Understanding the Basics of Lime Mortars

My family business has been supplying plaster, masonry and concrete materials to Chicago's construction industry since 1873. As a child I loved exploring our century old timber framed office building and warehouse lofts looking for long lost "treasures." I recall many times where, beneath a century of dust, I would uncover old signs and newspapers nailed to our warehouse rafters. Of all the trinkets I found over the years, the most memorable was when I stumbled across dozens of our company's early ledger books.

Our current office building as it appeared in the 1880's

The large, leather bound, gilt ledger books catalogued, in beautiful Palmer penmanship, every building material sold and each railcar of material delivered between 1888 and 1919. I have spent innumerable hours pouring over the pages within these ledgers learning about the materials our company once sold and trying to piece together how these materials differ from those we sell today. The most intriguing pattern evident in these ledgers was the countless entries describing the railcars of lime, hydrated lime, lump lime, rock lime and bulk lime ordered. According to the ledgers, during the first decade of the 20th century we purchased just one railcar of portland cement for every twenty or so rail cars of lime. Today far more portland cement is sold than lime-based binders.

Railcars of materials being unloaded at our facility circa 1940's

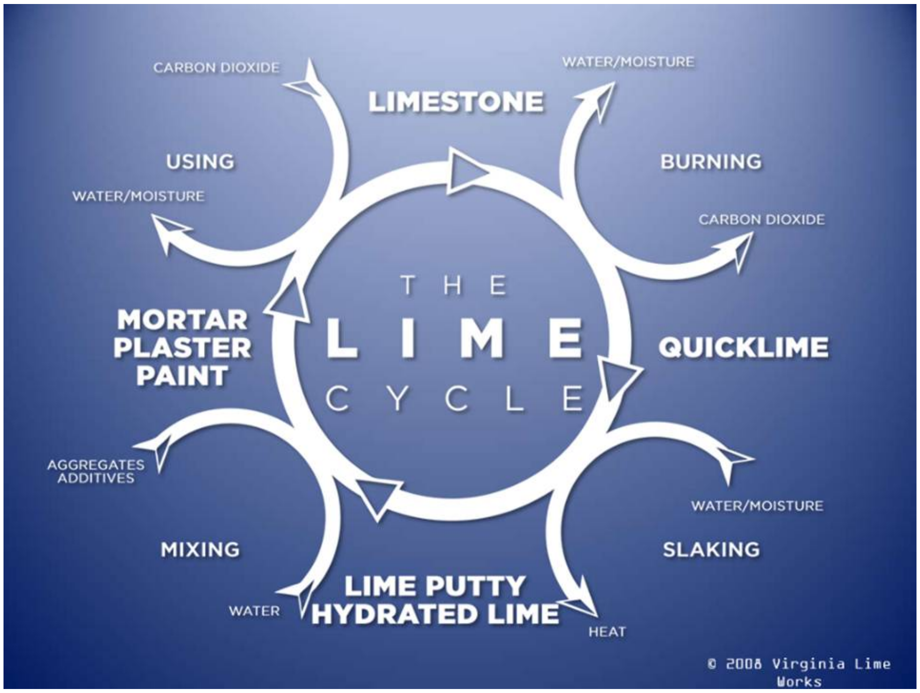
Although building limes were a staple construction material in America as recently as 90 years ago, they are now considered a specialty item that remains largely misunderstood by our industry. As a masonry material supplier specializing in historic restoration, we regularly field questions from architects, contractors and building owners who know that they should use a lime mortar when re-pointing historic masonry but do not know which lime mortar to use. Customers often start by asking for "lime putty" when in reality lime putty is just one of several types of traditional lime binders and is not an all-encompassing term.

THE LIME CYCLE

All lime binders are derived from calcium carbonate materials such as animal shells, bones and, most commonly, limestone. For at least 9,000 years humans have been transforming rock into a plastic workable paste, which then re-petrifies into its original rock-like chemical state in a process known as the **lime cycle**. When calcium carbonate (CaCO3) is fired in a kiln its chemical composition breaks down. At approximately 1,290 degrees Fahrenheit the chemically combined water within the calcium carbonate is driven off and at approximately 1,650 degrees the calcination process takes effect where carbon dioxide is expelled. The chemical composition of the resulting rock after calcination is called calcium oxide (CaO) but has also traditionally been referred to as rock lime, lump lime, bulk lime and most markedly **quicklime**.

After calcination, quicklime typically retains its original geometry (i.e. still looks like a rock) but shrinks in size and can lose up to 45% its original weight just from the expulsion of water and carbon dioxide from its chemical bond. Its appearance and texture are similar to that of white chalk and, as a result of being starved of water and carbon dioxide, quicklime is extremely chemically unstable. When water is applied to quicklime in a process known as **slaking**, a rather impressive reaction takes place as the calcium oxide rapidly re-combines the water into its chemical makeup to produce calcium hydroxide (CaOH2). This exothermic chemical reaction produces enough heat to cause excess water to steam. The calcium oxide pops and sputters as it fractures into pieces, expands, and eventually falls into a dry white powder called **hydrated lime**.

During slaking, the addition of water in excess of what is required for hydration produces a smooth workable paste called **slaked lime putty**. At this point sand may be added and the material worked into a fresh **hot mix**mortar. Lime putty can also be produced by mixing additional water to dry hydrated powdered lime and, with the addition of sand, this mix also produces a workable mortar.



The Lime Cycle

Once a lime is worked into a mortar and installed in masonry or plasterwork the hardening process commences. In a process known as **carbonation**, excess mix water evaporates from the lime during initial drying and the calcium hydroxide (lime) begins to re-combine with carbon dioxide introduced from the atmosphere or dissolved in water in the form of carbonic acid. Over a period of years, decades or in some cases even centuries, the eventual strength gain of a lime based mortar is achieved as the calcium hydroxide carbonates and returns to calcium carbonate, thus completing the lime cycle.

CLASSIFICATION OF LIME BINDERS

Appreciating that lime binders are typically produced from natural formations of calcium carbonate, it stands to reason that inconsistencies must exist in the mineralogy of the raw ingredients based on variations in geology. Limes produced from high calcium pure limestone such as chalk or marble rely solely on carbonation and achieve strength extremely slowly. These limes were historically referred to as **air limes**(also known as common limes, pure limes, rich limes or fat limes) because they only obtained strength if exposed to air and would never set under water. However, for hundreds of years mankind has understood that certain types of limestone produced quicker hardening limes, some of which possess the ability to set under water. Appropriately termed **hydraulic lime**(also known as water limes), these binders would chemically react with the mix water during mortar preparation and produce a crystal formation in a hydraulic set. Hydraulic setting limes are classified in the same two classifications as they have been for centuries, as "natural hydraulic limes" or "artificial hydraulic limes."

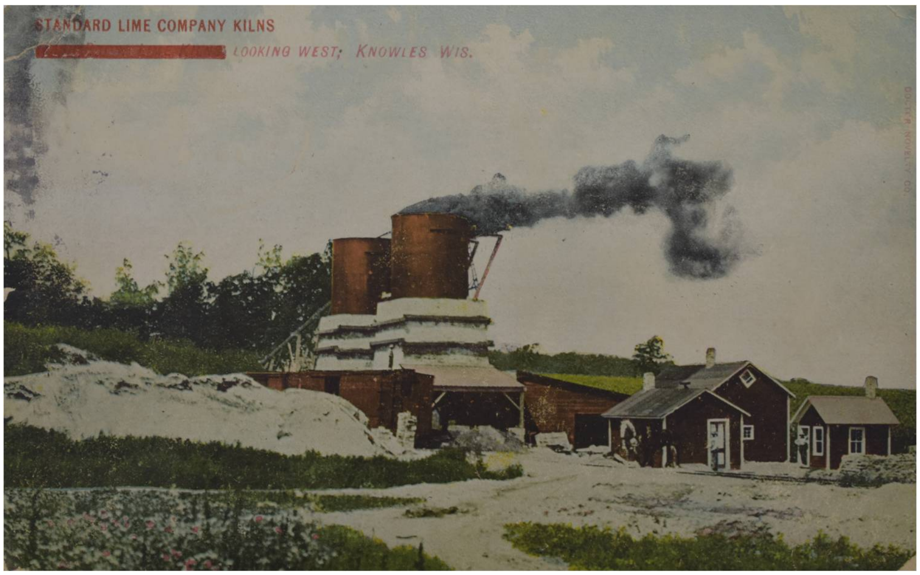
Natural hydraulic limes (NHL) are produced from calcium carbonate rock which naturally contains varying amounts of silica and alumina impurities. These impurities are typically found in argillaceous limestone that contains strata of clay or shale. During the calcination process the silica and alumina impurities form compounds which are reactive in the presence of water and contribute to the lime's hydraulic setting properties. Traditionally, natural hydraulic limes have been categorized by three varieties; NHL 2.0 "slightly hydraulic" or "feebly hydraulic," NHL 3.5 "hydraulic" or "moderately hydraulic" and NHL 5.0 "eminently hydraulic."

Another naturally occurring lime which has a hydraulic set superior to even the most eminently hydraulic of limes is **natural cement**(also known as rock cement). The construction of the Erie Canal in 1817 required large amounts of water resistant hydraulic setting cement to construct its locks, bridges and aqueducts. During this period, high quality natural cement producing rock was discovered in the town of Rosendale, New York, which was located near the eastern access to the canal system along the Hudson River. Natural cement bearing rocks had significantly more silica and alumina content than all of the natural hydraulic limes and, after calcination, would not slake. Consequently mechanical grinding was required to reduce the calcined natural cement into a palpable powder. With the addition of water, ground natural cement powder produced a very workable paste which historically was said to have capabilities of setting under water in as little as 2-3 minutes. Natural cements can be considered a close relative to modern portland cements.

For millennia, artificial hydraulic (lime) cements have been prepared throughout the world by combining clayey material with pure lime rock and calcining the material together. Another method for preparing artificial hydraulic cement was by mixing pure air limes during slaking with a variety of finely pulverized un-calcined material containing high concentrations of silica and alumina. The Romans famously produced pozzuolana cement by adding ground volcanic rock, found in the city of Pozzuoles at the foot of Mt. Vesuvius, with their pure limes. In Holland, a volcanic rock called terras was ground and incorporated into lime which produced similar hydraulic setting properties as the Roman pozzuolana cement. Other additives such as ground brick dust, arenes, ochreous earth and sands from certain granites, schist and basalt have also been employed all with similar hydraulic reactivity.

LIME HYDRATION METHODS

Traditional mortar mixes prior to the 20th century were almost always either produced from aged slaked lime putty or from "hot mixes." Because pure air limes contain no silica or alumina impurities they have no hydraulic set and can be stored in a wet putty like state indefinitely if protected from carbonation and drying out. It has long been believed, and recent studies support, that the longer pure non-hydraulic lime putties are allowed to age the finer and more workable the material becomes. Roman law required lime putty to be aged for at least three years in an earth covered subterranean pit before use.



Standard Lime Company Kilns owned in part by our company during the early 1900's

Due to the difficulty in transporting lime putty and the general inconvenience and expense of aging putty, it was very common to produce**hot mixed**mortars on jobsites. The hot mix mortar method also granted contractors an opportunity to use hydraulic setting limes which would harden faster than pure limes and increase productivity. I recall my grandfather re-telling stories his father told him about how our company delivered lime boxes to various jobsites throughout Chicago in the evenings. Our teamsters would mound quicklime in the lime box, cover the mound with dampened sand and lightly sprinkle the composition with water. Overnight the quicklime would slowly hydrate and by morning would be completely slaked and ready for "beating" (i.e. mixing with the sand) by the masons into a fresh hot mix mortar. According to family lore, it was not uncommon in those days for competing suppliers to dump our lime boxes onto the ground, ending the slaking process and rendering the mortar useless the next morning. According to my grandfather, this was a period in Chicago's construction history unofficially known as "The Great Lime Wars."

It was not until the early 20^{th}century when powdered hydrated limes gained popularity. Quicklime was bulky, and due to its chemical instability, was dangerous to transport and difficult to store without absorbing ambient humidity and "air slaking" prematurely. Our company ledgers show a significant shift in the frequency of orders for "hydrated lime" railcars compared to "lump lime" (quick lime) orders beginning around 1900.

Limes of various classifications continued to be the binder of choice up until the 1930s. As domestic portland cement production increased, its price continued to decrease until it reached a point where masons found it more economical to use faster setting portland cement instead of slower hardening limes. By the middle of the 20th century, the use of portland cement became the primary binder of choice and the use of limes as a singular product faded into history.

MODERN LIMES

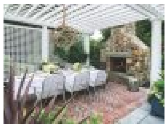
Over the last 20 years there has been a resurgence in the interest in lime binders for restoration work in America. However, with increasing frequency, I am hearing the term "lime putty" being used to define all lime binders. As previously discussed, lime putty describes the physical state of quicklime after being hydrated with excess water. Incorrectly referring to all limes as a "lime putty" and not carefully designating the correct type of lime can easily lead to costly mistakes in material selection.

Good quality modern lime putty remains readily available but, as its name implies, is packaged in a wet state and is therefore always produced from pure non-hydraulic setting limes. Many lime putties are available in an aged state, are highly workable and often fantastic binders for interior plasterwork. However, because these putties rely solely on carbonation for strength gain, they can be unsuitable for exterior use in harsh climates where short-term durability is necessary. Furthermore, freshly applied pure lime putties require extreme care during their initial carbonation process and must remain damp for a period of several days. Contractors who do not have experience working with pure lime putties may want to consider using a more forgiving hydraulic setting lime.

Natural hydraulic lime mortars continue to be extensively used in Europe and all three traditional types of NHL mortars are available domestically as a hydrated powder packaged in bags. Natural Hydraulic Lime 2.0 is the least hydraulic and weakest type of NHL binder. It can be suitable for re-pointing soft masonry or used as a finish coat plaster. Natural Hydraulic Lime 3.5 performs well as a general-purpose re-pointing mortar in most applications and also functions well as a binder in scratch and brown coat plasterwork. Natural Hydraulic Lime 5.0 is the most hydraulic and strongest of the NHL mortars and is particularly useful in masonry exposed to frequent moisture. In addition to the availability of NHL mortars, two classes of artificial hydraulic limes are domestically available, classified as Pozzolan Hydraulic Lime (PHL) 3.5 and 5.0 with the later being the strongest and most hydraulic.

Mortar is undoubtedly a critical component of any masonry system and it is critical we repoint historic buildings with compatible binders to preserve them. I am proud to be part of the current lime movement, which helps bring awareness to the materials which were once a staple commodity sold by my great-great grandfather over 140 years ago. The greatest challenge contractors currently face is finding guidance as one begins to navigate through the various lime options. With this in mind, next month we will discuss the primary functions of properly designed mortar and why lime repointing mortars can offer significant advantages over portland cement mortars in restoration work.

Words & Photos: Matthew Wolf



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