The use of dolomitic lime in historical buildings:  
History, technology and science

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The use of dolomitic limestone in lime production is historically well known in the north and south of Italy but it is also documented in France, Germany and United Kingdom, especially between the XVI and the XVII century.

This contribution intends to consider such material from three different points of view: the historical one, through the study of archive documents, treatises and manuals; the technological one, through the analysis of the still existing buildings as well as the production cycle; the scientific one, carrying out a research into the parameters that allow to expound the excellent result for ages of the mortar produced with the employment of such lime.

These three aspects, one to each other strictly connected, aid to reach a more complete knowledge about one of the most used materials in ancient buildings.

Archive documents and ancient manuals offer some information concerning typical usages in different areas, giving a general, even if incomplete, picture of production techniques that often were handed on orally and left to the craftsmen. The early technical-scientific publications dealing with this subject date back to the beginning of the nineteen century, when the scientific study of the building materials carried out methodically imposed itself. Such contributions are particularly interesting because the authors still keep in their minds the data provided from the experience. Stopping for a moment to consider the composition of the primary product, we can notice that an apparent discordance exists between practice in the pre-industrial era, result of centuries of empirics based improvement, handed on by word of mouth or at most by manuals and treatises of that time, and technical knowledge of the industrial era, based on behavioural observations and subject of specific analytic publications. In fact while in the past they considered useful, if not even necessary, the presence of suitable quantities of magnesium in the mixtures of mortars, instead in the last century the utilisation of such binder has been dropped because considered of inferior quality.

But the resistance and durability that magnesic mortars, in their different utilisation, have offered against physical and chemical agents of decay are the silent evidences of the performance they can offer, enabling to doubt all theories about binders from Louis Vicat on.

At this point science become absolutely necessary to give answer to questions that take root in the history of masonry. On this subject some of the early encouraging results of the scientific research will be enunciate.

INTRODUCTION

Lime is undoubtedly one of the materials most used in the history of building, both in bedding and lining mortars and in concrete imitating stone. It was widely used from the 3rd century BC to the start of the
twentieth century, after which lime was gradually replaced by cement, in the conviction that the «new» material was better than the old in every respect. Actually, restoration experience has shown that, apart from aesthetic problems, specific physical characteristics of cement do not make it compatible with lime-based structures and linings.

Today lime is once again present on the market, to satisfy the requirements of people working in the restoration field, who are continually in search of products respecting the theoretical criteria of compatibility and reversibility. However, it does not seem that the lime produced and cast today is able to provide objects that are as efficient and resistant as the majority of the old ones were. During the decades it took for people to become certain that in pre-industrial construction it was not advisable to use cement, except for structural purposes, know-how referring to the production and employment of lime was irremediably lost. Hence architects and restorers are now concentrating their attention more and more on historic mortars, both to copy their recipes in order to solve design problems, and to study and characterise them simply in order to know more about them.

The present paper fits into this broad panorama of studies, since it looks in some depth at a particular type of lime, dolomitic, deriving from the decomposition of dolomitic limestone, a rock constituted by a double carbonate of calcium and magnesium \( \text{CaMg(CO}_3\text{)}_2 \). It appears interesting to analyse it since the use of this rock for the production of lime, now abandoned — although dolomitic limestone constitutes more than 50% of the carbonates on earth — was historically very common in the North and South of Italy but is also documented in Spain, France, Germany and England (Newton 1987; Manzano et al. 2000), above all from the 16th to the 17th centuries. Indeed, numerous analyses, aiming above all at characterising mortars present in historic buildings, bear witness to the use of dolomitic lime even where this was not the only material available, nor even the most convenient to use. This observation, together with the finding of archive documents (Vecchiattini 1998; Fieni 2000) specifically requesting lime from dolomitic limestone quarries, and the empirical datum that dolomitic limestone-based mortars do very well in the «test of time», makes it possible to consider the choice of this material one made in full awareness and not by chance, that is to say one due to convenience or to incapacity of operators to make the right selection.

Interesting and revealing, regarding the capacity to choose binders, is the case of the celebrated Porta Bozzolo villa at Casalzuigno (Varese province) (Bassani e Cassani 1994; Fieni 1995, 64–68), in which the lining mortars were done with care and attention varying with the importance of the rooms, but always with magesic limestone from Valcuvia. What is particularly striking is that the variation in the quantity of magnesium in the binders used indicates the employment of limestone coming from the decomposition of both magesic calcareous rock and dolomite. Specifically, the magnesium content is higher in the outer layers, which are more exposed, than in the underlying ones, which are protected.

So why was such a resistant and widely used material considered inferior, starting from the first decades of the twentieth century, and gradually forgotten? It was in order to answer this question that an ongoing study on this theme was begun, with the aim not only of providing as much knowledge as possible on dolomitic limestone, but also of evaluating the possibility of bringing it back into building practice.

It is now clear that there is an apparent discordance between know-how in the pre-industrial epoch, the outcome of centuries of honing based on empirical criteria handed down orally or at most through the manuals of the day, and the theoretical knowledge of the industrial era, based on behavioural observations and dealt with in specific analytic publications. The art of producing limestone greatly changed during the last century, which was profoundly marked by a generalised technological renewal that was translated into the employment of raw materials which were more and more carefully chosen and of hi-tech equipment able to satisfy the needs of a big number of consumers, who were often not very qualified and were further and further away from the know-how of the past. Recovering the ways in which, in the past, traditional binders were produced and cast means re-examining and interpreting old «know-how» and also reconstructing, with the help of science, the route taken in the past to produce and cast materials that, as the facts demonstrate, gave better results than present-day ones. Hence in the framework of research applied to the conservation of the cultural heritage, it
is necessary to blend history and science, and to approach the theme from different points of view.

**THE CONTRIBUTION OF HISTORY**

The study of the written sources is fundamental to knowledge of some aspects of the production and employment of lime, which otherwise it would be impossible to recreate: archive documents and old manuals furnish notices on the specific customs of the various geographical areas, helping to build up a general though incomplete picture of operative practice, mostly left in the hands of craftsmen and handed down orally.

In the pre-scientific era the selection of materials was based on data from practical experience. After the works of Pliny the Second ([1469] 1982) and Vitruvius Pollio ([1486] 1992), nothing really important was added to knowledge of limestone down to the treatises of the modern epoch and laboratory experiments in the nineteenth and twentieth centuries. None of the authors mentioned above directly names dolomitic limestone, since classification of rocks is something comparatively recent, but each of them gives more or less cursory descriptions which, if correctly interpreted, furnish precious information.

In general the treatises may contain errors due to the authors being distant from building sites, but Vitruvius' text appears fairly reliable regarding materials and working techniques (Decri 2002). Vitruvius is aware that not all stones with which lime can be processed are the same and that not all of them give the same quality of lime, in terms of performance and use, when he defines some stones for making lime as *optima*; moreover, his explanations as a whole demonstrate that he realises that the quality of the binder is also influenced by the techniques used for baking, extinguishing and mixing. He distinguishes two types of rocks that are suited to making lime: light-coloured stone, *de albo saxo*, and hard stone, *silice* (Vitruvius Pollio ([1486] 1992, II-V-1). In effect, pure limestone, which is almost white, could be identified with light-coloured stone, while in Latium the word *silice* was used to refer to a tenacious basalt used to pave roads. It is quite evident that lime cannot be made from basalt, but in colour, hardness and fracture morphology this stone resembles dolomite limestone (Decri 2002).

Going further into the subject of lime production, the author indicates that «quella che verrà prodotta dalla (pietra) densa e più dura, sarà utile nelle murature, invece quella che verrà prodotta dalla (pietra) porosa, negli intonaci ... » (Vitruvius Pollio ([1486] 1992, II-V-1). This observation allows us to establish not only a clear relationship between the appearance of the stone for lime and the respective rock, dolomite limestone or calcareous rock, but also the correspondence between the quality of the product derived and the various uses, dolomite limestone being used to make bedding mortars and calcareous rock for lining mortars.

The theme of the careful choice of the raw material is also present in the work of Andrea Palladio, according to whom, in order to get good lime, the stones, whether from a quarry or a river, must be chosen with care and attention: «ogni pietra de' monti è buona, che sia secca, di humor purgata, e frale, e che non habbia in se altra materia, che consumata dal fuoco, lasci la pietra minore: onde sarà miglior quella, che sarà fatta di pietra durissima, soda, e bianca, e che cotta rimarrà il terzo più leggera della sua pietra. Sono anco certe sorti di pietre spugnose, la calce delle quali sarà molto buona all’intonacature de’ muri. ... Ogni pietra cavata à far la calce è migliore della raccolta, e di ombrosa, & humida cava più tosto che di secca, e di bianca meglio sì adopra, che di bruna. Le pietre che si pigliano dai fiumi, e torrenti, cioè i ciottoli, ò cuocoli; fanno calce bonissima, che fa molto bianco, e polito lavoro: onde per lo più si usa nelle intonacature de’ muri» (Palladio [1570] 1994², 8).

One of the first writers in whom we find a more modern scientific attitude is Francesco Milizia, who in 1781 wrote: «... tutte le pietre su le quali l’acqua forte agisce e produce effervescenza, sono proprie a far calce: le più dure e le più pesanti sono le migliori ... » (Milizia [1781] 1847²). Hence Milizia too indicates as the best one hard and heavy stone, which, from the cursory descriptions, sounds very much like dolomite limestone. Indeed, evaluating the degree of hardness in accordance with the Mohs² scale, and the specific weight of calcite and dolomite, one notices that calcite has a hardness of 3 and a specific weight between 2.65 and 2.80 g/cm³ while dolomite has a hardness of 3.5–4 and a higher specific weight, between 2.85 and 2.95 g/cm³. Hence the adjectives «dense», «hard» and «heavy» are well suited to dolomitic rock.
The first publications of a scientific-technical character on the theme being discussed here date from the start of the nineteenth century, when the scientific and systematic study of building materials was asserted. The contributions from this period are particularly interesting because the authors are still aware of the data of traditional experience, daily verifiable in the know-how of manufacturers and mason.

Laboratory experiments began with Vicat (1818), inspector-general des Ponts et Chaussées in France, who mostly dealt with hydraulic limes, whose main constituents he identified: calcium, silica, aluminium and magnesium. The author mentions a substantial difference between magnesic lime and dolomitic lime and, during an experimental discussion of the calcination of the raw material on the basis of the baking times and temperature, indicates that a calcareous rock containing 20–25% magnesium carbonate, 10–14% clay and 65–66% calcium carbonate gives rise to excellent hydraulic lime known as magnesic lime; he also emphasises that the latter is not to be confused with dolomitic lime, deriving from the baking of dolomitic limestone which, containing neither silica not aluminium, has no hydraulic properties.

Vicat also mentions an interesting observation made by the Piedmont engineer M. Signorile, according to whom the nature of the fuel has a particular influence on the characteristics of artificial limes deriving from the baking of a mixture of clay and dolomitic limestone. If wood is used as the fuel for calcinations, top-quality hydraulic lime is obtained, while if the fuel is coal, which contains sulphides, the result is lime that sets in a couple of days but crumbles altogether by the fifth. The explanation of this behaviour, according to Signorile, is that in the second case magnesium sulphate and calcium sulphate (chalk) are formed, depriving the mortar of resistance in time. Such a negative outcome seems to be due precisely to the presence of magnesium. Indeed, baking of a clayey calcareous rock without magnesium, with coal, which is saturated with calcium sulphate, gives a product which exhibits no swelling.

Greater sensitivity of dolomitic limes to impurities in the air containing sulphur oxides is also noted by the scholars Leo Wilhelm Berens and Eberhart Schiele, who highlight the fact that mortars containing hydroxide deriving from dolomitic lime are particularly affected by degradation processes, with evident sandiness or pulverisation phenomena (Berens e Schiele 1976, 437).

It was precisely observations like these that prompted specific research aiming at determining the possible differences, in terms of performance and resistance, between mortars made with dolomitic binders resulting from baking with wood-based fuel and those made with binders resulting from baking with coal-based fuel.

While Vicat maintained that 6–12% magnesium enhances the quality of the hydraulic binder, making it indestructible, Winkler (1856), again dealing with hydraulic binders, even considered magnesium oxide a detrimental component since, like calcium silicate, it remains unchanged in water. From that moment on, contradictory theses followed one another down to the start of the twentieth century, when Gallo (1908) published the results of an in-depth study carried out in the laboratory of chemistry applied to building materials at the Royal School of Engineers: he declared that magnesium was dangerous in lime-based mortars. According to the scholar, «la presenza della magnesia nella calce . . . riesce in particolarmodo dannosa perché si spegne molto lentamente, e riduce molto la quantità di grassello che una buona calce grassa può dare collo spegnimento; è per questo che si prescrive ordinariamente che una calce grassa, per essere impiegata con profitto, non debba contenere più del 5% di magnesia» (Gallo 1908, 146). The intrinsic incapacity of magnesium carbonate to aggregate in compact structures during evaporation of the mix water is the main reason for the exclusion of magnesic and dolomitic limes from good-quality binders. Indeed, Gallo indicates as fundamental, due to the consequences that can be deduced from it in relation to its use in building, «la grande differenza di solubilia propria dell’ossido di calcio e dell’ossido di magnesio . . . Mentre la calce è solubile in proporzione di gr 1,27 per litro d’acqua a 16° circa, la magnesia invece non è solubile che in rapporto di 1 per 50 mila litri di acqua». And he adds that «la piccolissima solubilità della magnesia, fa sì che sia minima la quantità di essa che può disciogliersi nella massa d’acqua presente, e d’altra parte è lontanissimo l’assorbimento dell’anidride carbonica, da parte della soluzione stessa. Quindi una calce magra per magnesia, fa presa più lentamente, e si disgrega.
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Although by that time many were against the use of dolomitic limes, in the work of enlarging Genoa harbour in the early years of the twentieth century, after a big debate and numerous experimental trials, concrete was used which was made up of a mortar based on dolomitic limestone from Sestri Ponente and pozzolana. Observation of the varying compression and tensile strength of mortars prepared in different periods of the year led to some experimentation taking various factors into account, including the period when the mortar was mixed, the dampness of the pozzolana and the magnesium content in the limestone. In this connection in 1932 Salvatore Levi noted that «l’elevata percentuale di ossido di magnesio non favorisce certo la resistenza dei calcestruzzi. (tuttavia) massi posti in opera nel 1882 per la costruzione del ponte A. Doria e recentemente salpalmi non presentano tracce di corrosione pur essendo stati confezionati con tali calci» (Levi 1932, 7).

Actually, we know of no in-depth studies on the subject, and even the regulations for the acceptance of limes, published in 1940, only give vague indications: alongside the subdivision between rich lime in lumps, poor lime in lumps and hydrated lime in powder, the possible use of air-setting magnesic limes containing more than 20% of magnesium oxide is also contemplated.

There are a lot of manuals that give the classification of binders and in these, magnesic limes are mainly defined as rich limes: in 1912 Licurgo Bertelli maintains that «... un tenore di magnesia del 10% è già sufficiente per dare ad un calcaire il carattere della magrezza, e quando la magnesia raggiunge il 25 o il 30% non può più essere impiegato ... Le calci magre contengono magnesia e questa ... è la causa della loro deficienza di rendimento; inoltre l’ossido di magnesio si idrata molto più lentamente e, per la sua debole funzione basica, compie più difficilmente le reazioni che producono l’indurimento delle calci grasse. Queste calci vengono generalmente rifiutate dai costruttori» (Bertelli 1912, 82 and 93) and in 1922 Luigi Mazzocchi indicates as «... “calci magre” quelle provenienti dalla cottura di calcari magnesiaci (dolomie). Esse possono contenere sino al 50% di magnesia, ma basta anche il 10% di magnesia per rendere “magre” una calce ... il loro rendimento in grassello è tanto minore quanto più è elevata la percentuale di magnesia» (Mazzocchi 1932, 11).

It is only in more recent times that different opinions have been expressed. For example, according to Bolis, «... le calci con più del 20% di magnesia (MgO) prendono il nome di “magnesiache”: una piccola percentuale di magnesia smarrisce la calce, una del 40-50% fornisce invece un’ottima calce paragonabile alla grasa ... » (Bolis 1961) and, like him, Piepoli maintains that «... le calci grasse, ottenibili da calcari con non oltre il 10% di impurezza (fra silice, magnesia, allumina), oppure anche da dolomie con quantità pressocché equimolecolari di calce e magnesia, si spengono rapidamente e con forte sviluppo di calore, dando un grassello bianco, omogeneo, dolcissimo al tatto e all’incirca il triplo, sia in peso che in volume, della calce viva adoperata ... » (Piepoli 1980).

TECHNOLOGY AND SCIENCE

It is curious to notice that in quite a short period of time, just over fifty years, scientific thought regarding the presence of magnesium in lime changed radically. So it seems natural to wonder what changed from the second half of the nineteenth century to the first half of the twentieth. The historical-archaeological analysis that has been going ahead for years in the Ligurian territory and more in general in the regions of Northern Italy shows that the change in the quality of products went hand-in-hand with one of the most important revolutions in the building field: the introduction of the cementitious binder and the revolution in production technologies. There was a transition from intermittent kilns of a pre-industrial type, with bundles of wood sticks as the fuel, to continuous kilns of an industrial type, burning first coal and then mineral oils and natural gases. The influence of the type of fuel used on the oxide product of dolomitic limestone decomposition is already reported on, alongside other indications, by various authors, though without ever being analysed from the scientific point of view. Deville, in a study on
cement made with magnesium oxide, obtained by means of calcinations of magnesium chloride, mixed with calcium carbonate, reports that «Per poter preparare il cemento Deville in proporzione industriale, si cercò di utilizzare la dolomite che, riscaldata a temperatura inferiore al rossò perde l’acido carbonico che è combinato alla magnesia e non quello combinato alla calce» (Gherzi 1903). Vicat too indicates that hydraulic limes are baked with wood fuels to set in soft water, because the heat produced is adequate, moderated in such a way as to arrive at shaded red and subsequently at red heat for enough time to expel all the carbone acid.15 Bertelli, quoting a study by Maede (1909), maintains that it is possible to eliminate the drawbacks connected with the use of calcareous stones with too high a magnesium content for making Portland cement, indicating that the disproportion phenomenon «... è dovuto essenzialmente alla cottura alla quale è stato sottoposto il cemento. Confermi questa opinione il fatto che nei cementi cott a temperatura bassa la magnesia non è nociva: tali i cementi romani; e ancora il fatto che proporzioni anche notevoli di magnesia, ottenuta per decomposizione del carbonato a temperatura normale, aggiunta ad un cemento, non ne modificano le proprietà» (Bertelli 1912, 498).

Once again there seems to be a link between the performance of the final product and the baking mode, though the explanations offered are vague and mostly based on empirical observations. These indications, linking the properties of dolomitic mortars to the temperature at which they are baked, in point of fact also indicate a dependence on the type of fuel used: wood or coal.

Hence it was considered interesting to analyse the influence of both the temperature and the type of fuel on the decomposition product, starting from the study of gaseous atmospheres.

The study of the atmospheres present in kilns fired with different fuels has made it possible to identify significant differences between the contributions of the different components of the fumes.

<table>
<thead>
<tr>
<th></th>
<th>$P_{\text{CO}_2}$</th>
<th>$P_{\text{H}_2}\text{O}$</th>
<th>$P_{\text{SO}_2}$</th>
<th>$P_{\text{N}_2}$</th>
<th>Total $V_T$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Wood</strong></td>
<td>130.805</td>
<td>95.381</td>
<td>0.113</td>
<td>0.113</td>
<td>0.836</td>
</tr>
<tr>
<td><strong>Coal</strong></td>
<td>136.183</td>
<td>65.752</td>
<td>0.696</td>
<td>0.836</td>
<td>0.113</td>
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Neglecting the partial pressures of carbon dioxide and nitrogen, which are decidedly low and hence have no influence on the dolomite limestone mass, an analysis was made of the effect of the carbon dioxide and the steam on the microstructure of the grains of calcium oxide and magnesium oxide produced during dolomite decomposition.

In the scientific literature, the effect of carbon dioxide on the microstructure of calcium oxide, produced by the decomposition of the calcium carbonate, was already well known. At low partial carbon dioxide pressure the oxide still has recollection of the initial crystalline form, while high carbon dioxide pressures favour sintering of the grains, so that bigger grains with a different shape are formed. The same effect has been observed between steam and magnesium oxide: the steam catalyses the decomposition of the magnesium carbonate, above all at low temperatures, rendering the oxide product unstable and provoking localised collapses in the microstructure. The sintering of magnesium oxide inside grains that maintain their global volume increases the total porosity of the sample and the average size of the pores.

Hence in an atmosphere of carbon dioxide alone, the zones of the oxide product prove to be made up of big grains of calcium oxide and small grains of magnesium oxide, not sintered. In an atmosphere of carbon dioxide and steam, both the calcium oxide and...
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The magnesium oxide zones are made up of big grains, with consequent higher porosity.

Decompositions carried out in wood-fired kilns and hence in an atmosphere rich in steam produce magnesium oxide with a large grain and pores that are more accessible to reagents. Towards liquid phases this microstructure should have greater reactivity\(^3\) that, in the case of extinction, is translated into better hydration because of the formation of lime paste.

Only now does it appear possible to understand indications like the one given by Misuraca (1900, 179), namely that «... Sembra che una corrente di vapore acqueo, durante il periodo di demolizione per calcinazione del calceare, agevoli la decomposizione medesima. Era ritenuta perciò buona norma quella di mettere un recipiente con acqua sulla soglia della bocca da fuoco, durante l’operazione di cottura, perché il vapore acqueo potesse facilmente essere trasportato nella massa incandescente ...»

NOTES

1. Utilised in Egypt, perhaps even before the Ptolemaic period, it was known to the Minoans, the Mycenaeans and the Greeks in the archaic epoch, who used it above all in linings, but it was also used in a systematic and widespread way in the Roman epoch, towards the end of the 3rd century BC (Davey 1965, p. ...)

2. «Il cemento è in realtà un legante in grado di produrre malte e calcestruzzi a bassissima porosità, molto rigidi e ad alta resistenza alla compressione, con un’elevata dilatazione termica, vicina a quella del ferro, ma con una conducibilità assai più bassa. Queste caratteristiche fanno sì che con il cemento armato si possano costruire strutture flessibili a volontà, e in grado di sostituire qualsiasi altro materiale portante, anche in presenza di acqua. In ambiente atmosferico, tuttavia, il cemento può dare luogo nel tempo a degradi fisici e chimici legati proprio alle sue caratteristiche intrinseche (per esempio: lesioni di spigolo per sbalzi termici, creazione di solfati dannosi).

Per un certo tempo si è creduto, inoltre, che l’impermeabilità del cemento ne facesse un ottimo materiale per i rivestimenti esterni: oggi si è capito che sono più igienici i muri idrorepellenti all’esterno, ma in grado di permettere una traspirazione dell’umidità dall’interno verso l’esterno» (Mannoni 2000, 7).

3. Dolomite limestone is a rock of sedimentary origin containing a large quantity of the mineral dolomite. Ideal dolomite is made up of a crystalline reticule of alternate strata of calcium ions and magnesium ions, separated by strata of CO\(_3\) and is typically represented by a stoichiometric chemical composition of CaMg(CO\(_3\)))\(_2\), in which calcium and magnesium are present in equal proportions.

4. I.e. hydrochloric acid (HCl).

5. A scale of hardness, defined as resistance to scratching, made up of ten mineral substances empirically ordered by mineralogists in such a way that each one incises the one immediately below and is incised by the one immediately above. Resistance to scratching is measured, for comparison purposes, by the incision produced by one of the minerals belonging to the Mohs scale (Talc 1, Chalk 2, Calcite 3, Fluorite 4, Apatite 5, Orthoclase 6, Quartz 7, Topaz 8, Corundum 9, Diamond 10). (AIMAT (ed.) 1996, 138-139).

6. «La chaux, la silice, l’alumine et la magnésie, sont les principes essentiels dont se composent les gangues qui lient les matériaux employés dans les constructions» (Vicat 1856, 1).

7. «On rencontre quelquefois des substances calcaires tenant, indépendamment d’une certaine quantité d’argile, du carbonate de magnésie; quand ces calcaires, pour 20 à 25 parties de ce carbonate, referment d’ailleurs de 10 à 14 parties d’argile et de 65 à 66 de carbonate de chaux, on peut en tirer pa la cuisson d’excellentes chaux hydrauliques qui prennent alors le nom de chaux magnésiennes, et qu’il ne faudrait pas confondre avec les chaux dolomitiques, provenant des dolomies proprement dites, lesquelles ne contiennent ni silice ni alumine, et conséquemment ne sont pas hydrauliques» (Vicat 1856, 11-12).

This is well demonstrated in the good 2. Piedmont limes, obtained from slightly clayey dolomite limestones.

8. «Un ingénieur piémontais d’un grand mérite, M. Signorile, dans un très intéressant Mémoire, a signalé l’influence particulière exercée par la nature du combustible sur les qualités de certaines chaux artificielles résultant de la cuisson d’un mélange, en bonnes proportions, d’argile et de chaux tirée de dolomies; il a reconnu que ce mélange, cuit à la houille contenant des sulfures, cette chaux, après avoir fait sa première prise en deux jours, tombait en boue le cinquième.

L’analyse comparée de ces deux produits signalait dans le dernier une notable quantité de sulfure de chaux n’existant pas dans le premier ; d’un autre côté, un calcaire argileux, exempt de magnésie, cuit aussi avec la même houille, et chargé aussi en sulfure de chaux, ne présentait dans les mêmes circonstances aucun symptôme de boursoufflement. Nous bornons à rapporter ces faits singuliers, dont la responsabilité reste à l’habile observateur de qui nous les tenons» (Vicat 1856, 14).
9. «On rencontre quelquefois des calcaires dont l'argile contient, outre la silice et l'alumine, une quantité de magnésie de 6 à 12 pour 100 ; la présence de cette base paraît exalter la qualité du ciment pour les travaux à la mer» (Vicat 1856, 42).

10. In the proportions, in volume, of 1:2 with calcareous gravel in the proportion of 1 of mortar and 2 of gravel, for slightly over 1 m³ of concrete (Levi 1932).

11. Levi reports the results of an analysis of Sestri Ponente lime that he followed: \(\text{SiO}_2 \ 2,74 \quad \text{Al}_2\text{O}_3 \ 2,04 \quad \text{Fe}_2\text{O}_3 \ 0,92 \quad \text{CaO} \ 56,76 \quad \text{MgO} \ 35,30 \ (\ldots)\) (Levi 1932, 7).


13. «... di colore pressoché bianco, è il prodotto della cottura di calce [con un] contenuto in \(\text{CaO} + \text{MgO} = 94\%\) in peso \(\ldots\) deve avere un rendimento in grasso \(= 2,5 \text{ m}^3/\text{t}\)» Norme per l'accettazione delle calce, Royal decree of 16 November 1939, 2231, Milan 1940, 13.

14. «... è il prodotto della cottura di calce [con un] contenuto in \(\text{CaO} + \text{MgO} = 94\%\) in peso \(\ldots\) deve avere un rendimento in grasso \(= 1,5 \text{ m}^3/\text{t}\)» Norme per l'accettazione delle calce, Royal decree of 16 November 1939, 2231, Milan 1940, 13.

15. «... il prodotto dello spegnimento completo delle calce predette, fatto dallo stabilimento produtore in modo da ottenervi in polvere fina e secca. \(\ldots\) Questa calce comprende due categorie di prodotti, per i quali devono essere soddisfatti i seguenti requisiti: fiore di calce: contenuto in umidità \(= 3\%\); contenuto in carboni e impurità \(= 6\%\); contenuto in idrati di calcio e magnesio \(= 91\%\); deve dare un residuo al vaglio da 900 maglie/cm² \(= 1\%\); deve dare un residuo al vaglio da 4900 maglie/cm² \(= 5\%\); deve rispondere alla prova di stabilità di volume; calce idrata da costruzione: contenuto in umidità \(= 3\%\); contenuto in carboni e impurità \(= 6\%\); contenuto in idrati di calcio e magnesio \(= 82\%\); deve dare un residuo al vaglio da 900 maglie/cm² \(= 2\%\); deve dare un residuo al vaglio da 4900 maglie/cm² \(= 15\%\); deve rispondere alla prova di stabilità di volume».

16. «Il rendimento di una calce [è] il volume assunto dalla pasta per rispetto all'originario volume di calce viva sottoposto allo spegnimento. È questo straordinario rendimento, per la calce dolce o grassalda 3 sino a 3 volte e mezzo il volume primitivo, il vero motivo per cui in talune fabbriche la calce dolce è tutta di costruttori preferita alle calce idrauliche» (Mazzocchi 1932, 8).

17. Kilns are defined as intermittent when they require distinct and successive phases to work: loading, baking, cooling and unloading (AA VV 1839, 512; AA VV 1878, 61–62). The typical layout of an intermittent production unit, fired with wood, is made up of a vase with a circular plan that develops vertically to create a cylindrical structure, ending in a pseudo-vault and surmounted by a chimney. Inside you can always see a wrapping ring going even two-thirds of the way up and marking the impost of the apertures above. This structure has the task of facilitating loading operations, in that the upper level can easily be reached. The inside diameter of kilns, measured at the height of the wrapping ring, varies from a minimum of four to a maximum of six metres; the inside height, measured in line with the central chimney, varies independently of the width, and oscillates between eight and twelve metres. The main entrance is the only aperture at the base of the kiln and is often done with a double splayed stone or brick arch. There are generally three upper apertures, placed at the vertices of an imaginary isosceles triangle inscribed in the base circumference. Above, other minor apertures and air vents vary in number, shape and position in the curvature of the pseudo-vault, in different kilns. A characteristic element of every lime kiln is the chimney at the top of the pseudo-vault, whose shape is always different.

18. «On remarque qu'à composition égale, les chaux hydrauliques sont, pour l'emploi en eau douce, meilleures, cuites au bois qu'au charbon; cela peut tenir, principalement, au degré d'intensité de la chaleur produite; la meilleure chaux, pour l'emploi spécifique, serait celle pour laquelle une chaleur modérée, correspondant au rouge qui succède au rouge sombre, aurait été soutenue assez longtemps pour en expulser tout l'acide carbonique; cette observation serait en défaut pour l'eau de mer» (Vicat 1856, 8).

19. This denomination comprises all hydraulic products from clayey calcareous stones with a high clay content, baked at a moderate temperature, below the fusion limit, and pulverised by grinding with mechanical means. The product of the grinding is yellowish with red-brown nuanced. Such cements set rapidly, in 5–10 minutes, with very elevated hardening. (Bertelli 1912, 352–358).

20. In the framework of the Postgraduate Course in Materials Engineering, 15th cycle of the Milan Polytechnic, held by the present writer at the Department of Building, Urbanistic Studies and Materials Engineering of Genoa University.

21. As regards the composition of the wood, an average was calculated between the trees that we know from historical sources to have been used (beech, pine, alder, juniper and sessile oak).

22. The quantity of theoretical fumes produced by wood (5,378 Nm³/kg) is lower than that produced by coal (6,259 Nm³/kg).

23. The next stage of the research, at present being organised, consists precisely in evaluating the reactivity of the oxide product in the presence of steam.
The use of dolomitic lime in historical buildings

**REFERENCE LIST**


