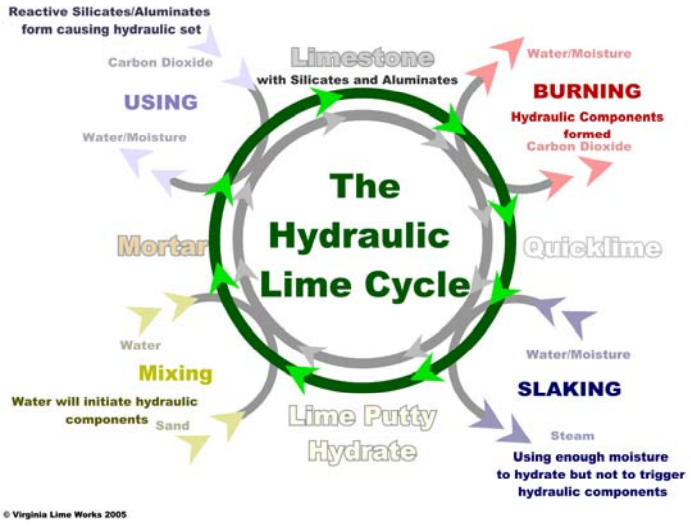
Natural Hydraulic Limes, by definition, are limes that begin to set or get hard, when they come in contact with water. The European Norm (EN459.1:2001.3.10.1) classifies Natural Hydraulic Limes as "limes produced by burning of more or less argillaceous or siliceous limestones with reduction to powder by slaking with or without grinding. All NHL have the property of setting and hardening under water. Atmospheric carbon dioxide contributes to the hardening process."

Hydraulic Limestone come from two sources, those with a clay content (argillaceous) or those with a silica content (siliceous). When these limes are burned in a kiln, reactive silicates are formed which will cause the material to set when it comes into content with water. After the limestone is burned the material is slaked or hydrated. Moisture is introduced to the quicklime ("cooked limestone") and during this hydration process the lime breaks down to a powder. Care must be taken to add just enough moisture to break the material down, but not enough to initiate the hydraulic components (reactive silicates). This material is then bagged and stored for use. When this lime is mixed with sand and water to make mortar or plaster, the reactive silicates are triggered causing the material to set. NHL will set quickly (in comparison to non-hydraulic limes) and over time carbon dioxide from the air is reabsorbed making the mortar stronger and more durable. This is also illustrated in the "Hydraulic Lime Cycle"

THE HYDRAULIC LIME CYCLE ILLUSTRATED

The information in black illustrates the basic lime cycle, which is the process of burning, slaking and mixing lime. In the blue the hydraulic lime cycle is shown. Natural Hydraulic Limes go through both of these processes. The reactive silicates that are formed are known as "belite" or di-calcium silicates. At higher temperatures the reactive silicates would form "alite" or tri-calcium silicates. Tri-calcium silicates are often found in Ordinary Portland Cement (OPC) and are highly reactive resulting in a material with high compressive strengths and extremely fast sets. The di-calcium silicates that are found in Natural Hydraulic Limes result in a faster early set, moderate to low compressive strengths, and higher flexibility, all of which are important when using as a mortar or plaster in a historic structure.



MAKING NATURAL HYDRAULIC LIMES

Burning

Natural Hydraulic Limes are made in a similar fashion as non-hydraulic limes. The limestone comes from the earth and is fired in a kiln. During this calcining process (i.e. burning or the transformation of limestone: $CaCO_3$ to Quicklime: CaO) moisture and carbon dioxide are released from the stone. The stone in the kiln must reach a temperature of 1560°F to convert from limestone to quicklime. During the burning of hydraulic limestone the silicates in the limestone convert to from an inert material to reactive form. These are the components that will cause the lime to set with they come in contact with water.

Slaking

Slaking (or Hydration) is the process of taking the quicklime and adding water to it, to bring it to a usable form for mortars or plasters. The quicklime is taken and moisture is added to it. If a minimum addition of water is added the quicklime will break down and become a hydrate. If an excess of water is added the material will break down into a "lime putty" or paste. When working with hydraulic limes only a minimum of water can be used because if an excess is used it will trigger the reactive components that were formed during the burning process. This is why Natural Hydraulic Limes are supplied as a dry powder or "hydrate".

After the lime has been burned and slaked it is ready to be mixed with sand or other aggregates to make a mortar, plaster, or render.

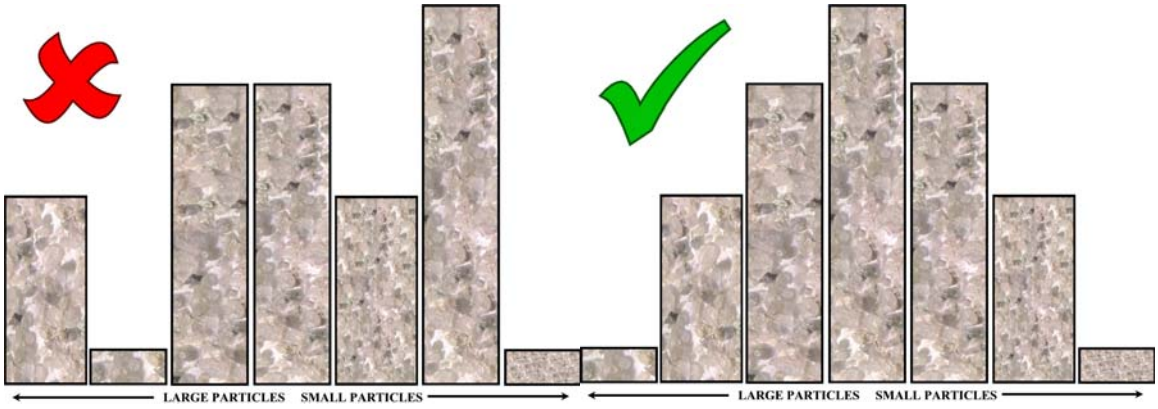
Making NHL Mortars & Renders

About Sands

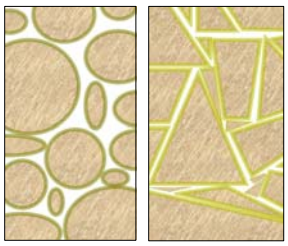
Mortar or Plaster is comprised of at least three components: Binder, Aggregate, and Moisture. Many historic mortar recipes were mixtures of lime, sand, and water. When making Natural Hydraulic Lime (binder) mortars, you must make informed decisions on not only the lime, but the sand and water content as well.

Sands for use with Natural Hydraulic Limes

Sands for NHL mortar should be well graded, sharp, and clean, but it is important to understand WHY this makes a good sand.



Well graded sands are best for building and repair work. If sands are comprised of particles that are overwhelmingly coarse or fine they will be less workable and harsher to "the trowel". When this happens, it is common to compensate by adding more water. This can lead to shrinkage cracking and potential "bleeding" or staining, particularly in brickwork, of the masonry wall. A good sand gradient will appear in a bell curve. On the microscopic level, these coarse, medium, and fine particles will form a tighter matrix within each other which should require a lesser amount of lime in addition to a lesser amount of water.

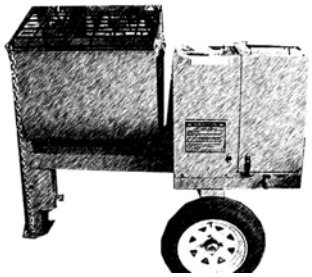


The sharpness of the sand is important too. Imagine the particles of sand as a tiny puzzle and you want to get the grains as close as possible. In rounded sands the particles will not fit together as well as in a sharper sand. Here you see illustrations of this point

A good mortar sand is clean, and free of clay and/or silt. Silt or clay in your sand can make your mortar "thirsty". The purpose of adding water to the mortar is to properly hydrate the lime to bring it to a plastic state. If water is being soaked into the particles of clay, then there will be a

tendency to add water to compensate. This can expand your mix which can lead to shrinkage cracking. It can also lead to a reduction in compressive and flexural strength making your mortar brittle and friable, and reduce vapor permeability, which accommodates water vapor in and out of your building.

When measuring sand it is important to have a consistent method of measuring. Ensure that the sand that is being used for mortar or plaster is not too damp or too dry. The difference between wet sand versus dry sand can lead to a margin of error of 40% when measuring by volume. The industry standard is to use a "damp, loose sand" when making mortars. Measuring sand by weight is often the best method, however using gauging buckets are acceptable. These are buckets that have been pre-measured for a certain amount, such as a 5 gallon bucket or a 5 gallon pail that has been marked and cut off at, for example, three and a half gallons. Using a "shovelful" as a measuring device should not be used with Natural Hydraulic Limes.

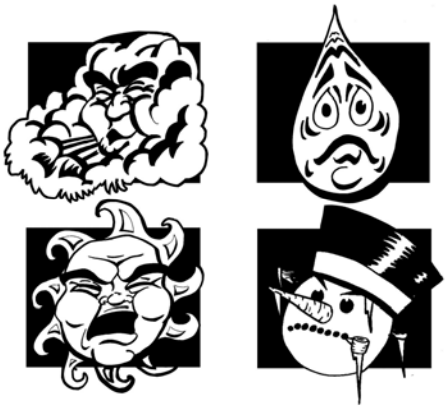


MAKING NHL MORTAR

When making a mortar using Natural Hydraulic Limes it is important to make sure that the lime:sand:water ratio is consistent to achieve a uniform mix. Ideally when mixing NHL mortars the lime and sand would be pre-blended, achieving a homogenous dry mortar. The mixing of dry lime and sand (although it may not be ideal for on-site working conditions) allows the abrasiveness of the sand to separate the small particles of lime and achieve an extremely uniform mortar. NHL mortars can be mixed by hand, roller pan mixers, paddle mixers, and the less effective drum concrete mixer. When working with a mortar mixer add the lime, then a portion of water (to minimize dusting) and then most of the sand, adding water slowly to achieve required consistency. Because of the fine particle size of Natural Hydraulic Limes, it tends to come together in little "bunches" of individual grains. This can prevent the lime from fully wetting which could cause the over addition of water to achieve workability. Keep in mind that often NHL mortars should be mixed for about 5-10 minutes to achieve maximum workability and homogenization. But more importantly ensure that you are not adding too much water. If too much water is added it could "expand" your mix which could lead to a higher risk of shrinkage cracks, lower compressive strengths, and a more friable material.

PREPARING AND PROTECTING YOUR WORK FOR NHL MORTAR

There are a few things that should be done to prepare your work for use with lime mortar. Before any repointing, plastering, limepainting, or other applications are performed, check the details of the project. Is there previous repointing work that needs to be repaired or removed? Are the gutters and downspouts in good workable condition? Is moisture trapped in the wall due to a non-compatible mortar? Are weather and climate conditions right? You shouldn't work without proper protection if drying winds, direct sunlight, rain, or freezing temperatures are an issue. Many of these issues should be addressed and resolved for NHL mortar to perform correctly. If the wall that you are working on has been sealed and is trapping moisture for years because of a hard incompatible mortar then it may be good to remove this and allow the wall to breathe for a while before you try to work on it.



After issues such as incompatible mortars are removed, and proper drainage are resolved then work can begin to proceed.

Planning must be done to protect your work once it is finished. For periods of time (7 days or so) of pleasant days with a relatively high humidity, and no wind you may not have to protect at all. But for the most part, you will need to make sure that the work is protected from drying winds, direct sunlight, freezing, and heavy rains. If the conditions are so that the craftsmen are comfortable then the wall is comfortable.

Also your rate of set may change depending on the temperature outside. Cold weather tends to slow down the set of hydraulic limes whereas hot weather tends to quicken the set. Make sure that if you are working in temperatures lower than 40° F that you protect and heat your work area to ensure that the mortar does not freeze. This may take an extended period of time due to the conditions of the project, but it is pivotal for its performance. Also if you are working in temperatures that exceed 85° F it will be necessary to protect from the harsh sunlight and heat where the mortars set may be accelerated. Use shade clothes to protect the work from the sun and use burlap that is thoroughly dampened to maintain a cool damp environment for curing. Some days it may be necessary to dampen the work directly using a fine mist spray. The mist will not harm the mortar but will keep it damp and open for the proper absorption of carbon dioxide. Natural Hydraulic Limes go through two separate sets. The first "hydraulic" set begins to take place as soon as water is added to the mortar. The second set, which takes place due to carbonation, is slower to take place. During this slow curing carbon dioxide will combine with moisture in the air to form carbonic acid. This combines with the calcium hydroxide (lime) in the mortar which forms calcium carbonate or limestone. If the mortar dries out too quickly then it will not receive the carbonate acid as readily, on the other hand if the mortar stays over saturated then it will not be able to receive the carbon dioxide and may not carbonate as easily. The best way to achieve the perfect curing conditions is by using a garden spray on the finest setting possible. This will allow the mortar to stay slightly moist, but not overly damp, resulting in an ideal environment for slow curing. On days where temperatures and conditions are moderate you will want to maintain an environment that will keep the mortar open to receive carbon dioxide for approximately seven days.

Now that steps have been taken to ensure slow curing the walls should be thoroughly dampened to receive the mortar. This may mean spraying with water a few days before work is to commence. Control the absorption of your substrate is extremely important. Many substrates, including historic brick and plaster, have extremely high suction rates. If absorption is not controlled then the substrate may pull moisture from the mortar and the mortar will dry out too quickly. This could lead to such problems as shrinkage cracks and potential mortar failure.

REWORKING NHL MORTAR

Mortars made with NHL 2 and some mixes with NHL 3.5 remain open and available for reworking for up to 24 hours. Other 3.5 mixes and NHL 5 mixes only remain re-workable for shorter periods of time. When Natural Hydraulic Lime Mortars "sit" the water within the mix will continue to hydrate the particles of lime causing a more workable mix. However, during this time the water will be reacting with the hydraulic components in the lime causing the mortar to stiffen. When re-working NHL mortars, use a small amount of water in the "knocking up". If a significant amount of water is needed to bring the mortar back to a plastic state it should be discarded whereas the hydraulic components may have already formed. As a rule of thumb, it is recommended that you only re-work twice within a 3 to 4 hour period. After this point, it may be best to discard your mix. Refer to individual NHL datasheets for approximate curing times.

CARING FOR YOUR WORK

Working with Lime Putty mortars often entail the slow curing and re-absorption of carbon dioxide over a period of 3-4 weeks. This entails slow mist spraying and protection from sun and drying winds during this time. When working with Natural Hydraulic Limes this period is reduced to 7 days. Slow cure NHL mortars for these 7 days by damp mist spray and covering your work with damp burlap. For best results, drape the burlap on the work, but maintain an inch or so of air space between the work and the substrate. This will keep a damp atmosphere, but will also allow airflow and carbon dioxide rep-absorption which will give your mortar its strength. ALL NHL MORTARS SHOULD NOT FREEZE WHILE CURING. It may take longer than 7 days to develop the strength and loss of moisture that will prevent freeze/thaw damage. Take care that while your mortar is curing and during freezing temperatures that your mortar/plaster/render is protected!

BENEFITS TO WORKING WITH NHL's

There are many benefits to working with NHL mortars. Natural Hydraulic Limes are available in a range of strength classes. NHL 2 mortars are ideal for situations that require work with soft friable brick or stone, consolidation of friable materials, and areas that have a mild, temperate, climate. NHL 3.5 mortars can be used in just about any situation. Their moderate compressive strengths, coupled with their quicker setting times make it a very good "general use" building lime. NHL 5 mortars develop higher compressive strengths and have fast setting times, which may be necessary for areas of work that involve exposure to harsh weather conditions, low suction materials (such as dense limestones, impervious granites, hard fired-modern brick), and sea works (sea walls, lighthouses, etc.). In addition to the range of strength classes,

Natural Hydraulic Limes have available free lime as well. This free lime is pivotal for the autogeneous healing properties of the mortar. Autogeneous healing translates to that the mortar is self-healing. If due to time or movement of the structure the mortar develops hairline cracks, the atmospheric carbon dioxide mixes with moisture in the air to form carbonic acid. This carbonic acid then dissolves the free lime within the mortar and brings it to the surface, healing the crack. This autogeneous healing property of lime makes joint-free or minimum joint construction available. NHL's are also vapor permeable which allows the building to bring in and release vapor and moisture. With all the benefits of working with Natural Hydraulic Limes with their ranges in ability it is easy to determine what kind of mortar is needed for a certain application.

DESIGNING THE RIGHT MORTAR FOR THE RIGHT JOB

Every project is different. Certainly a NHL 5 would not be used in repointing soft friable brick, whereas, an NHL 2 possibly wouldn't be strong enough to hold up to the abrasiveness and abuse that would accompany repointing a stone lighthouse wall in harsh New England conditions. Every lime has its different uses and every mortar has different mix ratios (lime sand combinations) that perform differently. We provide a Mortar Grade Identification Chart which offers information to the properties of how certain mix designs work. This is meant to be a guideline and is by no means a specification. It is a starting point to determining what options are available. Contact Virginia Lime Works or an authorized Virginia Lime Works dealer for more specific information in determining an appropriate mix design.