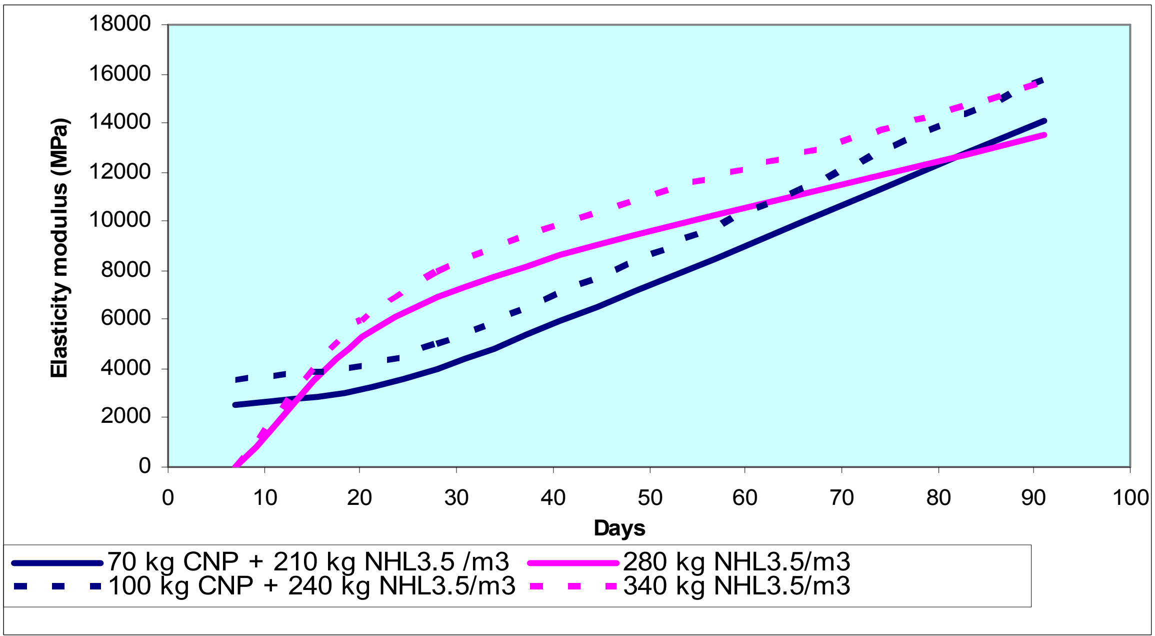
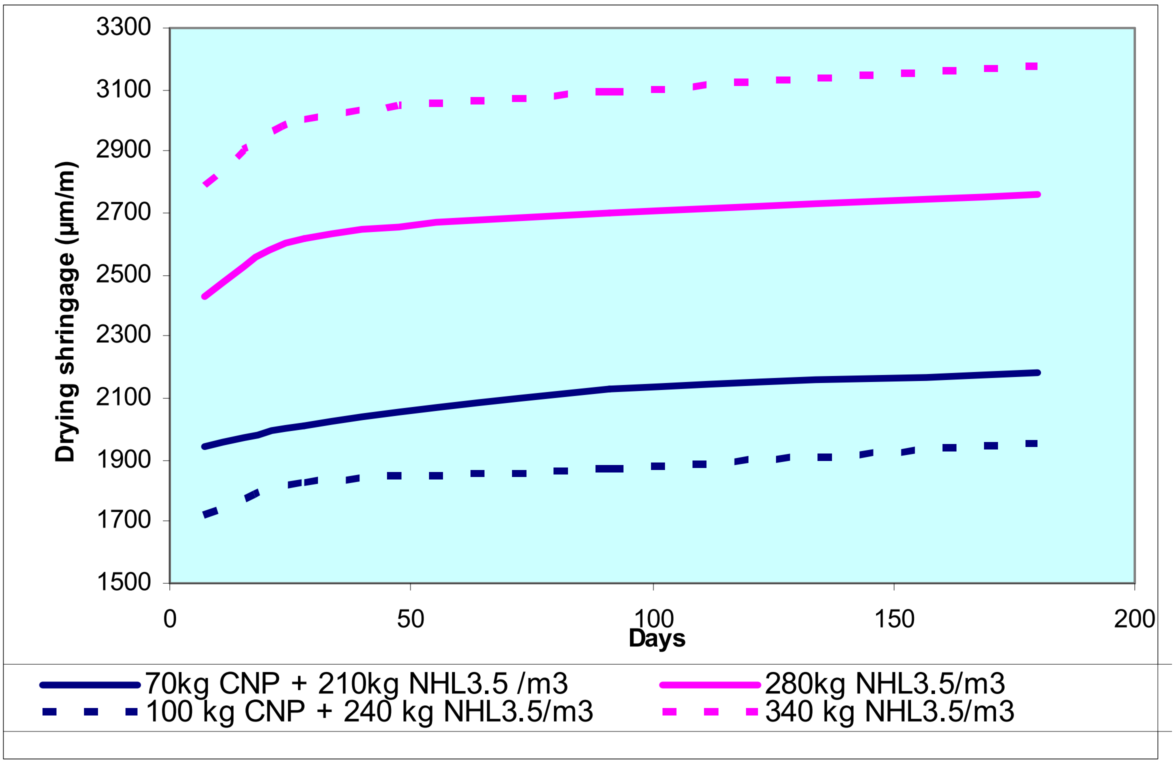


Figure 16: DRYING SHRINKAGE OF THE LEAN AND MEDIUM MORTARS



3.1.3 The finishing coat

This layer is solely intended for decorative purposes.

The time of sustained workability with these mixes is not sufficient for coating large surface areas without exposing the joints. On the other hand, applied at the wall base, this technique secures the wall base quickly against gushing rainwater, while leaving the possibility for the wall to "breathe" and develop minimal mechanical strength to resist various shocks and aggressive treatment.

3.2 THE PNC-NHL MIXES DURING ROUGHCAST APPLICATION

Roughcast mortar is the one implemented for assembling bricks or stone ashlar blocks that compose the wall. The choice of mortars used must account for the mechanical strength of both the bricks or ashlar blocks and the need to maintain a certain amount of structural permeance.

These structures comprise not only the aboveground walls, but also masonry arches and, in general, all construction made of stone ashlar blocks.

The addition of PNC to a roughcast lime mortar presents several benefits:

1. It improves bonding of the mortar to the building element, especially by limiting shrinkage during hardening;
2. It allows for rapidly advancing the roughcast works stage using small ashlar blocks or rubble, thanks to limiting creep of the beds by the onset of fast setting;
3. It makes partial loading of the base or supporting walls feasible, thereby facilitating operations in the substructure;
4. It shortens the waiting period prior to formwork removal of an arch or camber; and
5. It enables planning for works phases under cold weather conditions.

The concentrations recommended for this application have been adapted from widespread concentrations used for lime mortars, in accordance with DTU 20-1, such as for the lean mortar defined above:

	PNC	NHL 3.5	Sand 0-4R	Water
Lean mortar, in weight	70 kg	210 kg	1 m^3	-
Lean mortar, in volume	2 liters	8 liters	30 liters	9.5 liters

The preparation and onsite implementation techniques as well as the characteristics of these mixes have been established in the section on coating applications.

For works executed under emergency conditions, more heavily-concentrated mortars may be employed.

3.3 PNC-NHL MIXES IN INJECTION APPLICATIONS

Some existing masonry structures display structural disorders, yet must absolutely be held in place (i.e. common walls, elements of major archaeological significance, parts of structures that prove very costly or complex to replace). When these disorders entail cracking or disaggregation of the roughcast mortars, void filling by use of slurry may provide for effective consolidation.

This technique consists of gravity-pressure injection into the solid part of mixes containing binders, water and in some instances a fine sand. The structural consolidation provided by this technique requires preliminary jointing or the presence of coatings capable of performing this function. This technology must imperatively incorporate existing binders.

The solution proposed herein is incompatible with plaster-type binders. The introduction of fluid elements inside components already vulnerable has necessitated developing an expertise and special precautions regarding hydraulic pressure loading.

The addition of PNC to a lime-based injection slurry displays several advantages related to faster setting of the slurry:

- Possibility of injecting zones at the boundaries of structures not to be injected,
- Possibility of performing injections from one day to the next, or even more quickly, by means of shortening the loading consolidation period,
- Reducing leaks, the slurry is able to coagulate more rapidly,
- Possibility of working during cold weather,
- Adjustment of setting for enhanced control over the volume to be injected.

The recommended concentration level is:

PNC	NHL 3.5	Water	Retardant
3 liters	6 liters	8 liters	3 shimmed plugs of Tempo

<u>Preparation and onsite implementation techniques:</u>
Mixing steps at the concrete plant in the following order:

1. half the mixing water, then
2. sand, if applicable,
3. lime,
4. the other half of mixing water along with the Tempo retardant,
5. prompt natural cement,
6. a mixing time of less than 5 minutes,
7. the slurry is stored in small quantities during application in order to avoid excessively fast setting due to the mass effect,
8. the slurry is not to be tempered; once workability is no longer sufficient to be normally implemented, the slurry must be discarded,
9. injection is to be carried out by means of gravity flow.

<u>Mix characteristics:</u>
The use of retardant is vital to this application by virtue of controlling the time of sustained workability; it thus serves to control the volume of slurry to be injected.
At a temperature of 20°C, according to the above mix design, sustained workability is estimated to last 30 minutes. Setting on the wall will depend on both water absorption of the slurry by support aggregates and temperature. It is possible to add a fine- or coarse-grained sand to this mix design depending on the porosity to be sealed.
Strength levels are difficult to ascertain since the injected wall would have to be tested in its entirety.

3.4 MATERIAL APPLICATION DURING COLD WEATHER

The limited "liveliness" condition of lime mortars makes them particularly sensitive for works performed under cold weather conditions. This sensitivity will depend on temperature level:

- Below 10°C, setting will occur very slowly and the mortar will be especially vulnerable to efflorescence phenomena when the weather turns wet;
- Below 5°C, the lime mortar does not set during dry and windy weather conditions, with mortars tending to dehydrate, thereby causing a risk of dusting, cracking and delamination. The subsequent and inevitable hardening will thus be altered;
- Below 0°C, freezing adversely affects the mortar prior to setting; this phenomenon serves to fully disorder the mortar and is capable of leading to its destruction.

All NHL-PNC mixes discussed above have been tested both onsite and in the laboratory at temperatures of between 0 and 5°C; these test samples yield the following conclusions:

- Setting is slowed, yet still takes place during the subsequent hours.
- The period of sustained workability is extended.
- The rise in strength occurs more slowly; however, once temperatures start to climb, they reach the conventional NHL level.

These mixes thus lend the possibility of pursuing lime-based solutions during cold weather by means of providing what the use of lime alone can not.

Application of these mixes does not prevent against respecting all the good practice rules, i.e.:

- Excess water and use of water retention agents are to be avoided.
- Mortar application on frozen supports is prohibited.
- Thermal protection of structures under construction is essential.
- The use of colors either within the mortar mass or on the surface is discouraged.

3.5 PNC-NHL5 MIXES: STRENGTH VARIATIONS FROM NHL5 TO PNC

It is worthwhile to study PNC-NHL5 mixes in the aim of identifying solutions of natural hydraulic lime and natural cement for use in mortars or concretes inspired by the so-called "Roman" cements from the 19th century.

This type of mix generates all of the intermediate strengths between NH5 and PNC. Such a solution features a rise in strength over time that extends over several months, owing to a belitic-driven mineralogical composition similar to that of the Roman cements and lime used during the same period.

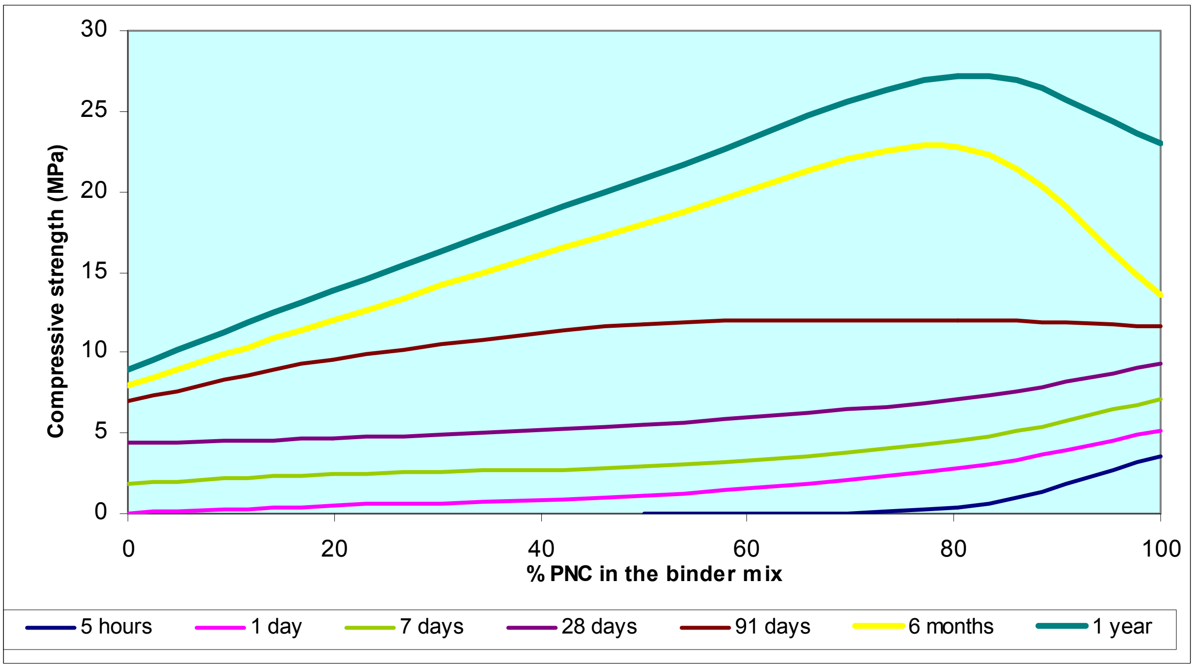
In time, it is also possible to derive strengths for impure NHL-CEM mixes or NHL(Z), while remaining natural without any contribution of minerals of the alite (C3S) type characteristic of Portland clinkers.

The applications anticipated with this type of mix are:

- restoration of mortars and concretes based on natural binders (lime or "Roman" cements and prompt natural cement) dating from the 19th and 20th centuries;
- "breathing" concretes that allow humidity to traverse in the form of vapor for smooth floors (terrazzo) or rougher floors in older buildings;
- mortars for facade ornamentation, cornices, or any form of dressing; and
- facade surfacing mortars on rigid supports or submitted to aggressive treatment (wall bases).

An example of a mix with NHL5 in the mortar has been shown in Figure 17. The concentration used is 300 to 350 kg/m^3, for a sand/binder ratio equal to 4 (in weight terms). Setting has been calibrated at 1 hour. It is important with these mixes to use a retardant in order to avoid any loss in workability before setting.

Figure 17: Example of PNC-NHL5 mix hardening kinetics



3.6 ABOUT TEMPERING

The standard tempering practice consists of remixing the mortar that had lost its workability in order to restore handling capability and a more oily consistency, which is highly appreciated during application of the finishing coating.

This loss in workability may be assimilated with a false setting due to hydration of the calcium aluminates (C3A and C4AF) and tricalcic silicate (C3S). These minerals are not present in sufficient quantity in NHL to cause actual setting, as is the case with PNC on its own. Let's not overlook that setting time measurement is, first and foremost, a rheological measurement.

The action of tempering the mortar also causes slaking of the lime, making it more heavily dispersed and hence finer; this phenomenon makes for an oilier consistency, again a characteristic highly appreciated during application.

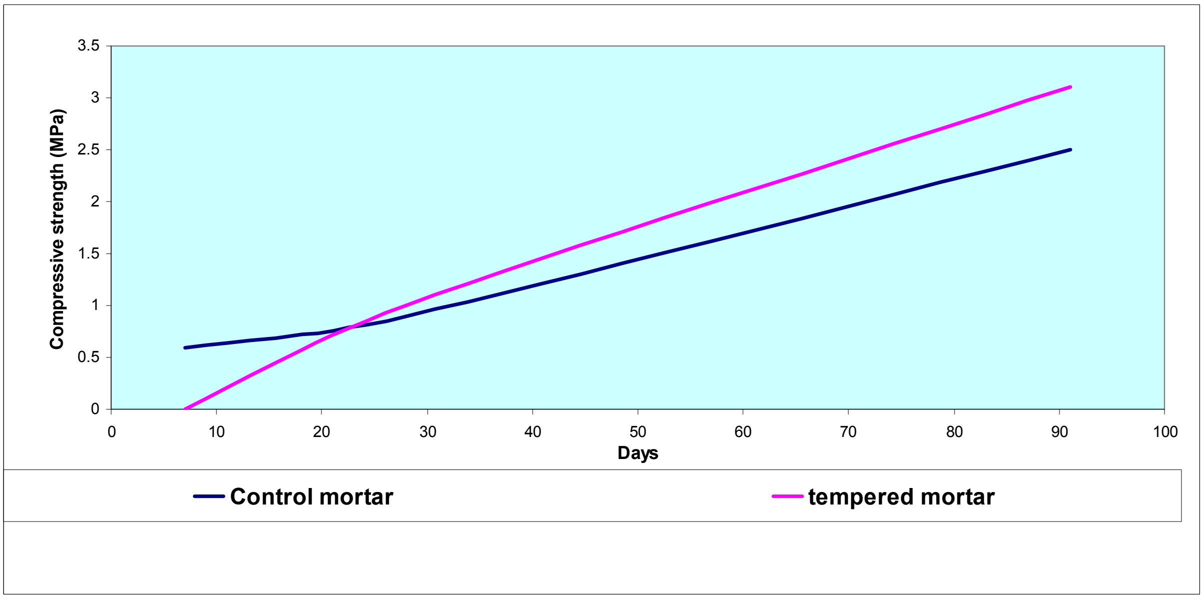
This tempering process does not affect the ultimate strengths of NHL lime since this strength level is primarily owed to hydration of the belite (C2S) and carbonation of the lime hydroxide. In contrast, the tempering of impure NHL-CEM mortar mixes and NHL(Z) with higher concentrations in calcium aluminates and tricalcic silicate, provided by the addition of Portland cement, and with lower concentrations in belite will experience modifications in their ultimate performance.

We have tempered a mortar, following loss of workability and prior to setting, with an initial mix composition of: 1.5 parts PNC, 4.5 parts NHL 3.5, 15 parts 0/3R sand, a retardant (Tempo), and 5.75 parts water. During remixing, it was necessary to add another 0.66 parts of water.

The rise in strength with respect to an untempered control mortar has been highlighted in Figure 18. As opposed to the control mortar, the tempered mortar does not exhibit any measurable strength at the 7-day cutoff. On the other hand, at both 28 and 91 days, the compressive strength is just slightly higher than the control mortar despite the very minimal addition of water.

A tempered PNC-NHL mortar mix does not display any long-term structural disorders, as the rise in strength progresses without aberration. The presence of a large quantity of belite in these two binders ensures excellent durability. However, the tempering step does remove the property of "liveliness" instilled in NHL by PNC, which constitutes the primary value of such mixes.

Figure 18: RISE IN STRENGTH OF A TEMPERED MORTAR



4. CONCLUSION

Hydraulic limes, natural cements, lime or so-called "Roman" cements appeared for the most part at the beginning of the 19^{th} century. They all display a good number of similarities: a single and identical raw material, clayey or siliceous limestone, the same firing process using a shaft kiln at the same temperature, the same mineralogical constituents, and a rise in strength in accordance with a belitic composition.

From this initial period of material application, natural hydraulic lime with a low clay content at a slow setting time (NHL) and prompt natural cement, which could also be qualified as a fast-acting natural hydraulic lime with greater clay content, are the only two to have lasted. PNC has made it through the centuries thanks to the exceptional quality of its deposits and remains the world's only natural cement to be produced in industrial quantities.

PNC is closer to NHL than are the Portland cements (CEM). Only the lime slaking and its fast setting time serve to distinguish it from NHL. PNC and NHL share the same mineral composition yet in differing proportions. Their mixes, while adhering to the same long-term dynamic hydration, are more consistent than impure NHL-CEM mixes and than using NHL(Z), in which the addition of Portland cement engenders a rapid rise in strength.

Various PNC-NHL mixes have been developed onsite and characterized at the L.M.M. laboratory for four applications: rendering mortars, roughcast mortars, injection slurries, and application under cold weather conditions.

The primary functions of water vapor permeability and support protection are indeed fulfilled. These mixes all display less shrinkage than the family of natural hydraulic lime mortars.

PNC adds the liveliness missing from lime in order to enable: shortening the waiting period between coating layer applications, along with the possibility of applying a thicker coat; compressing the formwork removal schedule; and working under cold weather conditions. Jobsites can progress more quickly and coatings are secured at very early ages.

Thanks to the time savings and added security provided at early age, the contribution of PROMPT NATURAL CEMENT to NATURAL HYDRAULIC LIME mortars is an entirely modern phenomenon with respect to current worksite constraints; and yet, this technique remains a conventional solution that has proven effective for over the past 150 years.