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

# TECHNICAL SPECIFICATIONS

# PROMPT NATURAL CEMENT

# THE ROMAN CEMENT OF GRENOBLE

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CENTRE TECHNIQUE LOUIS VICAT
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# TECHNICAL SPECIFICATIONS

## PROMPT NATURAL CEMENT THE ROMAN CEMENT OF GRENOBLE

## 1 ROMAN CEMENT

Since the famous Roman mortars, which were mixtures of sand, lime and pozzolana, no progress was made in the field of hydraulic binders until the end of the 19th century.

The first advancements took place in England : Parker filed a patent in 1796 on the burning of marl nodules (septaria). This invention is major ; it showed that a highly hydraulic binder with respect to meager limes and lime/pozzolan mixtures of those times is feasible by burning at low temperature (below the melting point) a limestone containing more clay than that of normally used limes without slaking (hydrating) the burned stone by simply grinding it.
In the early 19th century, this process spread throughout continental Europe from the burning of marl (clayey limestone).

This cement was called “Roman cement”. The term “Roman” is incorrect because it does not pertain to the rediscovery of mortars during Roman times.

In the 19th century, the names used on the same production site varied from natural cement, quick setting cement, prompt cement, Roman cement; elsewhere it was plaster cement. The most correct name would be rather “rapid natural cement”.

1875 Joseph Vicat, La-Pérelle, France.
1855 Dumas and Berger, Valentine, Marseille,
1850 Rozet et Menisson, Vitry-le-François, F
1849 Benoit Berthelot, Vif, France
1846 Velleret, Argenteuil, France
1846 Dupont and Demarle, Boulogne/mer, Fr
1844 Désiré Michel, Valdonne, France
1842 Capitaine Breton, Porte-de-France, Grenoble
1840 Charles Francis et John White, Médina, Newport, England
1836 Hyppolyte de Villeneuve, Roquefort, Bouches-du-Rhone, France
1836 Guipuzcoa, Spain
1835 Voisin, saint-Martin-le-Vinoux, France
1835 Pellegrini, Cahors, France
1833 Niel, Belgium
1832 Gariel et Garnier, Vassy, France
1828 Lamé et Clapeyron, Saint-Peterbourg, Russia
1827 Alexandre Lacordaire, Pouilly-en-Auxois,
1824 Joseph Aspdin, Leeds, proto-Portland cement, England
1822 Rosendale, NewYork, USA
1822 James Frost, British cement, Swanscombe, England
1817 Theory of Hydraulicity by Louis Vicat
1810 Charles Francis, Nine Elms, plaster cement, England
1802 Smith, Boulogne-sur-Mer, plaster-ciment,
1801 Francis and White, England
1796 Brevet Parker, island of Sheppey, UK

***Table 1 : Main dates in the production of Roman cement***

Its growing success from the middle to the end of the 19th century can be explained by the fact that :

1. it offers an economic and durable solution for facade decoration. It perfectly imitates stone at a lower cost and adds a warm yellow ochre to brown colour. It is used either on a brick base in elements (cornices, etc.) to be applied on the spot, or in prefabricated mouldings, or in stone imitating concrete ;
2. its quick hydraulicity allowed finding efficient solutions for civil engineering structures, especially those in contact with water ;
3. it led to the introduction of the prefabrication industry, especially the industry of water outlet pipes : the natural cement based pipes had a higher resistance to aggressive water than pipes formerly based on the first artificial Portland cements ;
4. it is easy to produce.

It is easy to produce :

- The raw material is available because it is burned at low temperature below the melting point ; as a result, marl or clayey limestone with a proportion of clay varying approximately from 22 % to 35 % can be used (Cf. Figure 1) in deposits found almost everywhere. Although Louis VICAT proved in 1817 that it was possible to make an equivalent cement with an artificial mixture of clay and limestone, grinding tools and energy costs at that time hardly allowed making this intimate clay/ limestone mixture at low cost. This is why the “natural” mixture of these two constituents in marls was preferred.
- Simple and existing technology traditionally used for lime furnaces. Contrary to lime, Roman cement does not slake due to the almost total lack of quick lime ; it is simply ground.

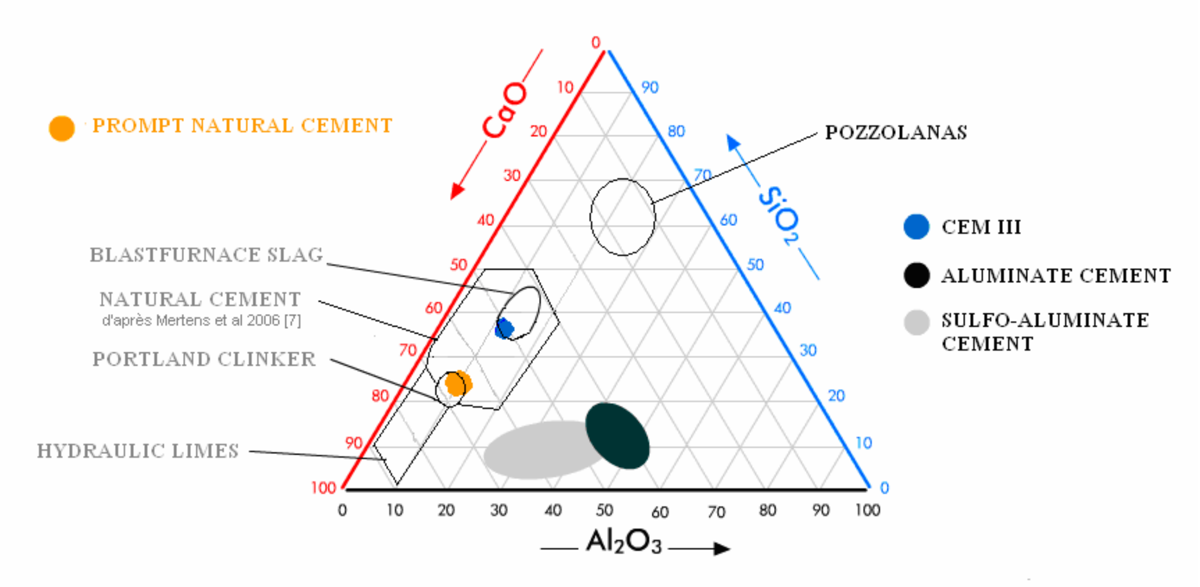

*Figure 1 Breakdown of the chemical composition of natural cements in Europe*

# 2 THE ROMAN CEMENT OF GRENOBLE

The prompt natural cement of Grenoble is a real Roman cement ; it has all the characteristics of this cement :

- utilization of only one raw material in the form of clayey limestone ;
- burning in a straight furnace at a temperature below the melting point ;
- low quenching ;
- no slaking, easy grinding ;
- hydraulicity ;
- quick setting and hardening ;
- a yellow to brown color.

In addition, for more than 150 years, it has been produced according to the same process ; that's the best of proofs.

## 2.1 Chemical and mineralogical composition

Prompt natural cement results from the burning of a material coming from only one and the same marl seam located at the base of the Cretaceous Period in the Chartreuse Massif in Isere.

This seam has a very constant chemical composition (Cf. Table 2) with a carbonate score (content in calcium carbonate and magnesium carbonate expressed in $CaCO_3$) of 72 compared to 78 with Portland clinkers.

It is therefore close to a typical classical Portland clinker. As a result, compared to all Roman cements that have existed, it has a low limit in clay content and is relatively rich in CaO as shown in Figure 1.

| MP 975°C | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | CaO | MgO | $SO_3$ | $K_2O$ | $Na_2O$ |
|---|---|---|---|---|---|---|---|---|
| 9.28 % | 18.09 % | 7.24 % | 3.2 % | 53.07 % | 3.84 % | 3.24 % | 1.16 % | 0.28 % |

| $C_3S$ | $C_2S$ | $C_3A$ | $C_4AF$ | $C_{12}A_7$ | $C_4A_3S$ | Periclase | Free lime | Calcite | Sulfates | Others, incl. amorphous phases |
|---|---|---|---|---|---|---|---|---|---|---|
| 5 - 15 % | 40 – 60 % | 6 ± 2 % | 9 ± 2 % | 3 ± 1 % | 3 ± 1 % | 4 ± 1 % | 2 ± 2 % | 10 – 15 % | 3 ± 1 % | 10 – 15 % |

***Table 2 : Typical chemical and mineralogical composition of the PNC***

The PNC's originality is not due to a special chemical composition - it is very close to that of a Portland clinker as explained above – but rather due to the burning at low temperature with a wide thermal spectrum from 600 to 1200°C (below the melting point) very slightly higher than that of hydraulic limes and a natural intimate mixture of clay and limestone.

This mixture at the micron scale is necessary for the formation of minerals during burning because the diffusion of the atomic elements is low in the solid state.

The result is the formation of a wide range of minerals (Cf. Table 2) which are very different from those of modern artificial Portland cements, but are identical to those present in natural hydraulic limes, although in different proportion (Cf. Figure 2) :

- A part of the stone not heated to a temperature sufficient to transform it ; it is simply dehydrated ;

- Another part of the stone was transformed to yield amorphous or poorly crystallized phases, including an entire family of aluminates ($C_4AF$, $C_3A$, $C_{12}A7$, $C_4A_3S$ and $C_2AS$) responsible for quick setting and hardening during the first hours of hydration, as well as silicates in the form of belite ($C_2S$) increasing resistance over several months. A little alite ($C_3S$) is present in small quantity because this mineral starts to form around 1200°C.

- There is a very partial melting (clinkerization) in very local areas forming a small quantity of alite. The fact that the chemical composition of the stone used as a raw material is close to that of a typical Portland clinker allows the formation of this well-known calcium silicate. Since it is very hydraulic, it adds further resistance after a few weeks.

This last point is very important because local material meltings are inevitable with the burning process in a straight kiln. The minerals formed in this liquid phase must not alter the natural cement when they are hydrated. For example, a raw material richer in clay will form in this liquid phase more aluminous minerals, whose hydration which is less well known may lead to serious durability problems.

This burning at low temperature obviously has a low thermal balance sheet on the order of 70 % compared to that of a CEM I and the $CO_2$ emissions from decarbonation which represent 80 % of that of a CEM I. Both of these last two data are very important for applications in the eco-construction field.

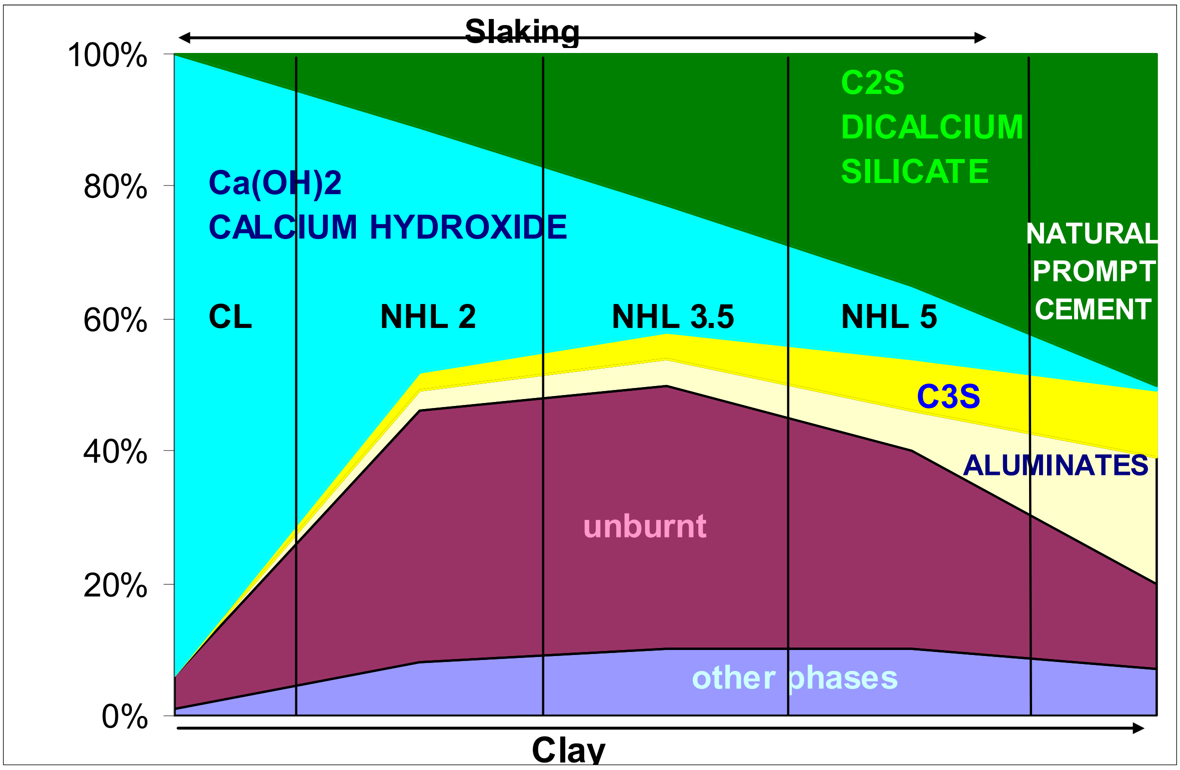

*Figure 2 Schematic mineralogical composition of limes and prompt natural cement*

## 2.2 General characteristics of Prompt Natural Cement mortars

### 2.2.1 Resistance buildup in two phases over a very long period

During hydration, the aluminates formed at low temperature are responsible for the quick setting (on the order of 2 to 3 minutes) and the first resistance buildup phase during the first hours. When belite is hydrated, the second resistance phase will take place and extend over many months as shown in Figure 3.

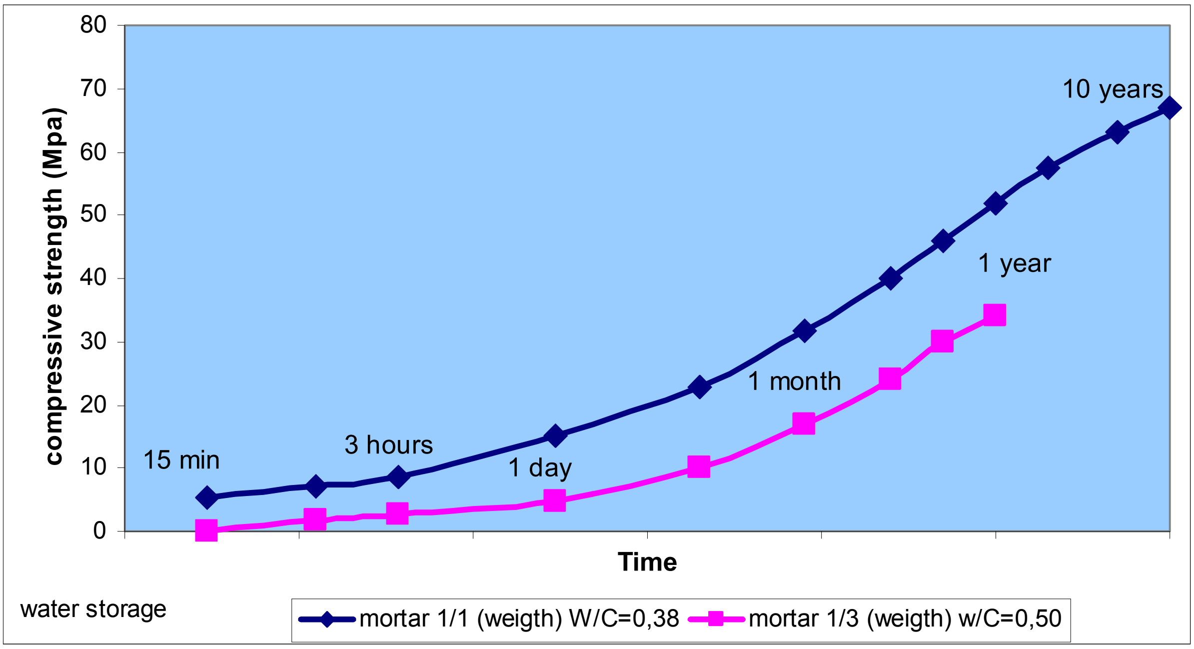

*Figure 3 Hardening kinetics over 10 years*

### 2.2.2 Resistances according to mix proportion and water/cement ratio

Prompt natural cement has the property of being usable in a very wide range of mix proportion going from 10 to 50 % of the dry mortar weight, and even 100 % in the case of grouting and slurry. Figure 4 gives an idea of the resistances attainable in case of conservation in water. Two areas are to be highlighted :

- The initial high resistance area defined by an W/C < 0.50 ; these high performances concern setting, quick masonry and waterproofing applications. The high resistances imply a low porosity. This area with its capabilities to respond to structural stresses is close to artificial Portland cements.
- The low resistance area with an W/C > 0.50 has mechanical performances and its mix proportions are on the same order of magnitude as those of natural hydraulic lime mortars. The water absorption and porosity characteristics are also closer to those obtainable with 19 century Roman cement mortars.

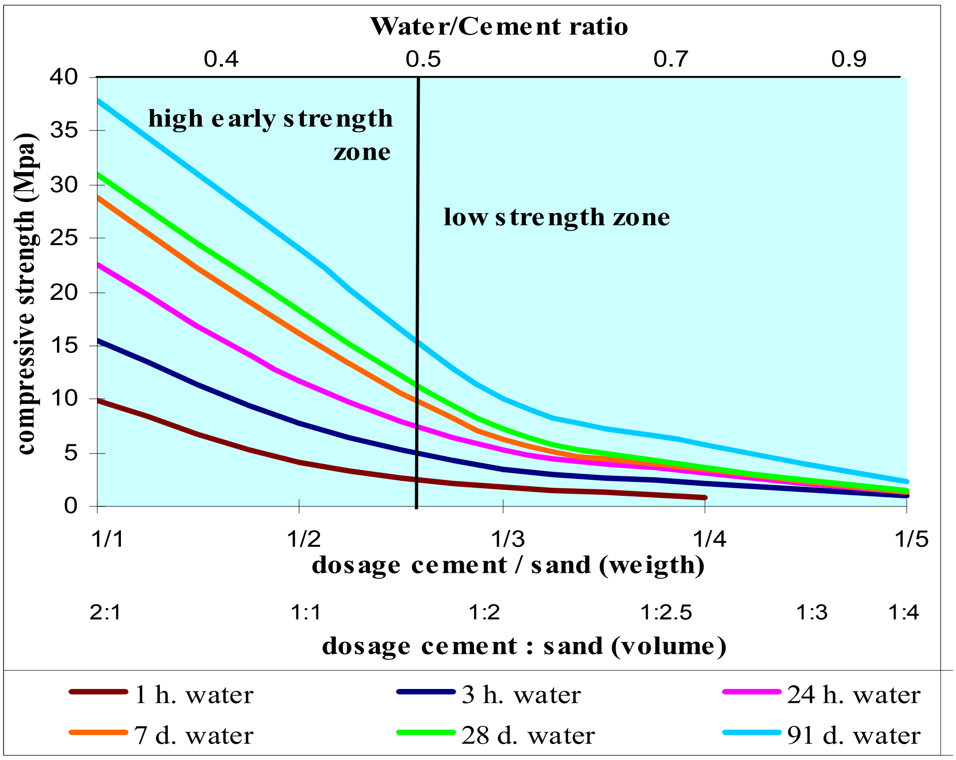

*Figure 4 Hardening kinetics according to mix proportion and water/cement ratio*

# 3 PROMPT NATURAL CEMENT PROPERTIES AS ROMAN CEMENT OF GRENOBLE

## 3.1 Characteristics of ancient mortars based on Roman cement

In order to be able to repair as closely as possible the elements in ancient mortar based on Roman cement, it is necessary to know their properties as best as possible.
After making sure that their chemical and mineralogical compositions prove that they come from natural cement burned at low temperature, the evaluation of the ancient mortars of Roman cement more than one hundred years old coming from different locations yielded the following results :

- Density varies from 1.4 to 2 kg/l. It is difficult to find the real density of the mortar before aging because the dissolution phenomena due to rainwater are extremely variable depending on the climate and exposures to bad weather. These data are indicative because cement mix proportion and aggregate quality vary widely. Some applications such as run mouldings have a high macro porosity due to the extrusion implementation method.
- Cement content by the soluble silica method gives an idea of the binder proportion : 14 to 45 % of equivalent prompt natural cement. Nonetheless, this method does not take into account the aluminates content of the original binder, and some aggregates can naturally contain soluble silica and, therefore, falsify the binder estimate.
- The total porosity to water is high ; it has values between 23 and 40 %.
- Water absorption varies from 9 to 30 %. Considering the dissolution phenomena mentioned above, these last two values are probably lower for young mortars at the beginning of this era than after an aging of more than 100 years.

The most important of these four characteristics are those involving porosity and water absorption because they condition the long-term durability of mortars applied to facades. The problematic which conditions durability is the transfer of humidity from the support to the outside. It is possible with prompt natural cement based mortars at low content to obtain these interesting characteristics as indicated in the rest of this document.

Roman cements were often used in fine mortar with a relatively high cement mix proportion. Also, an example is shown with a same type of mortar based on prompt natural cement in order to define their characteristics and understand their exceptional durability. These properties are explained in the rest of this document.

## 3.2 Characteristics of Prompt Natural Cement mortars with low mix proportion

Mortars with mix proportion in volume of 1:2 to 1:4 were tested with an addition of 0.6 % retarder (citric acid). The workability time was thus at least 40 minutes at 20°C. The sand used is a silico-limestone 0/4 mm round.

Workability was adjusted as typically for a render by adjusting the water content, accordingly, the lower the fines (cement) content the higher the need for water, and therefore the higher the water/cement ratio will be.

### 3.2.1Capillary absorption and porosity to water and water vapour

Table 3 below indicates the compositions of the mortars studied, as well as the water absorption, water porosity and vapour permeance values after six months of a wet cure followed by 7 days of drying at 50 % relative humidity.
These results are therefore close to maximum hydration. To be complete, it will be necessary to check these mortars after several years have elapsed.

| Composition in volume | 1 :2 | 1 :2,5 | 1 :3 | 1 :4 | Procedures |
|---|---|---|---|---|---|
| % prompt in weight | 19,85 | 16,58 | 14,3 | 11,30 | |
| water/cement | 0,67 | 0,825 | 0,95 | 1,12 | |
| Apparent density (kg/m$^3$) | 1941 | 1908 | 1923 | 1945 | AFREM |
| Capillary absorption at 3 h C(kg/(m$^2$.min$^{0,5}$)) | 0,76 | 0,88 | 1,4 | 1,67 | EN1015 |
| Capillary absorption at 24h C(kg/m$^2$) | 16,56 | 17,44 | 17,54 | 15,88 | EN1015 |
| Water absorption (%) up to constant weigth | 12 | 12,5 | 13 | 11,8 | CERIB DQI/DEE FG-02/12/02 |
| Total porosity water (%) | 25,67 | 25,88 | 23 | 22,89 | AFREM |
| Water vapour permeability (g/m$^2$.h.mmHg) | 0,42 | 0,43 | 0,46 | 0,45 | Cahier CSTB 08/1993 |

***Table 3 Porosity, absorption and permeance characteristics of mortar with low mix proportion***

The permeance values are between 0.4 and 0.5 ; these values are slightly below the NHL. For information, NHL5 based mortars with the same content are between 0.5 and 0.6.

The capillary absorption measured at 3 hours is the measurement which correlates best with the water/cement ratio. This same measurement after 24 hours gives neighboring values. Therefore, the higher the water/cement ratio is, the faster the capillary absorption will be. These permeance and absorption values are obtained after an ideal cure (> 90% RH) in the laboratory.

On the outside, the cure conditions are very different and varied in both temperature and humidity depending on the local micro climate and the facade’s exposure. As a general rule, on a worksite, a more or less intensive drying takes place at a young age which counteracts the mortar’s hydration. The porosity of a mortar conserved on the worksite will therefore be greater than that of the same mortar having undergone an ideal cure in the laboratory. The given values obtained from laboratory tests are optimum hydration values. They are in the range of values found on Roman cement mortars (Cf. subsection 3.1).

### 3.2.2 Strength

The mortars 1:3 and 1:4 have neighboring compressive strength (Cf. Figure 5 below). The strength buildup takes place over several months and here with a wet cure over 6 months.

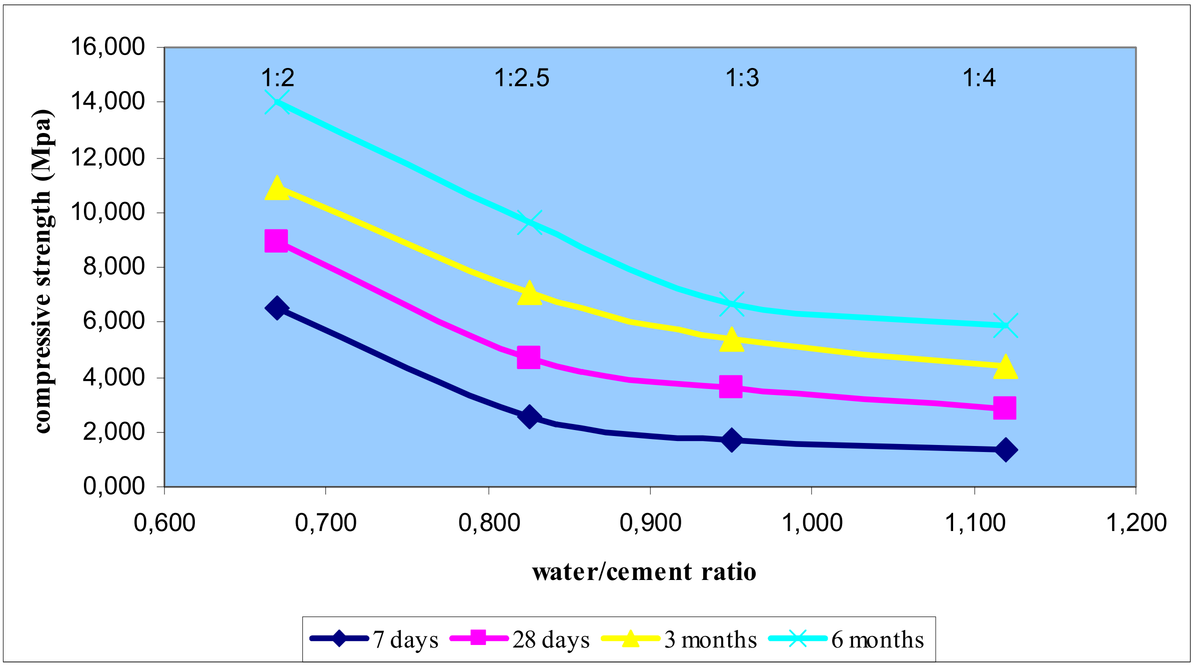

***Figure 5 Compressive strength***

Flexure strength are listed in Table 4 below :

| Mortars in volumes | 1:2 | 1:2.5 | 1:3 | 1:4 |
|---|---|---|---|---|
| Flexure strength at 3 points (MPa) | 5.4 | 3.4 | 3.1 | 2.5 |

***Table 4 : Flexure strength up to 6 months***

### 3.2.3 Elasticity modulus

These mortars also measured up to 6 months and kept in a damp environment present almost the same dosing modulus 1:2.5 to 1:4 practically at the same level as an NHL5. If kept in a conservation environment with a 50 % relative humidity, the values would drop approximately one third.

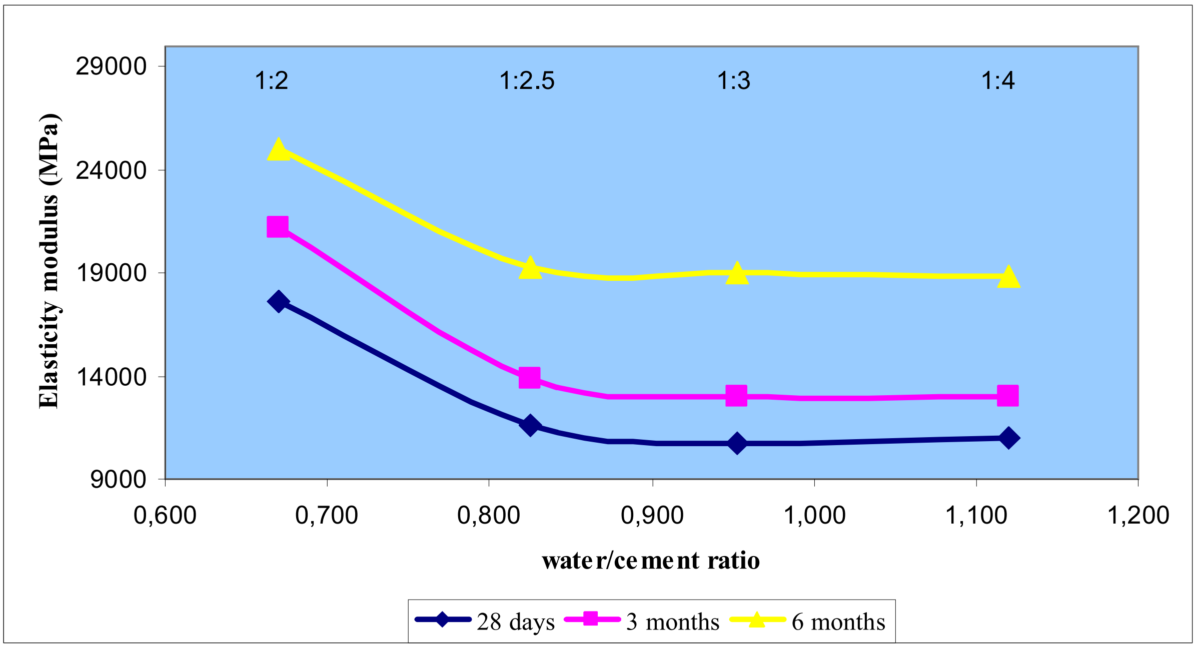

***Figure 6 Elasticity modulus***

### 3.2.4 Drying shrinkage

The initial shrinkage measurement is taken as soon as the mortar has sufficient strength to be able to be removed from the mould. As a result, shrinkage prior to the removal from the mould cannot be quantified. Being proportional to the binder content, it can be considered as low (Cf. Figure 7) with prompt natural cement. These relatively low values allow applying very thick render mortars.

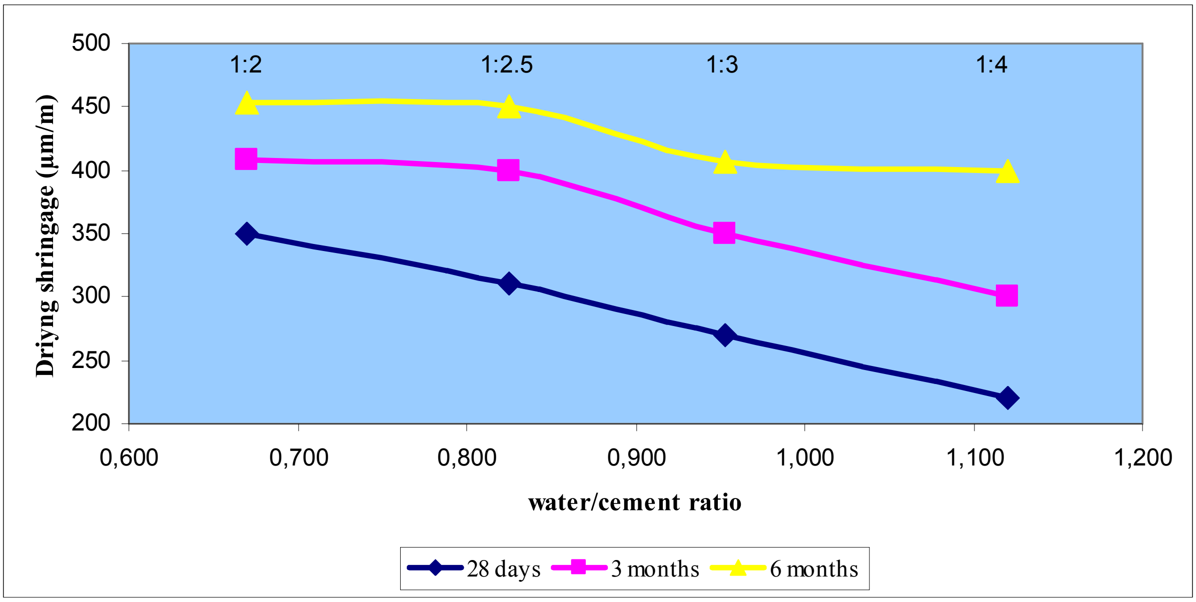

***Figure 7 Drying shrinkage***

### 3.3 Characteristics of Prompt Natural Cement mortars with very low mix proportion in mixture with filler

It is possible to lower the content of prompt natural cement by replacing a part of the cement with filler in order to keep a sufficient workability to install it. In the following tests, 30 % of the natural cement volume was replaced by the same volume in limestone filler (having a grain size close to this cement), mortar 1:2 and 1:2.5 in volume with the same sand (0/4 R) as previously. 0.6 % retarder (citric acid) was added to yield at 20°C a workability of more than an hour. Water absorption, water porosity and water vapour permeance measurements were taken after six months of a wet cure followed by 7 days of drying at 50 % relative humidity.

| Composition in volume Prompt : filler : sand | 0.7 : 0.3 : 2 | 0.7 : 0.3 : 2.5 | Procedures |
|---|---|---|---|
| % prompt in weight | 13.39 | 11.21 | |
| Water/cement ratio | 1.02 | 1.27 | |
| Apparent density (kg/m$^3$) | 1931 | 1867 | AFREM |
| Porosity Absorption Permeance | | | |
| Capillary absorption at 3 h C(kg/(m$^2$ x min $^{0.5}$)) | 1.39 | 1.76 | EN1015 |
| Capillary absorption at 24 h C(kg/m$^2$ | 16.13 | 17.63 | EN1015 |
| Water absorption (%) up to constant weight | 12.10 | 13.10 | CERIB DQI/DEE FG-02/12/02 |
| Total water porosity (%) | 23.83 | 26.08 | AFREM |
| Water vapour permeance (g/m$^2$ x h x Hg mm) | 0.61 | 0.64 | CSTB Specification 08/1993 |
| Compressive strength (MPa) storage at 20°C, > 90 % RH | | | |
| 7 days | 2 | 0.9 | |
| 28 days | 3.3 | 1.9 | |
| 3 months | 4.7 | 3 | |
| 6 months | 5.3 | 3.4 | |
| Flexure strength (MPa) Storage at 20°C, > 90 % RH | | | |
| 6 months | 3 | 1.9 | |
| Elasticity Modulus (MPa) Storage at 20°C, > 90 % RH | | | |
| 28 days | 11 400 | 7 500 | |
| 3 months | 12 100 | 9 900 | |
| 6 months | 15 800 | 12 400 | |
| Drying Shrinkage (µm/m) | | | |
| 28 days | 290 | 280 | |
| 3 months | 340 | 320 | |
| 6 months | 380 | 360 | |

***Table 5 : Characteristics of prompt natural cement mortars with very low mix proportion***

At the same mix proportion, permeance results are close to what can be obtained with an NHL 3.5, as well as resistance and elasticity modulus results. The additional advantage (at these concentrations) with prompt natural cement is to have resistances after 7 days that NHL 3.5 will have after a month and with less shrinkage. This promptness property allows securing the work performed at young ages in case of unfavourable weather conditions. Instead of this filler, a calcic lime or an NHL2 can be used to full advantage.

The results of the 3 absorption tests and the porosity test are close to those indicated in Table 3 (characteristics of mortars with low content), while the water vapour permeance results are better here. Therefore, there is no evident correlation between the liquid water and water vapour transfer measurements.

The characteristics of this type of mortar even though with a low cement proportion conform to ancient characteristics based on Roman cement, especially if a low elasticity modulus, as well as a high water vapour permeance, are sought.

### 3.4 Characteristics of a fine mortar of Prompt Natural Cement with high content

The study of ancient mortars of Roman cement showed that some were rich in fine aggregates while having a certain strength and good durability. In order to try to understand this exceptional durability, we tested a fine mortar using instead of sand the limestone filler with a grain size close to that of the cement (Cf. Table 6). The setting retarder was used at a dosing of 0.6 % of the cement's weight. The obtained setting time was approximately 30 minutes at 20°C. Water absorption, water porosity and water vapour permeance measurements were taken after six months of a wet cure followed by 7 days of drying at 50 % relative humidity.

| Volume composition | 1 :1 | | Procedures |
|---|---|---|---|
| % prompt in weight | 34.6 | | |
| Water/cement ratio | 0.524 | | |
| Apparent density (kg/m$^3$) | 1807 | | AFREM |
| Porosity Absorption Permeance | | | |
| Capillary absorption at 3 h C(kg/(m$^2$ x min $^{0.5}$)) | 0.33 | | EN1015 |
| Capillary absorption at 24 h C(kg/m$^2$ | 6.88 | | EN1015 |
| Water absorption (%) up to constant weight | 16.7 | | CERIB DQI/DEE FG-02/12/02 |
| Total water porosity (%) | 30.32 | | AFREM |
| Water vapour permeance (g/m$^2$ x h x Hg mm) | 0.52 | | CSTB cahier 08/1993 |
| Compressive strength (MPa) Storage at 20°C, > 90 % RH | | | |
| 7 days | 11 | | |
| 28 days | 19 | | |
| 3 months | 23 | | |
| 6 months | 30 | | |
| Flexure strength (MPa) Storage at 20°C, > 90 % RH | | | |
| 6 months | 5 | | |
| Elasticity Modulus (MPa) Conservation at 20°C, > 90 % RH | | | |
| 28 days | 19 200 | | |
| 3 months | 24 900 | | |
| 6 months | 27 400 | | |
| Drying Shrinkage (µm/m) | | | |
| 28 days | 610 | | |
| 3 months | 780 | | |
| 6 months | 870 | | |

***Table 6 : Characteristics of fine mortars of prompt natural cement mortars with high mix proportion***

As expected, the strength, elasticity modulus and drying shrinkage values are high.

The results of the capillary absorption tests at 3 and 24 hours are low with respect to the previous mortars, but surprisingly the values of the water absorption tests up to constant weight, total water porosity and vapour permeance are the highest. This demonstrates a very interesting behaviour for this kind of mortar with water : it absorbs 2 to 3 times less water at 24 hours than the previous mortars. It is necessary to push the water absorption test by wetting all the sample's sides and letting it soak for at least 4 days in order to have a constant weight to reach a high value. This means that this mortar will be hardly sensitive to short wetting cycles (case of a few hours of rain), while keeping a high water vapour permeability. This last property is essential for facade applications and shows the good durability of these fine mortars based on a Roman cement over more than 100 years. Strength and permeability are therefore reconciliable. This good behaviour despite a high elasticity modulus can also be explained by the fact that this fine mortar was often used in thin applications.

# 4 APPLICATIONS OF PROMPT NATURAL CEMENT AS A ROMAN CEMENT OF GRENOBLE

With all the characterization elements of all the mortars described above, it becomes possible to make formulations close to those of the ancient mortars of natural cements, while respecting vapour permeability values that ensure a good durability. Ancient supports very often made of brick require facade mortars with this type of permeability so that the humidity present in these walls can be evacuated toward the outside.

In the 19th century and the early 20th century, natural cement mortars were used in a facade like a render, run moulding or prefabricated moulding in order to replace stones, while ensuring a similar aspect. The utilization of natural cement concretes imitating stone was less geographically widespread.

The rest of this chapter is intended to give lines (non exhaustive) on the formulation and installation of these specific mortars. The rules of the trade must be followed, particularly on sand cleanliness.

## 4.1 Render application

In order to fulfill its protection functions of the ancient support and decoration, the render must have a low elasticity modulus, be permeable to water vapour coming from the support and be adhesive :

- The adhesion on the support will be given by the bonding coat at the mix proportion indicated in Table 7 ;
- The adhesion between the various layers will be obtained by a "fresh on fresh" application.

The float coat due to quick hardening and low shrinkage can be applied in thick layers up to a thickness of 5 cm. Its dosing will be a low 1:3 in volume in order to have a low modulus.
Contrary to the bonding coat, it must be necessarily retarded.
For good adhesion, the finish layer (top coat) will also be applied fresh on fresh on the float coat. It plays a decorative role. As a result, a colored sand or a colorant may be used. On large surfaces, to have more time to take care of joint settings, the use of a lime / prompt mixture or a natural hydraulic lime is wise to save more time for workability.

| | Proportion in volume | Sand grain size distribution | Retarder (citric acid) |
|---|---|---|---|
| Bonding coat | 1:2 | 0/5 mm | None |
| Float coat | 1:3 | 0/3 mm or 0/2 mm | 0.5 to 1 Tempo cap/liter of cement |
| finish coat | 1:3 | 0/1 to 0/2 mm | 0.5 to 1 Tempo cap/liter of cement |

***Table 7 : Compositions of the render mortars***

A time of workability of approximately 40 minutes at 20°C associated with the advice to work fresh on fresh requires high technical for this application and does not allow improvisation.
Batches are made in small quantities on request. For an applicator, there is a batcher. Moreover, in the former literature of the period on prompt natural cements, it is said : "render mortar batched by hand – 2 batchers make a cubic meter of mortar in 10 hours and supply 3 or 4 masons, the masons covering 10 to 20 superficial meters per day".

## 4.2 Run moulding application

The specificity of this application is that it is installed by extrusion, which calls for some dexterity. Adhesion to the support is created by a grouting "thrown" on the support.
The first layer of the core coat will be applied to the grouting once it has lost its workability by suction of the support, but before setting starts to have a good adhesion. After each pass of the form to remove excess mortar, another thicker layer of mortar of the core coat (Cf. Table 8) will be applied as soon as

the previous layer has lost its workability, but still before setting starts. It is this mortar which will make the cornice's thickness.

To prevent the form from tearing out too much mortar, it is recommended to spray a little water before passing the form.

Fine mortar for a first finish will be used for maximum thicknesses of 1 cm to fill in large empty spaces. It can be coloured by using marble powder, oxides or earth. Its workability should be rather very malleable to enable a good extrusion. A still finer mortar to fill in small defects with a slurry consistency using a very fine, coloured sand, filler or pigments will give the final colouring aspect.

| | Proportion in volume | Sand grain size distribution | Retarder (citric acid) |
|---|---|---|---|
| Bonding coat | slurry | / | None |
| Core coat | 1:2 | 0/4 mm | 0.25 to 0.5 Tempo cap/liter of cement |
| 1st finish | 1:1 | 0/0.5 or 0/1 mm | 0 to 0.5 Tempo cap/liter of cement |
| 2nd finish | 1:1 | 0/0.1 to 0/0.5 mm | None |

***Table 8 : Compositions of the run moulding mortars***

This outside fine mortar was characterized in subsection 3.4.

In order to apply this kind of moulding correctly, at least 2 people are needed : a batcher to make small batches on request, and a specialized applicator.

### 4.3 Prefabricated moulding application

Moulding is a real art and there are many ways to do it. Mix proportion, type and grain size of the sand, as well as workability, will also be varied : from firm mortar to liquid mortar, from 2:1 dosing to 1:2 dosing. We are going to describe two types of makings : the first in bilayer very often observed on Roman cement based mouldings during the 19th century and the second in a better dosed single layer with a fluid workability for complex shaped moulds difficult to fill in and to unmould.

Bilayer moulding : the outer layer consists of a rather dosed fine mortar (1:1 in volume). The sand used is less than 0.5 millimeters. It can be a coloured filler with an added pigment. It is applied first on the mould wall. Its workability will be sufficiently firm, but not too firm to allow details to be moulded without causing air bubbles. Its characteristics – very important to explain its excellent durability – are described in subsection 3.4. Compositions are indicated in Table 9 below. The elasticity modulus and drying shrinkage are rather high : this is why it must be as thin as possible. It is a "skin" which provides protection and a rather granular surface aspect close to that of stone. The second layer, a rougher mortar (volume dosing 1:2) described in subsection 3.2 comprising the mortar body, will be applied "fresh on fresh" on the first layer to promote adhesion between both of these layers. These two mortars ensure a rather important transfer of steam due to their permeance value, respectively, 0.52 and 0.42.

| | Proportion in volume | Sand grain size distribution | Retarder (citric acid) |
|---|---|---|---|
| Outer bilayer | 1:1 | 0/0.5 mm or filler or pigment | 0 to 0.5 Tempo cap/liter of cement vs. ext. T° |
| Inner bilayer | 1:2 | 0/4 mm | 0 to 0.5 Tempo cap/liter of cement vs. ext. T° |
| A single mortar | 2:1 to 1:1 | 0/1 to 0/3 mm | 0.5 to 1 Tempo cap/liter of cement |

***Table 9 : Compositions of the prefabricated moulding mortars***

With complex shaped mouldings difficult to fill in and requiring higher resistances for mould removal, it is easier to use a better dosed mortar with a fluid workability. In this case, the use of a superplasticizer to reduce the water/cement ratio and provide more fluidity is necessary. Since all superplasticizer families are not effective on prompt natural cement, consult us to choose the appropriate one. The surface of this kind of moulding will be smoother and less granular than that of the previous bilayer moulding.

Although resistances at young ages are rather high, a wet cure over at least two weeks is indispensable so that the mortar's surface is correctly hydrated to prevent a superficial powdering with possible cracks to ensure good durability.

# 5 CONCLUSIONS

Prompt natural cement has a long history extending over more than a century. It belongs to the family of the first cements : rapid natural cements incorrectly called Roman cement north of the Loire and outside our borders in the 19th century and the early 20th century. As a precursor of modern cements, artificial Portland cements, a transitional work of constructive techniques, it made the transition between stone constructions and concrete constructions. It imitates to perfection the stone aspect, while being much cheaper. A facade material, it was used as a render, in run mouldings or in prefabricated mouldings.

The compositions of the mortars used for these various applications were found. The characterization of them was made with our current means and knowledge. Setting was adjusted to have a time of workability of 40 to 60 minutes.

The parameters explaining a good durability, particularly porosity, water vapour permeance, low shrinkage and low elasticity modulus, were highlighted. They prove that prompt natural cement mortars with low mix proportion (equivalent to those of natural hydraulic limes) are perfectly relevant due to not only their physical properties, but also their mineralogical properties, which explain why they have a durability of more than 150 years.

Since the first productions, mason inventiveness allowed adapting to the intrinsic promptness of this natural cement : in the 19th century by using human resources on the worksite or mixtures with limes, then adapted mechanical methods and finally a retarder. This control of prompt setting has an interesting counterpart : quick hardening. Extremely current today, it allows saving time on the worksite during the summer as well as during the winter.

Natural, durable and prompt are the most suitable qualifiers for prompt natural cement, which despite its age upholds all its modernity. It has traversed centuries and it remains the only natural cement industrially produced. This sustainability is due to an exceptional deposit allowing the burned stone to have very well adapted mineralogy, a pledge of durability.

Prompt natural cement is capable of restoring to their original aspect facades made of Roman cement of the 19th century, while satisfying current performance criteria. At that time, besides facades, it proved also viable in prefabrication (pipes, for example) and in civil engineering structures. In the 20th century, a speed king, it is suitable for setting, quick masonry and waterproofing applications. At the dawning of the 21st century, prompt natural cement upholds all its novelty in the field of restoration and facade decoration.

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