Chapter 1

Introduction

Natural plasters are beautiful, nontoxic to live with (though not always to work with), and steeped in tradition. The act of plastering is generally enjoyable, even addictive for some, but it's very hard work. It's also serious business — along with roof and flashing details, the plaster skin of a building protects the materials inside from degradation by water, wind, sun, and animals. The job of the natural plasterer today is to take millennia-old techniques and materials, combine them with contemporary materials and tools, and employ them safely and efficiently on a modern construction site. This book gives detailed direction on how to do this. Many natural builders have collaborated to share their expertise for this book; the variety of recipes — and the diverse approaches to plastering they reflect — make this book a valuable resource for beginner and professional alike.

Why Use Natural Plasters

Before we launch into nine chapters on how to use natural plasters, it's worth taking a moment to reflect on why you would want to use them. There are several situations in which you'd be likely to use natural plasters: to cover a natural wall system, in which case the permeability and flexibility is important and often essential; to cover more conventional wall systems, such as a stud wall sheathed with wood lath or drywall, where natural plasters add beauty and are a nontoxic alternative to paint or other wall finishes; and in restoration, to match or repair heritage plasters.

Here's a short list of some of the advantages of natural plasters:

- In our increasingly sealed homes, indoor air quality is important, and there's a growing body of evidence that the chemicals we surround ourselves with can cause harm in relatively low concentrations. Natural plasters are free of these environmental toxins.
- Natural plasters connect us to our heritage. They have a track record going back thousands of years. We know that they work, and we know how they interact with other natural building materials, including wood. Some of this knowledge has nearly been lost, but as a natural plasterer, you can help keep this knowledge alive.
- Natural plasters have greater flexibility and vapor permeability than most synthetic materials. They tend to protect the materials they are bonded to from moisture damage. They are essential as a coating for many forms of natural building, and can be beneficial for many forms of conventional construction.
- Natural plasters typically have a low embodied energy — the energy it takes to mine, process, and transport them. They can often be sourced locally and thus contribute to the local economy.

Fig. 1.1: *Natural plasters are a nontoxic and beautiful finish with many benefits to the homeowner, and the planet.* Credit: Deirdre McGahern

- They are beautiful. There is evidence that human happiness is tied to our connections to the natural world, and natural plasters can contribute to human well-being by introducing natural products, forms, and textures into homes.
- Natural plasters can help regulate temperature and humidity in homes, improving comfort and reducing the need for air conditioning and heating.

How to Use This Book

While at heart this is a recipe book, to be a successful plasterer you will need to understand the materials and how they interact with environment, substrate, and design.

The opening chapters of this book describe the materials, how to design for them, how to prepare the walls, and how to mix and apply natural plasters in general. It's tempting to jump straight into putting mud on the walls, but the preparatory steps leading up to that moment are more likely to determine success or failure than the days spent plastering. Chapter 3, Planning and Preparation, is probably the most important chapter in this book.

Fig. 1.2: *Damage to the base of this wall was caused by a poor choice of exterior plaster combined with a poor design for roof drainage.* CREDIT: MICHAEL HENRY

Before you begin, you will want to make sure you have chosen the best plaster for your application and that your house is designed appropriately. Too often, we have been called in to repair plasters that weren't appropriate for the site or design of the building. This may cause the plaster to fail quickly, or — even worse — it can cause damage to the underlying building materials.

When you're ready to plaster, Chapters 5 through 8 will tell you how to process and use earth, lime, gypsum, and cement plasters, giving you recipes for a wide variety of plasters. A plaster recipe is only a starting point. When you use a recipe from this book, there will be a learning stage as you come to understand the properties of the plaster: how to lay it on the wall, how thick it can be applied, how long it needs to set up before a finishing pass, whether it needs burnishing or compression, and how many coats are needed. Much of this information can be gleaned from the recipe, but some things you'll have to learn by doing. This all becomes more complicated in the real world, where there are multiple variations: change the substrate, or use a different aggregate, or if the weather changes while you're working, and you will get different results.

Testing

Always do tests.

Make the patches large (3–4 square feet) and as thick, or thicker, than you intend to apply your plaster. Also, if possible, try it on a wall at home and live with it for a while before plastering a whole room or a whole house. Get to know the plaster and understand how it works with your locally available materials. Take detailed notes, and monitor the coverage rate. Rates in recipes, when they are given, are only guidelines.

Good notes are essential when you start modifying recipes — which will happen sooner than you expect. When you change a recipe, try to change only one thing at a time. If the plaster is cracking, try adding aggregate, or changing the type of aggregate, or add fiber, or simply apply it in a thinner coat. But only do one of these things before trying something else.

Finally, be cautious. Experiment on a wall of your own house or (preferably) an outbuilding. Use mistakes as learning opportunities. Take it seriously, but have fun too.

A Note on Measurement Units

We've tried to give imperial and metric units without making things unwieldy. In some cases, we assume a liter is the same as a quart instead of being 1.06 quarts. When in doubt, always use the *ratio* in the recipe as your starting point.

Appendix 1 has useful conversion tables.

Safety: The First Priority

Toxicity and Material Safety Data Sheets

People who are new to natural plasters sometimes think anything natural must be nontoxic: earth plasters are made out of materials dug from the ground, so how could they be dangerous? In fact, although the end result is nontoxic, these products can still be hazardous to work with. Take clay for instance, which often contains large amounts of crystalline, or "free," silica (fine quartz). When inhaled, this can cause *silicosis* (a debilitating lung disease) or lung cancer. Silica is also found in cement and fine sand, but not in pure lime (which nevertheless isn't great to breathe in). The long and the short of it is that plasterers work with materials in fine powder form and need to be very careful about what they breathe in.

- Always wear an appropriate respirator when mixing, or anytime there is dust — *including cleanup!* Don't make dust when unprotected co-workers are present.
- Use a mop or a vacuum with a HEPA filter instead of sweeping when fine plaster dust is present. Wear a mask even while vacuuming.
- Read the Material Safety Data Sheet (MSDS) for materials you are working with, including bagged clays and pigments.

An MSDS (or SDS) sheet can be found for most materials by doing an internet search. For example, searching for "msds epk" finds that EPK (Edgar Plastic Kaolin) bagged clay contains 0.1–4% crystalline silica, whereas Bell Dark ball clay contains 10–30% silica.

If you are an employer, it is your responsibility to have current MSDS sheets available on site. You must make sure everyone is adequately trained to use all material and equipment safely, and that everyone knows what to do in case of an emergency.

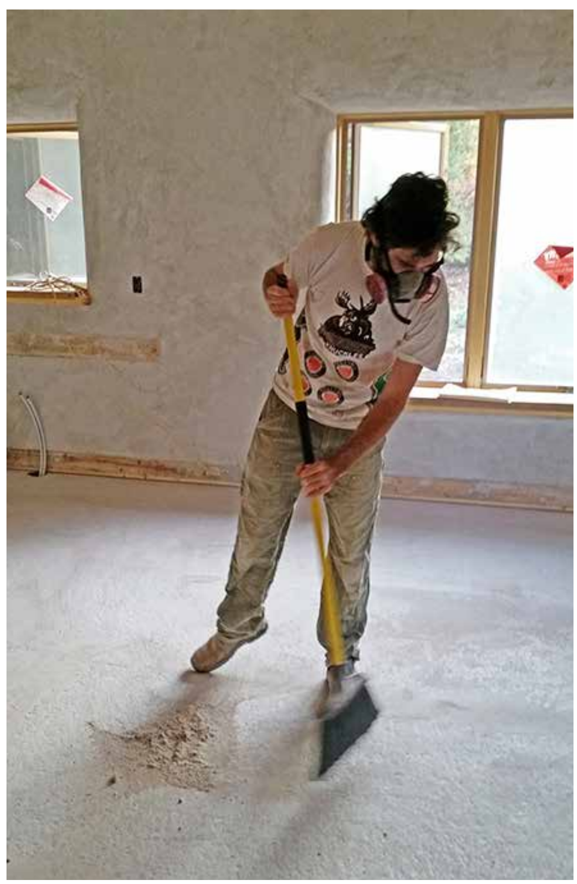

Fig. 1.3: *One of the most overlooked hazards on the jobsite is the dust raised by sweeping. Always wear a respirator during cleanup. A vacuum with a good filter is better than a broom.* Credit: Solomon Johnston

Pigments vary greatly in their toxicity. The composition and toxicity of pigments is discussed in Chapter 2, Natural Plaster Ingredients.

Some natural materials may not have a safety data sheet, but be careful of *any* material that can produce dust. For example, straw contains enough silica (3–5% — or more) that dust from processing straw should never be inhaled.

Choosing respirators and vacuum filters

Plasterers generally use a half-face mask respirator with rubber or silicone seals that accept replaceable filters. Filters have a NIOSH (National Institute for Occupational Safety and Health) rating that ranges from N95 to P100. *N* stands for *Not oil resistant, R* indicates *oil Resistant,* and *P* is *oil Proof.* The number 95 or 100 represents the percentage of 0.3 micron particles that are blocked by the mask in tests — so 100 is the best you can get. Oil resistance is not usually a consideration for plasterers, but filters rated as P100 (oil proof, 100% efficiency at 0.3 microns) are widely available, and they offer maximum protection against fine particles, so this is what we usually use. HEPA vacuum filters also provide close to 100% protection against fine particles, and they should be used for clean-up in combination with a respirator.

Organic respirator cartridges can be used against dust only if they have the appropriate NIOSH rating, but they are primarily designed to protect against chemicals and high-VOC products, including natural solvents such as citrus solvent or turpentine.

Site Safety

Site safety should become part of your workplace culture, and it can't be over-emphasized. Take safety seriously and invite input from everybody on site about how to make the workplace safer. Not only will this uncover problems that supervisors or team leaders may have overlooked, but group participation will raise individual awareness. Make sure workers have the necessary training. Set realistic rules, then stick to them. A single accident can have significant financial, legal, and personal implications. If you are an employer, depending on where you are located, you may be obliged to have a safety representative who checks daily to make sure that any potential job hazards are addressed and discusses any dangerous work habits with the crew.

Don't use combustion engines inside of a building, and if you are doing cold-weather plastering, make sure to have proper ventilation if propane heaters are used. Plan for proper ventilation when spraying *any* material or when dust is created. Ensure that all crew members have respirators.

How Accidents Happen

Accidents often happen due to *inattention.* When using a plaster pump or sprayer, the pace is often set by the machine, and things can become frantic quite quickly. When a plaster job is rushed, the quality of the job will suffer, as can the safety of those present. Inspect all equipment regularly prior to use. Be particularly careful with plaster pumps; pressure can build up in the hoses that can release explosively — so all workers need to wear eye protection *at all times.*

Plaster is heavy. Make sure that buckets and wheelbarrows can be safely moved — there's no point in filling buckets to the brim if no one can lift them!

Sometimes, other crews are working on a jobsite at the same time as the plastering crew. If the site changes (e.g. if there is trenching going on, or heavy equipment is moving around the site), make sure that everyone on your crew is aware of the hazards.

Accidents regularly happen when ladders aren't set up on level ground, or when scaffolding isn't properly erected. Do regular inspections of all tools and ladders; make sure that scaffolding is set up according to regional safety standards. Wear a hard hat.

Be organized!

Falling, slipping, and tripping are among the most common jobsite injuries. One of the best ways to have an accident-free jobsite is to keep it organized. Plastering is inherently messy — sometimes it looks like a tornado has blown through at the end of a work day. Have a plan for regular cleanup, and have systems in place (i.e. set locations for where the buckets of plaster are to be kept vis à vis the plasterers, and a well-thought-out flow for equipment and materials, etc.).

Weather conditions

Extreme cold or heat can be problematic both for your plaster and for workers. Be aware of daily conditions, and be flexible about working hours (i.e. on hot humid days, you could start work early in the morning, and/or do a stint later in the day, when it's not so hot). Extreme winds can be dangerous to workers, as can extreme temperatures.

Using common sense

In an ideal world, there would be no accidents because everyone would use common sense at every step of the way on a jobsite. Reality tells us that, in fact, many accidents are preventable. One of the jobs of a site safety representative is to ensure that every reasonable precaution to prevent foreseeable dangers has been taken. It might seem obvious that using a power tool that creates sparks next to loose straw is a potential fire hazard, or that using a straw bale as a footing for scaffolding isn't safe, or that scaffolding that isn't securely tied to the building or properly leveled can tip, but we have seen all of these situations on jobsites. If we could rely fully on common sense, there wouldn't have to be construction safety requirements. Although some rules about safety on jobsites seem like overkill, they *must* be adhered to.

Personal Sustainability

Work habits can mean the difference between *damaging* your body and *strengthening* your body. If you want to continue working as a natural plasterer for a long time, pay attention to what your body is telling you and work hard to develop good work habits.

Lift with your legs, not with your back. It's an overused saying because it's true, and despite everyone knowing this phrase, few people consistently do it. Back injuries are common in construction, and they are often preventable — by lifting with your legs, and not your back.

Applying plaster by hand is a heavy job! If you are using a machine, it is fatiguing both physically and mentally if you factor in the sound of the equipment. Anyone who has been on a plastering site knows that sigh of relief at the end of the day when the mixer/plaster pump is shut down. Make sure to wear hearing protection around machinery; your hearing can't be regained once it's been damaged.

Repetitive stress injuries are common in construction. Plastering is no exception — a full day of plastering represents a high number of repeated actions: it could be thousands of strokes with the trowel, or lifting and moving large quantities of sand, binder, and water. Switching up jobs (when possible) can be helpful; if you are usually the mixer, perhaps part-way through the day, or the job, you might want to go and apply plaster, and have someone from the wall take over the mixer. Switching jobs gives everyone's muscles a chance to recover.

Finding more ergonomic ways to do certain tasks can help reduce strain on your body. Many tools are more suitable for larger hands, so if you have a smaller frame, try to find tools that are more comfortable for your body; they will fatigue you less. Stretching before and during the plastering day can be beneficial. Pace yourself, and, as a team, decide on realistic goals for the day. Olympic plastering days aren't really something to brag about — they're exhausting, and safety is jeopardized when people are overly tired.

Use warm water for cleaning if possible; it will be easier on your joints in the long run. Plan for adequate days off after big plastering jobs to allow yourself to recover. Long, hot soaks in the tub, massage, tai chi, yoga — all can be helpful.

Wear gloves and eye protection, even with earth plasters, but especially with lime-based plasters.

Safety Equipment and Training

There should be a fully stocked first aid kit on site in a central location; it should be well labeled and up to date. There should also be an on-site eye wash kit. A qualified first-aider should be present when plastering, and all personnel should be trained to use the eye-wash kit.

Fig. 1.4: *Although these plasterers may not be setting a fashion trend, they are well protected from lime burn.* Credit: Leslie McGrath

Certain plasters are caustic, such as lime. Protective clothing, including long pants and shirts, should be worn, as should gloves. If using cement or lime, the gloves should be waterproof to protect against lime burn. In the plastering world, we often gush over new purchases of gloves, comparing their strengths, weaknesses — it's rarely about fashion; it's about function and durability.

If a caustic plaster gets on your skin, wash it *immediately* and rinse with vinegar. We have found that vinegar is a useful item in our kit, as it helps to neutralize the lime; it can be diluted with water to cut the sting. (Incidentally, vinegar can be a useful agent to clean cement or lime plaster off of wood [and in the rinse cycle of laundry to get lime off of clothing].) Minor burns are common despite protective clothing, so it is helpful to have something in your first aid kit to soothe a minor sore or burn (vitamin E gel capsules work well, as does aloe vera). Any cuts should be well protected from plaster.

Have emergency phone numbers, such as 911 (if applicable), hospitals, and fire department posted on site, as well as a map to the hospital. These will save time in the event of a true emergency. Have an emergency plan in place, so that all crew members will know what to do.

Make sure to keep a fully charged fire extinguisher on site and in a visible place.

The Law

Depending on where you live, there will be different national and regional construction safety laws and guidelines. Make sure you are familiar with all that apply to you and your project. Fines and repercussions can be significant. Construction site safety and the law is everyone's responsibility.

Chapter 2

Natural Plaster Ingredients

How Natural Plasters Work

Plasters are made up of four main components: binder, sand, fiber, and water. Many other ingredients can be added, and sometimes the fiber or the aggregate is left out. But these are the main ingredients that define a plaster; the most important is the binder.

Over thousands of years of natural plastering, four major binders have traditionally been used: clay, gypsum, lime, and cement. All are variable in their properties, so each has its own section in this chapter.

Ratios

The golden ratio of binder to sand is usually given as 1:3. This ratio usually works, but it is an oversimplification. In reality, the ratio depends on several factors, especially the type of sand you are using, the depth at which you will apply the plaster, and the end result you are seeking. Anywhere between 1:2 and 1:3 binder:sand is common.

The ratio of binder to sand is determined by the volume of the binder that is needed to fill the voids in the sand. With a well-graded sand (most commercial masonry sands) this ratio will probably be close to 1:3. However, the ratio will vary significantly depending on the sand, sometimes being as low as 1:2 — or even less. There's a simple way to test this. Take a sample of sand that has been dried in the oven, or has had prolonged drying in hot sun. Place a measured amount of it in a bucket and fill it with a measured amount of water until the water level exactly reaches the top of the sand. The amount of water you poured in is the volume needed to fill the voids in the sand, and the ratio of water to sand is also the ideal ratio of binder to sand.

Is this always the ratio you will use? By no means. You would not usually add less binder than this, because it could result in a significant weakening of your plaster. But you might add more binder than the ideal amount to fill voids. The result will probably be a harder, more durable plaster, but one that will be more prone to shrinkage cracking. More binder is often used in fine finish plasters because it results in a smoother and more polished plaster, and because these plasters are applied in thin coats and are less prone to developing shrinkage cracks. High binder is also used in some earth plaster base coats that have a lot of straw or other coarse fiber to control shrinkage cracking, because the extra strength is desirable. In this case, the fiber is acting as a partial substitute for aggregate.

Fig. 2.1: *All the ingredients for one mix of lime-stabilized earth plaster.* Credit: Deirdre McGahern

Volume vs. weight

On the majority of jobsites, plaster measurements are made by volume. This is done for several pragmatic reasons: because of the relationship between voids and binder volume just discussed, because it's easier and faster, and because the weight of materials varies a lot depending on how wet they are. However, density also varies with water content, so volume isn't a perfect measure. Some plasterers work exclusively by weight, particularly artisans who specialize in fine finish plasters and mostly use dry ingredients. Weight can also be useful when small quantities of an ingredient are added and consistency is desired, such as with pigments. Recipes in this book use volume measurements; they will need to be adapted if you work by weight.

Table 2.1: Clay at a Glance

Uses	Interior plasters. Exterior plasters only in special circumstances.
Permeability	High (18 US perms)
Embodied energy	Low
Compatible binders	Lime, gypsum, cement.
Safety	Clay dust is very hazardous to breathe due to the presence of very fine silica. Always use proper protection during mixing and cleanup.
Key properties	High shrinkage. Can be reworked after drying. Very flexible (low structural cracking). Relatively easily damaged and repaired.

Fig. 2.2: *The adobe settlement in Taos Pueblo is estimated to be about 1,000 years old. The multi-story buildings are remudded as required and well maintained.* CREDIT: TINA THERRIEN

Introducing the Binders

Clay

Clay is usually considered to be the most ecological of all binders because it can simply be dug from the ground and used. Even when it is mined and sold industrially, the energy cost of processing it is typically lower than for other binders. Unlike other plasters that undergo an irreversible chemical set after being applied to the wall, clay (earth) plasters can be repeatedly wetted back to a workable state, and then dried again.

Earth plasters have a suite of distinctive properties, including high vapor permeability and flexibility, which make them ideal for use in natural building systems. However they are not weather resistant, so they are not generally suitable for exterior use as a finish plaster.

It's important to realize that one can't simply substitute one type of clay for another in a recipe and necessarily expect the same result — or even that the plaster will work properly.

History

Until very recently, earth was the most common building material in the world, and it is still widely used in Africa, parts of Central and South America, the Middle East, India, China, and Southeast Asia. In Europe, earth was used in most countries including France, Spain (adobe blocks), and Britain (cob). In the southwestern U.S., adobe was (and to some extent still is) a common building material, and sod homes were often built in the prairies — some are still lived in today. Many of these buildings were plastered with earth plasters, sometimes with lime, and these traditions inform many of our modern earth plastering practices. (In her book *Clay Culture,* Carole Crews delves into the long history of earth building in New Mexico. It's well worth reading.)

Origins and chemistry

> One might think of clay, then, as being almost a representative sample of the crust of the earth after it has been disintegrated and pulverized to very fine particle size by the action of erosion.
>
> — Daniel Rhodes,
> *Clay and Glazes for the Potter,* 1957

Clay is the product of many thousands of years of erosion of rocks (particularly feldspar), and the deposition of very fine particles, often on ancient lakebeds. Chemically, clay is primarily composed of the mineral *kaolinite* ($Al_2O_3 \cdot 2SiO_2 \cdot 2H_2O$), but with widely varying quantities of aluminates and silicates, as well as oxides of iron, calcium, magnesium, and many other compounds/impurities. But this doesn't tell us much about what clay actually is: incredibly fine particles usually flattened into miniature platelets. It is the interaction of these platelets that gives clay its properties.

The platelets are readily lubricated with a layer of water, and they have a small electrical charge that helps them stick together very strongly, yet they still slide over each other — making clay extremely plastic and malleable when wet, but quite hard when dry (because the lubricating layers are missing). The collective surface area of platelets is huge but also variable — a single gram of clay soil can have a total surface area of anywhere between 10 and 800 square meters depending on the type of clay.

As clay becomes saturated, it expands. As it approaches becoming fully saturated, it tends to resist further water penetration.

Dry clay maintains the shape it had while plastic; however, as the water disappears from between the platelets, the clay shrinks a lot. This is why, as a general rule, clays with greater plasticity and workability (and more platelets) tend to have higher shrinkage rates. It's also why, as with most binders, it's important to balance the amount of clay in a plaster with fiber and aggregate — to reduce shrinkage cracks. Clay plaster base coats tend to be very fiber rich compared to plasters made with other binders.

Types of clay

Site soil

Evaluating soil types

Site soils differ in the amount of clay, silt, and sand they contain. Ideally, soils used in earth plasters should contain 20–30% clay — or more. Soils with more than 30% clay can sometimes be substituted directly for pottery clay in recipes (but you should still test the resulting plaster). In fact, a good clay-rich site soil is often considered to make a stronger plaster than would pottery clay in a recipe. It's often possible to make a good plaster with as little as 10–20% clay content in your soil, but test — always test!

Silt can be either benign or harmful in plaster, depending on how much there is. Preferably, it would be less than ¼ of the clay content of your soil. This rule can bend a little, but if the amount of silt in the soil is equal to the amount of clay, it probably won't make a very good plaster. In general, you should aim to use the best soil possible for your plaster, which may mean trucking it in or using bagged clay. There are several ways to test your soil; you should do all of them and compare the results.

The ball test

The ball test is a first quick test, but don't depend on it solely, as it is imprecise and may give false positives. Moisten a handful of your soil and knead it until it feels consistent. You want it to be malleable and moist but not wet — roughly the consistency of playdough. Form it into a ball and drop it from shoulder height. If your soil has low clay content, it will tend to fragment; with higher clay content, the ball will simply flatten somewhat.

The ribbon test

Now take the damp soil and squeeze it between thumb and forefinger to produce a ribbon about ⅛ inch (2–3 mm) thick and less than ½ inch (about 1 cm) wide. Keep pushing the ribbon out to see how long you can extend it before it breaks. A minimum of 1½ inches (4 cm) usually indicates at least 20% clay. Evaluate the feel as you squeeze it: does it feel smooth and plastic or can you feel sand grains in it?

A variation on the ribbon test is the worm test — try to roll the soil into a worm shape and see how long and thin you can make it. The longer you can make it, the higher the clay content.

The jar test

The jar test can be a fairly accurate way to determine your soil type, but it takes time because clay can take days to settle out of suspension. Any jar will work for this test; a 1 liter mason jar is a nice size. Have a timer (with an alarm) and a permanent marker handy.

Fig. 2.3: *A jar test can tell you a lot about what's in your soil, but you often need a timer to be sure where layers begin and end.*
Credit: Michael Henry

- Fill the jar no more than ⅓ full with soil, then top it up to ¾ full with water. Optionally, you can add some detergent or salt to help disperse the clay particles.
- Shake the jar well, until you feel that any soil clumps have broken up. If not using a dispersant, you may need to let it soak, and come back to shake it again. Start the timer when you stop shaking.
- After 40 seconds, all of the sand component of the soil will have settled out — mark this level on the jar.
- After about half an hour, most of the silt will have settled out, mark another line at this level.
- When the water is fairly clear (a day or more) the clay has settled out.

Measure the height of each layer and divide it by the total height of the layers to obtain a percentage by volume of the soil. The measurement of clay will be high because the clay hasn't had time to settle. Clay continues to compact over time — even more so as it dries. To improve the accuracy of the test, the levels can be measured after the sample dries, but in practice we rarely do this.

The importance of tests

Plaster tests patches are essential when using site soil — unless you have used the identical soil (dug from the same spot), on the same substrate, in the past.

Trucking soil in

Maybe you want to use local clay, but there's none on your site. Does clay soil occur near your building site? It may be worth trucking it in. The clay itself will usually cost less than the shipping — for short hauls, the total price tag can be very reasonable, and this might be a better option than using a soil that isn't quite good enough.

Sports field clays

Infield mixes for ball diamonds are formulated very close to the needs of plasterers, though they sometimes have too much silt. A typical infield mix would be about 60–70% sand, with the remainder made up of silt and clay. Commonly, the silt fraction is about equal to or more than the clay fraction, but this is variable. Good infield mixes have a nice diversity of particle sizes in the sand, perfect for plaster.

Infield mixes are fairly universally available (because ball diamonds are ubiquitous) but shipping will vary, and you'll need to find out the ratio of sand:clay:silt, which may be as easy as a phone call. Arrange to get a sample before ordering a truckload. The goal with infield mix is usually to just add fiber and go — if a sand or clay delivery is necessary to modify the mix, it becomes less worthwhile. Once you've found a mix that works, your recipe can remain consistent, and you can have it delivered to any jobsite in the area.

Bagged clay

In some cases, bagged pottery clays are the most logical way to get clay. For veneer plasters over drywall, bagged clay is often a good way to go because it is uniform, free of contaminants, and available in a variety of colors. But bagged clay sometimes makes sense even for base coats if site clay is unavailable.

Bagged clay requires little or no testing once a recipe is established, and it is easy to estimate and mix for crews who are used to working with bagged product. Bagged or bulk clay may be available from a number of local sources; in many urban areas, the supply chain for selling bagged pottery clay in the relatively small quantities we need is well established.

Economics

Dry pottery clay ships in 50 lb bags. Once bulk discounts have been applied, and if the distributor is close to the building site, the price may be comparable to cement and lime products. Since bagged clay can be used directly in the mixer with no processing, the labor savings from using it vs. site clay might justify the cost of buying it, depending on shipping costs. This is less true if high-quality local clay is available, and, of course, bagged clay will have a higher embodied energy and ecological footprint than local clay will (but less than that for lime or, especially, cement).

Terminology

When choosing a pottery clay for your plaster, it helps to understand the vocabulary that potters use to describe clays. A good resource if you need more information about clays is the staff at your local pottery supply store.

Plasticity is one of the most important attributes of clay, and it is closely related to strength and shrinkage. Generally, clays with very fine particle sizes have high plasticity and high strength because the clay has a lot of binding power (which is good), but they also have higher rates of shrinkage (not so good). On the whole, plasticity is a great thing, and clays that lack plasticity (called *short clays*) are less desirable for plaster. *Water of plasticity* is the measurement used by potters for how plastic a clay is — the higher it is, the greater the plasticity. Dry bagged clay will improve in plasticity after being mixed with water; we find that letting the mixed plaster sit for a few hours can have a positive effect on workability.

Shrinkage increases with plasticity; however, some clays with only moderate to good plasticity have relatively high shrinkage — particularly kaolins. In evaluating clays, it's the *dry shrinkage* that matters, which typically ranges from 5% to more than 6%. (Dry shrinkage refers to the amount that a clay will shrink as it dries. If the percentage is too high, there will be far more shrinkage cracks.)

Some clays are considered to have more *tooth* (variation in particle size, which can reduce slumping and add dry strength). This results from the granules of the clay being less finely ground, and/or other impurities that may be present; it is largely a product of how the clay was processed. When a mesh size is given, it indicates a clay that has been processed with a hammer mill and screened; other clays may be *water washed* or *air floated*. The larger particles that are typically found in a screened clay give it more tooth, but may lower plasticity slightly. This size diversity may cause the clay to act more like site soil, and have a better result for a body coat.

Types of pottery clay

Many types of bagged pottery clay can be useful in earth plasters. In fact, a number of them can be used in either body coats or finish coats. The main exception is kaolin clays; most work well in thin finish coats, but not in body coats.

Ball

Ball clays have very fine grain size and, thus, high plasticity and shrinkage. They are the most plastic clays used by potters or natural plasterers. Ball clays are often stratified with coal seams, and their dark gray or brown color comes from organic matter in the clay. Ball clays are commonly used in base coats.

Kaolin

Kaolins, used in porcelain, are the whitest clays available to the plasterer. They are nearly pure kaolinite (clay mineral) with very low impurities. The particle size of kaolin clays tends to be

Table 2.2: Characteristics of Bagged Clay

Name	Clay Type	Plaster Type	Colour	% Silica	% Dry Shrinkage	Water of Plasticity	Notes
Redart	Earthenware	Body or finish	Earthy red	10–20			Limited plasticity. Moderate strength.
Hawthorn Bond	Fire	Body (or thick finish)	Light tan	0–50			Very good plasticity and workability, with a fine but variable particle size. Good "tooth."
Tile 6	Kaolin	Finish	Warm white	0.1–1			An air-floated plastic kaolin with relatively high green strength.
EPK	Kaolin	Finish	Grayish white	0.1–4	5.8	26	Edgar Plastic Kaolin. Plastic, fine-particle.
Kentucky Stone	Ball	Body (or thick finish)	Gray	10–30	5.4	26.6	Coarse-grained ball clay with good strength and plasticity. High silica content.
Kts-2	Ball	Body (or thick finish)	Gray	10–30	5.4	32.6	Intermediate-grained ball clay with very good plasticity and strength.
OM-4	Ball	Body (or thick finish)	Gray	10–30	6.2	32.8	Fine-grained ball clay with excellent plasticity and strength. Commonly available.
Bell Dark	Ball	Body (or thick finish)	Gray	10–30	6.1	33.5	Very plastic. Commonly available.

large — so, while they vary greatly in their properties, they are generally less plastic than many other clays. Compared to the other extreme, ball clays, the most plastic kaolin falls short of the least plastic ball clay.

Because of their purity, kaolin clays are low in free silica and tend to be the safest clays to work with. Kaolin clays are typically used in finish coats.

Fire Clays

The types of clay referred to as *fire clays* are a hodgepodge — the term *fire* simply refers to the ability of a clay to withstand high temperatures without melting. Fire clays vary amongst themselves in most properties, including plasticity, however they are typically not ground as finely as other clays, and so commonly have more *tooth*. When fire clays have high plasticity, they are good for base coats.

Bentonite

Bentonite is not for plaster. It has such fine particle size that it behaves quite differently than other clay. Bentonite is typically 10 times finer than ball clay. Although highly plastic, its very high rates of shrinkage and very low permeability make bentonite unusable in natural plasters. Potters sometimes mix small amounts (2–5%) of bentonite into clay bodies to add plasticity. It's possible that similar additions could benefit natural plasters, but there are many unknowns, including reductions in permeability.

Properties and uses

Clay, or earth, plasters are the most vapor permeable and flexible of all the natural plasters — they readily allow humidity to pass through, and they adapt to movements of the substrate without cracking. These properties are important when plastering over natural wall systems.

However earth plasters trade these virtues for lower impact and erosion resistance — earth plasters can erode relatively quickly under driving rain. Clay also has very high shrinkage as it dries, so earth plasters are either applied very thinly, or they contain large amounts of fiber and/or aggregate.

Clay tends to protect any natural material it is bonded to because clay is more *hydrophilic* (water loving) than wood, straw, etc. So earth plasters actually pull moisture out of adjoining materials, then let the moisture dry to the outside of the plaster in dryer weather. Clay is very permeable, letting moisture move through it readily, but it resists liquid water because, as it becomes wet, it swells and becomes less permeable (thus becoming hydro*phobic*). Earth plaster also tends to moderate relative humidity in the air, adsorbing moisture onto the clay particles when the air is above 50% relative humidity, and releasing it when humidity drops lower.

Clay can be blended with any of the other binders to modify the properties of each (see "Blending Binders" later in this chapter) as long as it is blended in the correct proportions.

Earth Plaster Coats

Earth plaster is usually applied in two or three coats. Unlike lime-based plasters, where the base coat and finish coat often have very similar recipes and properties, earth plasters often vary a great deal between coats. Over straw bales or a similarly soft substrate, a bonding coat of clay slip must be applied before the base coat. Earth base coat plasters (see Chapter 5) are applied much thicker than finish coats and contain a lot of coarse fiber. Earth finish coats (discussed in Chapter 6) sometimes contain fiber, but if they do, the fiber is usually much finer than what is used in base coats. Finish coats may be applied anywhere from 1⁄32 to 1⁄4 inch thick.

Letting Plasters Age

The Japanese have a rich history of creating perfectly detailed and beautiful earth-plastered structures, and they are also preeminent when it comes to *aging* earth plasters. In Japan, plaster is often mixed, complete with straw, and allowed to sit (or "brew") for a period of weeks or years. It is said that this increases strength, workability, and plasticity, and it reduces cracking.

In the North American context, it's hard to imagine planning this far ahead. In fact, when we first started working with clay, we were surprised to discover that some of our finish plasters needed to sit for a few hours or overnight to attain good workability. Now we know that most earth plasters will improve if left to sit for hours or days after mixing. This allows the clay to more fully hydrate and reach maximum plasticity. A beneficial process of fermentation begins and other positive reactions occur between straw and clay. That said, many earth plasters can be used almost immediately after mixing when need dictates.

Additives

Manure

Manure has two functions in earth plaster: it can add fine processed fiber, and it can add strength and water resistance. A variety of manures can be useful in plaster, but the most commonly used are horse and cow.

Horse manure is good for adding fine fiber to the plaster, whereas cow manure contributes more enzymes that add strength and waterproofing. Cow manure has a much stronger smell — but don't panic, the smell goes away.

Manure should be fairly fresh and not composted, which destroys enzymes and fibers. If the manure is lumpy, you may need to push it through a fairly fine screen (⅛" or even ¼" works). You can either sieve it dry/damp, or blend it with some of your mix water to make a soup, and sieve that. Sieving fairly fresh cow manure has the added advantage that it may kill some of the larvae that are in it, which otherwise leave trails and exit holes from your plaster.

We usually blend manure with mix water using a paddle mixer because the resulting mix is faster to sieve. Dryer manure is harder to sieve, but will have less of a smell.

Lime

Adding lime to clay creates *lime-stabilized earth,* which is a plaster with properties that differ from either earth or lime. It is important to use the appropriate amount of lime for this reaction to work. Lime is covered in some detail later in this chapter, and Chapter 7 is devoted entirely to the subject of lime plasters.

Starch Pastes

Starch pastes glue the particles of plaster together, resulting in very hard plasters that resist many kinds of abrasion and have little or no dusting. Starch pastes are especially useful for interior finish plasters that won't be painted. In such cases, starch paste, or something similar (such as casein) is usually used to prevent dusting.

Wheat paste and rice paste have similar properties, but they require cooking, whereas pre-gelatinized starch comes in the form of an instant powder. When starch pastes are used, they usually make up 5–10% of a recipe by volume (excluding water), but the amount can be much higher in the case of *alis* (clay paint) or certain finish plasters. Five percent adds some strength, and the plaster is still very workable. Ten percent or more makes a very strong plaster, but it can be sticky and difficult to apply. There's generally a learning curve to working with plasters that have over 10% wheat paste in the recipe. A rest period of at least a few hours (and up to overnight) between mixing and application will make the recipe more workable. However, plasters with wheat or rice paste should be used within a day or two of mixing, especially in warm weather — otherwise, they will begin to decompose, mold, and smell unpleasant.

Pre-gelatinized starch is wheat starch that has been pre-treated so that it forms wheat paste with the addition of cold water, no cooking needed, and it has several big advantages. It's a purified form of the starch, and therefore has less unwanted food in it that could promote mold growth or lead to bad smells. It can be used immediately without processing; the labor cost to make wheat paste is probably greater than the cost to buy pre-gelatinized starch. A downside seems to be that it may be more prone to leaving unsightly drying marks on the plaster surface, particularly when the plaster dries very unevenly. Pre-gelatinized starch can be difficult to source — it's used as glue in the restoration of old books — online retailers specializing in conservation supplies may stock it, or some wholesale food suppliers.

Casein

Casein, a milk protein, is the main binder in milk paint. It is mostly used in natural paints, but may be used in finish plaster coats. Sometimes plasterers will throw a variety of milk products into all sorts of earth plasters, a sort of cowboy approach to introducing casein.

Borax

Borax is sometimes used as an additive in plasters, the idea being that it reduces the likelihood of mold on the plaster surface, especially when drying conditions are poor, but it is generally used in very small amounts.

Oils

Oils, usually linseed oil, can be soaked into the surface of plasters to create a durable, waterproof surface identical to an oiled earth floor. Several heavy applications of oil may be needed to do this. However, the permeability of the plaster will be reduced dramatically; so, if moisture does get behind the plaster, it could cause delamination. Alternately, we've heard of people adding less than 1% oil by volume of the mix, but we've never tried it. An addition of some amount of oil may increase toughness and flexibility, but there is still the same risk of delamination from the other earth plaster coats an oiled plaster is bonded to.

Fermented Products

Among the leading proponents of fermented products in plasters is the French builder, Tom Rijven. In fact, fermentation is key to his body coat recipes. Rijven adds fermentable products to base coat plasters — typically replacing half the straw with highly fermentable grass clippings — then he adds a fermentation liquid (a starter culture) that comes from a fermentation vat. The fermentation liquid may come from submerged corn silage or some other sugar-rich base. The plaster is aged for a few days in a warm, low-oxygen environment, then applied to the wall. Fermentation continues until the plaster dries on the wall.

Tom has found that when a plaster with grass ferments, bacteria feed on the glucose present in the fiber, elongating the fibers and resulting in more reinforcement. In addition, he finds that fermented plasters are more durable and waterproof.

A more common way to add fermented/fermentable material to the wall is to use manure, particularly cow manure. Whichever approach is used to introduce fermentation, expect bad smells. However, they will go away after the plaster is fully dry.

Using straw as a fiber in earth plasters starts a chemical reaction that adds strength and waterproofing to the plaster. In his book *Earth Render,* James Henderson describes tests by Allen Kong who found that simply boiling straw and using the water strained off of it added significant strength and hardness to mud bricks.

While a minority of plasterers intentionally add fermented products (other than manure) to their plasters, many a wall has benefited from the fermentation that occurs naturally when earth plasters containing straw or other organics are left to age before being applied.

Safety and Handling

Clay contains very fine silica in widely varying amounts, from less than 1% to greater than 50%. The particles are so fine, it is easy for them to become airborne. Inhaled silica causes chronic debilitating disease and death, so wearing a proper respirator during mixing and cleanup is essential (see "Choosing respirators and vacuum filters," in Chapter 1).

Kaolin clays often contain less than 1% silica, making them good for earth plaster finish coats. Ball clays and fire clays are more common in earth plaster base coats, and typically have large amounts of free silica. Site clays are typically processed wet, so they are hazardous only during cleanup.

Lime

Lime is used all over the world for foundations, walls, plasters, mortars, and for decorative cornices and moldings. It can be used in a wide variety of applications, including exterior plasters, and can have many different finishes — from pebble dash to smooth and highly polished. Lime plaster has stood the test of time; it is permeable, yet water resistant, has fungicidal properties, and is relatively inexpensive.

Table 2.3: Lime at a Glance

Uses	Interior and exterior plasters, cornices and moldings.
Permeability	Good (14 US perms)
Embodied energy	Medium
Compatible binders	Clay, cement, gypsum
Key properties	Is self-healing (can be wetted down and will fill in cracks while in the curing stage). Requires well-graded sharp aggregate. Relatively slow to cure. Must be applied in subsequent thin coats. Fungicidal properties.

History

Lime has been used in construction for at least 9,000 years. The earliest known uses of burnt lime is in floors and plasters in the Middle East; it was widely used in Greek and Roman architecture. The use of lime-based plasters is evident all around the world. You can find it in the Pantheon of Rome, Michelangelo's frescos, and in the ruins of Mexico and Peru.

Lime plaster in Britain in the 1200s was used for structural and fireproofing purposes, and decorative elements were adopted later. In 1501, King Henry VII granted a charter to the Worshipful Company of Plaisterer's in London. In the United States, plaster guilds formed in Philadelphia in the 1790s. The long line of the craft of plastering was thus passed on to journey apprentices in the guild.

Apprenticeship programs and guilds are emerging once again today. If you have the opportunity to work alongside someone from a lime plastering tradition, jump at the opportunity to learn from them. This knowledge will be lost if it isn't passed on. You may have to travel far to find an expert, but it will be worth the journey.

Origins and chemistry

Lime is manufactured from limestone, which is sedimentary stone created from the skeletal remains of marine organisms, layered with clay and silt — simply put, it comes from seashells and the skeletons of plankton accumulating, compacting, and eventually hardening into rock that contains high levels of calcium carbonate. There are different kinds of limestone — some contain clay, aluminum, iron, or potassium, others have magnesium, and some are relatively pure calcium carbonate. Limestone with large amounts of magnesium is referred to as dolomitic limestone, which is common in the U.S.

Impurities in limestone can dramatically change the properties of lime used in plastering. These changes can sometimes be quite useful because they create *hydraulic limes* and *natural cement* — but more on that later.

Limestone, or calcium carbonate ($CaCO_3$), is taken from a quarry, crushed, washed, and then heated to 1500°F (900°C). The heat breaks the chemical bond between the calcium oxide and carbon dioxide, resulting in the loss of carbon dioxide (CO_2) and leaving behind calcium oxide (CaO), commonly called *quicklime.*

Quicklime is a highly reactive form of lime. It can be purchased in the form of pellets, lumps, or sometimes powder; care must be taken to wear protective gear when working with it.

When water is added to quicklime, heat is given off, and the resulting product is *hydrated lime* (calcium hydroxide, $Ca[OH]_2$). In North America, manufacturers of lime add precisely measured amounts of water (in the form of steam) to the quicklime under pressure. This transforms the quicklime into *dry hydrated lime* which can be bagged and shipped out for immediate use in plasters and mortars.

If the $Ca(OH)_2$, or hydrated lime, continues on in the lime cycle, and is allowed to soak, or *slake,* in more water, it forms what is called *lime putty,* which must usually mature before it can be used (although North American Type S limes do not require extended slaking to be useable).

When lime in any of these three forms is mixed with sand and water (and often fiber) to form a plaster, it absorbs CO_2 from the atmosphere as it cures and hardens.

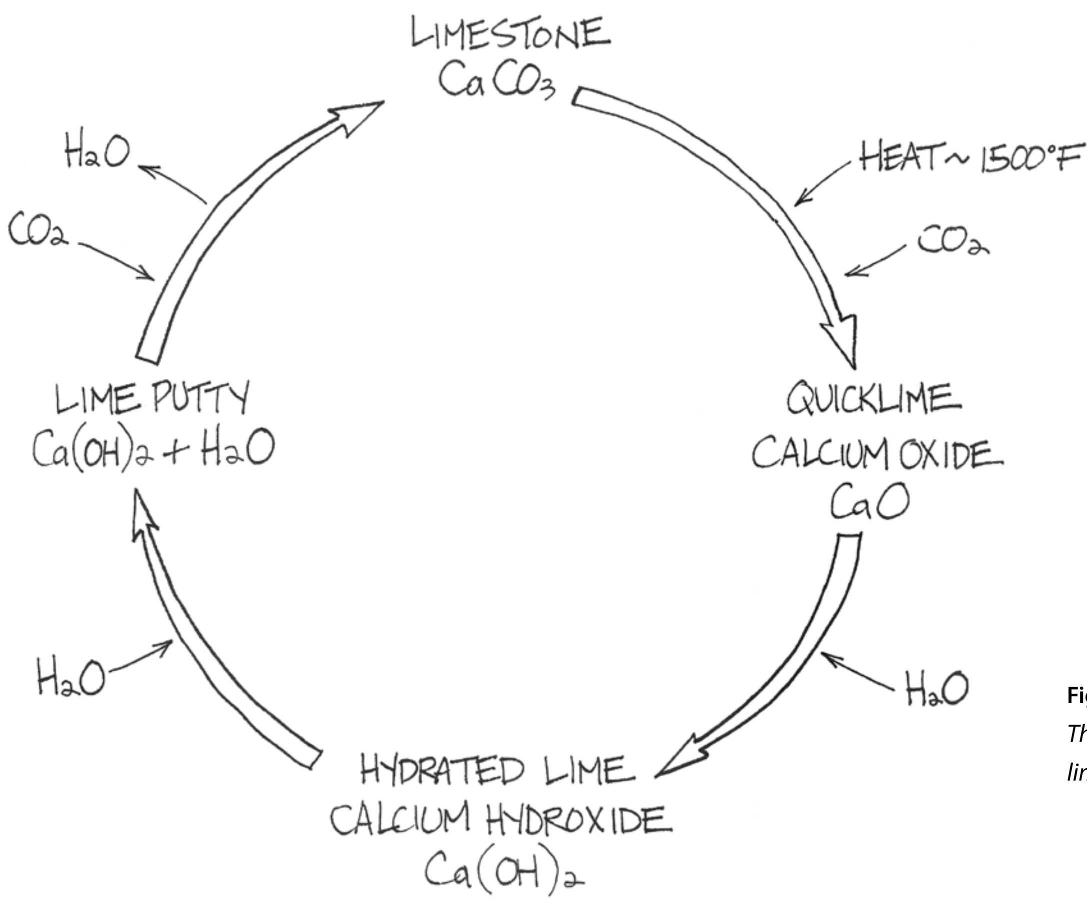

Fig. 2.4: *The lime cycle. The cycle of making hydrated lime from limestone.*

And thus we have come (sort of) full circle, with the resulting calcium carbonate being very similar in chemical composition to the original limestone. Hydraulic lime undergoes the same process, but has a slightly different cycle due to its impurities. Reactive silicates are a by-product of this cycle after water is added to hydraulic quicklime, so technically, it isn't a closed cycle (it's non-repeatable).

Manufacture

To obtain lime, limestone is heated to high temperatures in a kiln. Modern kilns are fueled by gas or coal, but the earliest kilns were merely dug out of hills, lined with heat-resistant rocks, and fueled by wood. Kilns in subsequent years, such as draw kilns or stack kilns, were more sophisticated, with thick stone walls and a tall chimney for draft. The ash from the wood fire would sometimes mix into the lime, which wasn't necessarily undesirable in the plaster, as it created a *pozzolanic effect* on the plaster (see "Pozzolans," later in this chapter). By the end of the 1920s, the age of draw kilns had come to an end because modern gas-fired kilns made the process more efficient. But historic quarries, lime kilns, and slaking pits can still be found around the world close to where limestone deposits are located; they dot the countryside in North America, having been attractive sites for settlers.

While there is pollution emitted during the manufacture of lime, it gains back some environmental points by reabsorbing some CO_2. When 100 lbs of limestone is kilned, it yields 56 lbs of quicklime and 44 lbs of CO_2. Additional CO_2 is released when fossil fuels are burned to heat the kiln. When lime plaster carbonates, it reabsorbs much of the chemically released CO_2, but the CO_2 that was released in the burning of fossil fuels is outside this cycle and remains in the atmosphere. Depending on the impurities in

Fig. 2.5: *Wood-fired draw kilns dotted the countryside a century ago. It was typical to have slaking pits near the kilns, wherein the quicklime was slaked with water and buried for at least a few months. In some places, the lime was slaked for a year or more.*
CREDIT: MICHAEL HENRY

the lime, the amount of CO_2 that is reabsorbed will vary, with the result that hydraulic limes reabsorb less than other types of lime. Portland cement does not reabsorb CO_2 the same way, and in fact when it is blended with lime, it blocks effective carbonation and absorption of CO_2 by the lime.

Types of lime

All types of lime plaster can be tricky to work with — there is a definite learning curve associated with them, and each type has its own set of challenges. It likes weather that is "not too hot, not too cold, but just right." It needs to be protected from sun and wind, and regularly misted after application — for a week or more. Types of lime to consider using include natural hydraulic lime, dry hydrated lime, lime putty, and quicklime. Each has its place, and one important factor to consider is whether you can obtain the material locally or not. In North America, dry hydrated lime is the most readily available. In our region (Ontario), natural hydraulic lime is also available, although it must be imported.

Natural hydraulic lime (NHL)

When limestone that contains impurities such as clay or amorphous silica is burned to create lime, natural hydraulic lime (NHL) may be created. (In the U.S., you may see the term *hydrated hydraulic lime* [HHL]; it is the same material as natural hydraulic limes.) Hydraulic limes behave quite differently than non-hydraulic hydrated limes. The impurities create a different set of chemical reactions that give a hydraulic *set*, meaning it will start to set as soon as water is added, even in the absence of air (hydrated lime, by contrast, can be mixed into a putty that will store indefinitely if it is covered with water). The advantage of the set is that natural hydraulic lime cures in days instead of weeks, and the resulting plaster is a little harder and less porous. Due to the faster set time, NHL may be a better choice than hydrated lime for plastering close to frost season, but it must be protected from frost until fully dried, and it will continue to cure and gain strength for months. Hydraulic lime is less permeable than hydrated lime.

When talking about NHL plasters, there are two standards, the European Norm EN-459, and the American Standard ASTM C-141. Note, though, that any lime that has had a pozzolan or other material added to it, either in the kiln or afterward, is referred to as an *artificial hydraulic lime* (AHL), and it doesn't conform to either standard.

In Europe, there are three main strengths of natural hydraulic lime that are available:

NHL 2	Contains 6–12% reactive clay; feebly hydraulic (softer)
NHL 3	Contains 12–18% reactive clay; moderately hydraulic (medium hard)
NHL 5	Contains 18–25% reactive clay; eminently hydraulic (hard)

When trying to select the proper NHL plaster, keep in mind that the plaster should be of similar strength to the substrate. NHL 5 would be most appropriate over top of a solid masonry wall, for instance, whereas NHL 2 is a good choice on earth bricks or straw bale buildings.

Hydraulic limes are not as sticky or as readily workable as non-hydraulic limes (they feel sandy), but they do tend to crack less, as there is less shrinkage (the sand and lime fuse together more tightly than in non-hydraulic plasters). Natural hydraulic lime can't be used to make lime putty, as it begins to set with the addition of water.

Dry hydrated lime powder

Hydrated lime doesn't set in the presence of water alone, but rather, by the carbonation of calcium hydroxide to calcium carbonate via a slow reaction with atmospheric carbon dioxide while the plaster is moist. This plaster should remain damp for a week for the initial set, and should be rewetted periodically for several weeks after application in order for full carbonation to occur. Plasterers in North America use bagged hydrated lime purchased from masonry supply stores; unlike the type available in Europe, these bags contain high-quality lime, comparable to lime putty.

Hydrated lime is obtained when quicklime has a small amount of water or steam added to it during manufacture. Dry hydrated lime is sold in bags, and must be used when still fresh, because over time it reacts with air (in the presence of humidity), which will be evident if there are chunks in the bag. It's best to check the date it was bagged; aim to get lime that is less than a year old. Hydrated lime (including lime putty) needs to be applied in relatively thin layers; generally to a maximum of ⅜ inch (10 mm), so it may take three or more layers to level a wall.

Within hydrated lime powders, there are two types, according to ASTM standards: Type S (Special) and Type N (Normal). Within the construction industry, Type S is used almost exclusively, especially for plastering. Type N lime is produced with normal hydration (at atmospheric pressure), and generally contains a higher amount of unhydrated oxides. A Type N lime needs to be slaked in water to be acceptable as a plaster, but Type S can be used directly, as it has been adequately slaked in the factory. You may find books and websites that tell you *not* to use bagged hydrated lime for plastering — this reflects the reality in the UK and continental Europe, where high-quality Type S lime is far less available (and lime putty is far more common).

Type S gets its name from ASTM C207 standards; it refers to dolomitic lime (lime with magnesium) that gets a pressurized hydration in an autoclave, resulting in full hydration of both the magnesium oxide and the calcium oxide.

Agricultural lime is finely pulverized chalk (calcium carbonate) or limestone that hasn't been heated and chemically changed to calcium hydroxide. It is useful as a soil additive, but has little to no binding ability, and should not be used for plastering.

Hydrated lime putty

In the lime cycle, after steam is added to quicklime, it becomes dry hydrated lime powder. If that same hydrated lime is soaked (slaked) in water, it will become lime putty — a creamy, luxurious form of lime for plastering. The longer the lime putty has been slaked, the better. A minimum of three months is recommended for Type N limes. Lime putty can keep indefinitely, as long as it has a skim of water over its surface in an airtight container.

Lime putty is more readily available in Europe, where cement hasn't eradicated the use of lime. Some plasterers claim that by slaking even Type S hydrated lime, you get a much more workable, creamy plaster. We don't usually bother.

If you find a recipe for lime putty, but you only have dry hydrated lime, or vice versa, it is helpful to know that lime putty can have 1–1.5 times as much lime by volume as dry hydrate. So, if a recipe calls for lime putty, and you don't have any, you can substitute with Type S hydrated lime powder, but you may need to multiply the volume of lime by up to 1.5. Do some tests with the resulting plaster to make sure it performs properly before using it on an entire building.

When to use hydraulic lime vs. hydrated lime

Hydrated lime and lime putty make soft, flexible plasters that are suited to flexible substrates such as cob, straw bales, clay/straw, etc. This type of

Hot Lime

By Nigel Copsey

Hot lime is experiencing a resurgence in the UK and France. Until at least 1800 in the UK, and until later elsewhere, plastering systems included both earth-lime mortars and lime mortars. Until 1800, the majority of stone buildings were built with earth or earth-lime bedding mortars, pointed to the exterior with lime-rich, hot-mixed mortar and plastered within with an earth-lime basecoat over which was laid a haired, lime-rich finish coat of between 3⁄16 and 3⁄8 inches (5–10 mm). In our observation, similar systems predominate in Spain, Italy, France, and Ireland and were doubtless as common elsewhere. Ukrainian migrants carried the routine use of similar mortars into northern Alberta during the later 19th century.

There are different methods of hot mixing (described in Chapter 7). In our experience, mixing the lime and the aggregate whilst the lime remains hot delivers the best mortar. Quicklime was usually slaked to a dry hydrate when it needed to be transported long distances, or by sea, and this became more common for plastering during the 19th century. It was also not uncommon in Italy for fine stucco finishes, mixed with marble dust.

Contrary to common assumption, the use of quicklime is no more hazardous than the use of other routinely used alkaline binders, such as Portland cement or hydraulic or hydrated lime — if done correctly, with adequate knowledge and reasonable precautions. Properly slaked, the temperature of a hot-mixed mortar will not exceed 248°F (120°C) during slaking and will fall to between 122–140°F (50–60°C) once sufficient water to produce a workable mortar is added. This process takes a matter of minutes.

Quicklime is available in most parts of the world, and can be made on a small scale wherever there is a supply of suitable limestone or sea-shell.

lime is more porous, and thus more permeable, than hydraulic lime, and it works well on flexible substrates that may be apt to slight movement. It is an ideal plaster for interior finishes; when used on exterior walls, it must be paired with a suitable finish, such as a silicate paint. Hydraulic lime could fare better in exterior situations that are exposed to extreme weather, assuming the somewhat reduced flexibility and vapor permeability is acceptable. Using a weaker hydraulic lime, such as NHL 2, can be a good compromise.

There are significant differences in application season between NHL and hydrated lime, which can be important to plasterers. Hydrated lime is a good choice for early fall plaster, when weather is cool but risk of frost is a minimum of several weeks away. Hydraulic lime sets much faster and may be better suited to short windows of good weather in later fall (but it must not freeze while still wet, during the initial cure). If ice crystals get into the pores of a plaster, it will likely fail. Lime plasters that freeze before curing won't fully carbonate, nor will they develop full strength. This can result in crumbling or flaking of the plaster.

Hydraulic lime plaster is also more forgiving than hydrated lime during summer months, though hot windy days are still a no-go.

In North America, hydraulic limes are imported from Europe. Until recently, the price has been a significant barrier, but lately it has been coming down significantly, with availability varying regionally. The least expensive way to obtain the qualities of a hydraulic lime is often to take a hydrated lime plaster and add a pozzolan to it to achieve similar effects (see "Pozzolans," below).

Lime: A Summary

A well-balanced binder, lime is used for its weather resistance, permeability, and flexibility. Its permeability is less than that of clay, but it is still appropriate for natural buildings, and it works well with other binders. Lime plasters, which are blended with 1–3 parts sand, are extremely sticky, and generally they adhere well to most prepared surfaces, including metal or wooden lath, bale walls, or solid walls that have been primed appropriately (See Chapter 3). Relatively strong, yet flexible enough to move with buildings, lime doesn't crack in the same way that cement does. Lime plasters are autogenous (self-healing), meaning that when exposed to CO_2 and water, the uncarbonated, or *free lime,* can help fill in any cracks that form. Vapor permeable paints or other sealants can be important, especially on fairly exposed sites.

Pozzolans

Pozzolans are materials that enable plaster to set more rapidly. The word *pozzolan* is derived from a type of volcanic rock found in Pozzuoli (Naples). Pozzolans have been used in plasters for thousands of years. When pozzolanic materials are added to non-hydraulic limes, they react with the calcium hydroxide in the lime, resulting in a more cementitious plaster, similar to plasters used in the time of the Romans. Pozzolans serve two purposes: not only do they speed the setting time of the plaster, they also increase durability. In the 18^{th} and 19^{th} centuries, experimentation with pozzolans created hydraulic cements out of hydrated limes, and eventually led to the discovery of Portland cement. All lime plasters, whether hydrated or hydraulic, are altered by the addition of pozzolans — but they are most commonly added to hydrated non-hydraulic limes. Most pozzolanic materials are comprised of silica and alumina, along with clays and iron oxides.

There are natural and artificial pozzolans. Natural pozzolans are pozzolans that haven't had any artificial heat added to them, such as volcanic rock or ash. Diatomaceous earths and high-silica rocks are also natural pozzolans. Artificial pozzolans have had some external source of artificial heat added to them; these include lightly fired clay products (like tiles or bricks), blast-furnace slag, clays, tile and pot shards, burnt clays, forge scale, and wood ash.

Pozzolans suitable for use in plasters include the following:

- Volcanic ash.
- Lightly burnt clays (kaolinite).
- Welding slag.
- Metakaolin (manufactured from kaolin clay).

Table 2.4: Lime Properties and Uses

Hydrated lime	$Ca(OH)_2$	Interior or exterior, if well protected.	Slow set time; cures with exposure to air; bags of hydrated lime should be fresh; should be applied between 5°C–30°C and protected from freezing for several weeks.
Hydrated lime putty	$Ca(OH)_2$	Interior or exterior, if well protected.	Slow set time; cures with exposure with air; lime putty can last indefinitely as long as it is kept covered with water; should be applied between 5°C–30°C and protected from freezing for several weeks.
Natural hydraulic lime (NHL)	$Ca(OH)_2$	Interior or exterior use.	Fast set time; cures with exposure to water; more tolerant to cold weather application, but can't freeze until initial curing/drying is complete.
Quicklime (hot lime)	CaO	Interior or exterior use.	Extremely hot while mixing; can be used hot or cool; historic plaster.

- Ground brick dust (only if bricks have been fired at a low temperature — most modern bricks are fired at temperatures that are too high to create pozzolanic effects).
- Fly ash (a by-product of most coal-fired power plants in North America).
- Forge scales and ashes.
- Agricultural waste products including wood ash, rice husk ash, bagasse (sugar cane husks), and rice straw.

If brick dust is used as a pozzolan, it should either be mixed with water or wetted down prior to mixing into the plaster. In fact, most pozzolans will behave better if they are mixed with a minimal amount of water before being added to the plaster. Pozzolans should only be mixed into the plaster right before it is to be used, as the pozzolanic effects will start taking place immediately. A mix that is older than 24 hours should probably not be used.

The amount of pozzolan required for a plaster will vary depending on how reactive that particular pozzolan is. Higher pozzolan ratios will speed up the cure, but may affect the overall strength of the plaster. Holmes and Wingate (*Building with Lime,* 2003) state that an appropriate pozzolan ratio in a lime plaster is 1 lime:2 pozzolan:9 sand. Some historic mixes included ratios of 1–2 lime:1 pozzolan:1 sand. The exact ratio depends on the particular pozzolan in question. As always, make sure to do test mixes to find the right ratio for your mix. The Endeavour Centre shares a recipe for a lime-metakaolin base-coat mix in Chapter 7; metakaolin is a pozzolan.

Additives

Fibers in plaster allow for slight movement of the plaster as a building moves — without allowing cracks to develop. Fibers also reduce plaster shrinkage, which also helps ward off cracks in the plaster. Traditional lime plasters on lath would have contained hair (ox hair was preferred, but hair from horse, goat, or donkey have been used). Any hair to be used in plaster needs to be grease-free, strong, and in the range of 1–3 inches long. Human hair is not suitable because it is too fine and not particularly strong, although it has certainly been used. Other fibers include chopped straw, reed, manila, jute, and sawdust. Modern plasters may include synthetic fibers, such as polypropylene.

Other additives

Various materials have been added to lime plasters over the centuries, including ox blood, nopal cactus gel, egg, linseed oil, urine, seaweed, hemp, gypsum, molasses, casein powder, and manure. Some additives can assist with water repellency, reduce shrinkage cracks, and increase bond and strength, while others can act as *air entrainers* (air entrainers add tiny bubbles into plaster, using a surfactant, to give more protection against freezing). Each additive has its own purpose in a plaster, and tests should be done to determine their effectiveness in your plaster. Finding someone who has used a particular ingredient in their lime plaster can be helpful in determining quantities to use in the mix, and the expected results.

Substrate

Lime plaster can be applied over a variety of substrates, including, but not limited to, the following: drywall, wood lath, straw bales, and masonry walls. If lime is desired as a finish coat on a cob or other earth wall, there should be a lime-enriched clay base coat first to allow the two to bond.

Safety and Handling

Lime is caustic in nature, and can cause nasty burns on the skin. Proper protective gear is essential when plastering with lime; make sure you wear long sleeves, pants, rubber gloves, and safety glasses. If you are mixing lime, as with any plaster, a proper respirator should be used.

Natural and Artificial Cements

Finally, there's *cement* — which is a dirty word in natural building circles. The manufacture of cement contributes enormous amounts of greenhouse gases, which seems like an odd choice in a natural building. In some parts of North America, during the revival of straw bale building, cement became a go-to plaster for many bale builds. In part it was due to accessibility, and in part, due to lack of experience or awareness of other binders.

There are natural and artificial cements. Natural cement occurs as a result of very specific (aluminate) impurities in limestone. This argillaceous (clayey) limestone, when calcined, produces a hydraulic cement. Some pozzolans, such as metakaolin, also create weak cementitious reactions. On the other hand, Portland cement is an artificially created cement. Natural cement can be used almost interchangeably with Portland, except that it has a very quick set time (which can be partially managed using retardants). Portland cement has a higher embodied energy, and it contains more toxins than natural cement, but it is nevertheless more widely used in plastering natural buildings than natural cement because of its low cost, availability, and controlled set time. When we talk about cement, we therefore are usually referring to Portland, even though it is manufactured in a way that excludes it from being a "natural" plaster.

Cement plasters are very strong, but they are prone to cracking and have low permeability. Pure Portland cement has such low permeability that it virtually guarantees rot (when bonded to natural materials) — but when mixed at least 1:1 with lime to make a cement-lime binder, it does have some limited applications in natural building — if treated with caution. We include it in this book because we recognize that it is, and will continue to be, used in natural building. When it *is* used, we'd prefer it be used correctly.

Table 2.5: Natural and Artificial Cements at a Glance

Uses	Interior and exterior plasters
Permeability	Low (2–10 US perms)
Embodied energy	High
Compatible binders	Lime
Key properties	A very hard, strong and brittle plaster. Requires sharp well-graded aggregate. Relatively fast to cure. Low permeability limits acceptable uses. Prone to cracking. Controlled set times. Rapid strength gain.

History

In the 17th and 18th centuries, pozzolans made their way from Italy to England, where plasterers incorporated them into hydraulic limes used for bridge construction. When John Smeaton was engaged to build a new lighthouse on Eddystone Rocks in England in 1756, he experimented with various limes and pozzolans, finally discovering that limestone deposits containing significant amounts of clay, when calcined (burned), were hydraulic. It was Blue Lias lime, containing clayey marl, along with a pozzolan from Italy, that was used for the famous lighthouse. It is said that Smeaton opened the door to natural hydraulic limes and natural cements.

Experiments in France, England, and the U.S. led to the discovery of natural cements, which can be made by burning clay-rich limestone; the result is a fast-setting cement. One such cement was patented by James Parker in 1796. He called his product *Roman cement* (although it differed from the plaster that Romans would have used), and it was used extensively in the U.S. for bridges, forts, dams, and the Erie Canal due to its strength and water resistance. Natural cements, although similar in content to hydraulic limes, are very fast setting — sometimes there are only minutes to work with the product. The quick set is due to a high active clay content. The silicas and aluminates contained in the clay portion of natural cements are the components that cause the almost immediate set.

Natural cement production in the U.S. became well known around the world; this is partly because of the extensive limestone deposits in Louisville, Kentucky, and in Rosenberg, Texas. There were even a couple of natural cement factories in Canada at the turn of the century. Natural cement was used in North America from the late 1800s until the early 1900s. Natural cement can be seen as a bridge between lime plasters and modern cement.

Joseph Aspdin was an American brick layer and inventor. In 1824, he patented what he would call Portland cement, which was a combination of pure limestone, clay, and other minerals, such as silicates. Portland cement was named thus because it resembled the color of the limestone quarried on the Isle of Portland in the English Channel. These minerals resemble the chemical composition of marl (which is unconsolidated clay and lime rock, or soil), but are controlled in a laboratory setting. Portland cement proved to be more reliable than natural cement in that the mix was consistent every time. It allowed a longer working time, and it was strong. The manufacture of Portland cement didn't start in the U.S. until 1871 and in Canada in 1889.

On its own, Portland cement wasn't particularly workable, but with the addition of lime, it provided a strong plaster with good workability. The mix quickly replaced natural cements, and it became the most popular artificial cement. The Hoover Dam and the Grand Coulee Dam, built in 1936 and 1942 respectively, were feats of engineering that were made possible by Portland cement. Close to 12 million cubic yards of concrete went into the construction of the Grand Coulee Dam.

Origins and chemistry

Cement is made from limestone, plus clays and other minerals such as silica and alumina, all in particular ratios. They must be baked at much higher temperatures (2732°F, or 1500°C) than lime is; and they have to be baked for an extended period of time. Because of the large energy inputs needed for this amount of sustained high heat, a tremendous amount of CO_2 is expelled during the fabrication of Portland cement, contributing greatly to greenhouse gases. In the kiln, though, when CO_2 is given off, calcium oxide forms. The alumino silicates from the clay react chemically with the calcium oxide. Cement clinkers form in the high heat, which are then cooled and pulverized. As they are cooling, a limited amount of gypsum powder is added, forming what we know as Portland cement. While Portland cement is the most readily available cement in North America, natural cements are still

The Cement-Lime Controversy

Cement quickly replaced lime in many plaster applications in the early 1900s in North America. Cement became the new go-to plaster, and it was used to "protect" adobe buildings, brick homes, and plastered buildings. Formerly permeable wall systems became impermeable. Within decades though — and too late for some buildings — it became clear that the low permeability of Portland-based plasters was trapping moisture within walls, causing failures of the plaster or the substrates — or both. In some cases, buildings that had stood for centuries were irrevocably lost after "renovations" using Portland-based plaster.

Cement-lime plasters can be — and have been — used on straw bale buildings (including by the authors); however, we believe that they are never the best choice, and we advise against using them. Hopefully, there will continue to be a return to traditional earth and lime plasters when appropriate.

being produced, and they are more appropriate than Portland cement in restoration of construction originally done with natural cement.

Types of cement

There are different types of bagged Portland cement products. Some types are 100% Portland, while others have some lime content. When we have had to use cement for any of our plastering, especially on a bale building, we would typically seek out Type N Portland-lime, a blend of 50% Portland and 50% lime, which is to be mixed 1:3 with sand. In some of our later plastering, we used site-mixed Type O Portland-lime (1 part Portland:2 parts lime:9 parts sand). All Portland-lime blends are defined by volume, not by weight.

Safety and handling

As with the other binders, make sure to have an MSDS (material safety data sheet) on hand for cement. Portland cement contains crystalline silica, which can cause silicosis and other respiratory and autoimmune disease with prolonged exposure. Ensure that the people who are mixing wear proper respirators, safety goggles, sleeves, and gloves; the crew cleaning up dry plaster afterward also needs the same protective gear.

Gypsum

Gypsum is one of the oldest plasters, and, because it can be cooked as low as 350°F (177°C) to create a binder, it is among the most ecological. Most gypsum plasters can't be used in exterior applications or anywhere they will be exposed to moisture.

Table 2.6: Gypsum at a Glance

Uses	Interior plasters, moldings
Permeability	High (18 US perms)
Embodied energy	Low-medium
Compatible binders	Clay, lime
Key properties	Expands while curing (no shrinkage cracking). Does not require aggregate. Sets quickly. Good depth tolerance. Fire retardant. No weather resistance.

History

The best preserved examples of gypsum plasterwork in the pre-Classical period are found in the monumental architecture of ancient Egypt, dating from the 3rd millennium BC; examples include the pyramids of Giza, which contain gypsum mortars, and countless surviving works of frescos and ornament, such as the renowned gypsum bust of Nefertiti. In fact, the gypsum plasters produced in Egypt were in many cases of superior quality to what is commercially available today.

Origins and chemistry

Gypsum is a naturally occurring stone that forms when limestone is exposed to sulfuric acid from volcanic activity. It is easily dissolved, and gypsum deposits meters thick commonly formed through cycles of evaporation in lagoons or dead seas.

Gypsum is a metallic salt of calcium. The most common form of naturally occurring gypsum is calcium sulphate dihydrate, or $CaSO_4 \cdot 2H_2O$. This hydrous gypsum binds water to calcium sulphate molecules in a dry, crystalline state. As we'll see, this imbues gypsum plasters with some unique properties.

Types of gypsum

Unlike clay, gypsum must be baked in preparation for its use as a plaster. Fortunately, this occurs at a relatively low temperature, so it is not an energy-intensive process. Gypsum can be efficiently baked at temperatures as low as 350°F (177°C). At this temperature, gypsum quickly loses 75% of its water content, off-gassing steam. The resulting material has the chemical formula calcium sulphate hemi-hydrate or $CaSO_4 \cdot \frac{1}{2}H_2O$

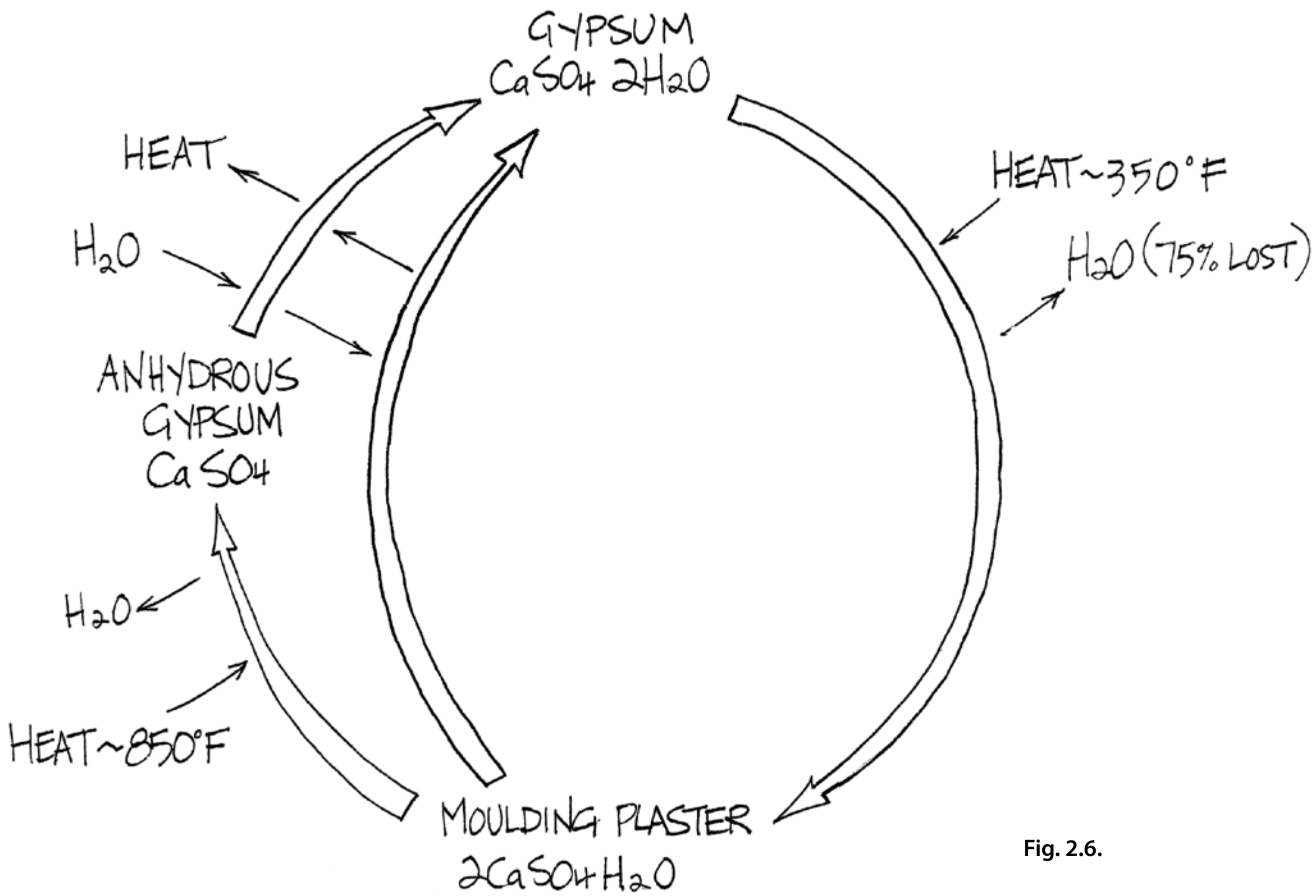

Fig. 2.6.

($2CaSO_4 \bullet H_2O$). This is commonly known as plaster of Paris, or moulding plaster. *Gauging plaster* is chemically identical to moulding plaster, but it has a coarser grind; it is used with lime plasters to speed up the set.

Anhydrous gypsum can be manufactured by continuing to bake the hydrous form to a temperature of 800–850°F (425°–450°C), producing calcium sulphate or $CaSO_4$. This anhydrous or *dead burnt* gypsum, sometimes with a small addition of alum, is characterized by a slow set and dense crystallization that is useful for floor, exterior, and other specialty applications. Anhydrous gypsum deposits can also occur naturally.

There are several characteristics that are unique to all gypsum plasters. Notable among them is that gypsum is *self-binding.* Aggregates may be added as an inexpensive filler or for decorative effect; however, unlike with clay or lime,

Understanding Drywall and Drywall Compounds

Off-the-shelf drywall mud may contain toxic compounds. It is premixed joint compound that hardens by drying (rather than setting); it isn't really gypsum-based, and should usually be avoided. Drywall itself is less ecological than most gypsum plasters because the gypsum used to manufacture drywall is usually a by-product of pollution control on coal-fired power plants. A great deal of energy is used to process this manufactured gypsum, and there may be heavy metals or other contaminants in it.

Table 2.7: Gypsum Properties and Uses

Molding plaster	$CaSO_4 \cdot ½H_2O$ (fine grind)	Interior use only.	Very fast set time, primarily used in moldings. Commonly sold as plaster of Paris.
Gauging plaster	$CaSO_4 \cdot ½H_2O$ (coarse grind)	Interior use only.	Intermediate set time used pure or blended with other binders in plaster.
Dead-burnt gypsum	$CaSO_4$	Interior use, sometimes exterior.	Slow set time blended with other binders in plaster.

they are not necessary for the plaster to hold together. A closely related quality is that gypsum plasters have no shrinkage. As it incorporates most of the added water into its crystalline matrix, it actually expands slightly as it sets; as a result, gypsum plasters have no shrinkage cracking. Plaster of Paris and gypsum cements are fast-setting materials that permit work to be conducted expeditiously. Gypsum plasters have excellent adhesion to most any solid, fibrous, or lath substrate and provide a permeable, breathable coating. Gypsum may be blended into interior lime or clay plasters to reduce shrinkage and provide a rapid initial set.

Although all natural plasters are incombustible, one of gypsum plaster's unique and most cherished qualities is its inherent capacity to actively retard fire. This is due to its hydrous chemistry. Should a fire occur in one room, gypsum will continue to off-gas steam, thus suppressing the temperature on the other side of the wall well below the temperature needed for spontaneous combustion. This arrests the ability of the fire to spread.

Historically, gypsum plasters have been used primarily for interiors. Plaster of Paris produces a plaster that is far too porous and soluble for exteriors. However, there is a long history of exterior stuccoes in Europe based on anhydrous gypsum. As with earthen *renders* (exterior coats of plaster), reasonable precautions need to be taken with overhangs and other flashing details to ensure protection from streaming water, and capillary breaks must be established to prevent water from wicking. Nevertheless, the self-binding nature of the material itself allows a great range of technical and aesthetic freedom. Gypsum stuccoes are very manageable to work as a wall plaster and can be applied up to 1" (25 mm) or more in a single coat. They have a rapid set that permits working in almost any season, so long as there is a brief window of good weather. Furthermore, molding profiles can be run *in situ,* elements and ornamentation can be cast and affixed, and many aggregates can be added just for decorative effect.

Safety and handling

Gypsum is relatively safe to handle. A respirator should be used when mixing, because bagged material may contain small amounts of silica.

Blending Binders

Almost all of the binders are compatible, and they can be blended to take advantage of their combined properties in plasters; however, the ratios can sometimes be very important. One exception is that cement and gypsum are generally incompatible.

Gypsum and lime are blended to make *gauged lime plasters,* which are commonly used as a finish over gypsum plasters, or drywall. Gypsum and clay can also be blended to change the working properties and finish time of earth plasters.

Clay and lime are often blended to make *lime-stabilized* earth plasters, but it's very important to add the right amount of lime — in particular, not too little lime. When a small amount of lime is added to a clay, it causes the clay particles to clump together (called *flocculation*). This causes the clay to act more like silt than clay, and it destroys much of the binding property of the clay. As more lime is added and the pH increases above 11, chemical reactions occur between the lime and the clay, basically creating a hydraulic lime.

Clay, lime, and gypsum can also all be blended in a single plaster — e.g. gypsum can be used as an accelerant in a lime-stabilized earth plaster, but only for interior use because gypsum plasters are highly absorbent and will break down when exposed to moisture.

Sand

Sand provides structure and is very important in many plasters, so the quality of your sand can make the difference between success and failure. Good plaster sand should be sharp, clean, and have a diversity of particle sizes.

Properties and Uses

Because plastering sand should be sharp and angular, some natural sands make poor plaster sand. Beach sand in particular should usually be avoided, because waves have been rounding the sand grains for many years (picture building a structure out of round balls).

Particle size diversity is important to create good structure and to reduce the amount of binder needed. Imagine a bucket filled with softballs — how many golf balls could you add to the bucket without changing the total volume very much? Then how many marbles could you add to that? Ideally, a mix has nearly every grain size so that few large voids are left — this creates a structure that resists movement and requires less binder (because there are few voids to fill). Less binder equates to less shrinkage cracking.

Sand should not contain silt (the particle size between sand and clay), which fills the voids in place of the binder, resulting in weak plasters. Clay can sometimes also cause problems in lime-based plasters. Salt can lead to plaster failure, as well as causing rusting of metal lath or any other metal used in plaster preparation. So, when we talk about sand being clean, we mean free of fine particles and unwanted salt, chemicals, or organic matter.

As a conservative rule, the largest particles in your sand should be no more than half the thickness of your plaster, and preferably no less than one quarter. So, if your plaster coat is ½ inch, your largest aggregate would ideally be somewhere between ⅛ and ¼ inch.

Types of Sand

There are several types of sand that are widely available, so when you call a sand yard or any construction materials supplier, you need only tell them what you want, and it will promptly appear at your jobsite … maybe. Unfortunately, the definition of sand types allows huge variability (even assuming it is followed correctly), and what you receive on the jobsite will depend on what that supplier carries or what is locally available. Nevertheless, as a rough guideline, the main sand types are *masonry sand, concrete sand, stucco sand* (regionally available), *bagged silica sand,* and *calcite* (white limestone sand).

Masonry sand

Masonry sand has a maximum particle size of 3⁄16 inch (4.75 mm), which should mean that it's a nearly ideal sand for many base coats. Unfortunately, using the ASTM standards for particle size distribution, anywhere from 70–100% of the sand can be less than 3⁄64 inch (1.18 mm). This explains why, when we order masonry sand on a jobsite, sometimes it's a nice mix of coarse and fine sand, perfect for a base coat, and

Fig. 2.7: *Some different sands. Top row (left to right): masonry sand, silica sand, 30–50 mesh calcite; bottom row: quarried calcite, 40–200 mesh calcite, 12–350 mesh calcite.* CREDIT: MICHAEL HENRY

other times it's almost 100% fine sand. Worst of all, masonry sand can be 99% rather fine but have just a few pebbles, making it useless for fine finish coats — unless you take the time to sieve it. With masonry sand, you should look before you buy; however, it is still often the best choice available for a given plaster. Brick sand is commonly used as a synonym for masonry sand; it is often a relatively fine version of masonry sand.

Concrete sand

Concrete sand (technically, "fine aggregate") has a maximum particle size of ⅜ inch (9.5 mm), and 5% should fall between 3⁄16 and ⅜ inch (4.75–9.5 mm). It also must have a variety of mid-size particles, and up to 10% can be finer than 100 mesh. Even though the ⅜-inch maximum is more than we'd like for many plasters, concrete sand may be a good choice for a plaster coat that will be applied over ½-inch thick.

Large aggregate doesn't necessarily interfere with a finish, as it tends to push to the back. However it makes finishing extremely difficult and frustrating if the largest aggregate is the same size as the depth of the finish coat.

Silica sand

Most sand is primarily made of silica; however, fine off-white silica sand (available in 50–100 lb bags) can be useful for some finish plasters. Silica sand is commonly used in earth plasters that are applied in a very thin coats and pigmented (vs. painted). Silica sand is available in various mesh sizes; for finish plasters, you want mesh sizes between about 60 and 100. One hundred mesh or finer would make an exceptionally fine and smooth finish plaster that would be prone to cracking if not applied in very thin coats. Silica sand can be used for sandblasting, so it can sometimes be found in rental centers, as well as being fairly commonly available in masonry supply stores. Finer mesh sizes are often available at pottery supply stores. Silica sand is often quite uniform in particle size; larger mesh sizes are often not that good for plaster, so it's sometimes worth blending different silica sands.

Limestone sands

Limestone-based sands are traditional in many lime finish plasters, especially ones that are highly polished. They are also used in some unpainted earth plasters, where they impart a subtle sparkle. Fine white limestone-based sands are hard to find in bags, but are sometimes used in swimming pools and other types of stucco, so they may be available at masonry or stucco supply stores. You could try going directly to limestone quarries; they may sell you some (though they may have a minimum order size that's more than you want). For finish plasters, quarry sand often needs to be sifted, which means it needs to be dry — that pile of sand stored outside at the quarry looks much less appealing when it's time to sift it. Even bagged sands often need to be sifted for use in finish plasters.

You may encounter the term *marble sand*; often, this is actually calcite sand. The confusion in terminology probably stems from stonemasonry conventions that label some types of good-quality calcite (a sedimentary limestone) as marble (a metamorphosed limestone). So if you buy marble sand or *marble dust,* you may not be buying marble — and that's fine.

Stucco sand

Stucco sand is what you probably want for your plaster, but depending on where you live, the trouble may be actually getting it. It's similar to masonry sand, with a maximum particle size of 3⁄16 inch, but has a greater proportion of large particles, and less very fine sand. Stucco sand is ideal for anything but thin finish coats; however, it is far less widely available than masonry or concrete sand.

Sieving Your Own Sand

If you can't buy the sand you need, you can "make" it. It's not unusual to modify sand for use in fine finish plasters by sieving out the larger particles from a commercially available sand. To sieve your own, you need dry sand and an appropriate screen. First, you need to know what mesh size you want (the recipes in this book will specify this, if it's important). Window screen

Fig. 2.8, 2.9: *Sieves of all manners can be used for sieving sand, but it's usually easiest if the sieve is sloped and there's an opening for coarse aggregate to drain.*
CREDIT: TINA THERRIEN, MICHAEL HENRY

is typically about 16 mesh. A smaller mesh size can be purchased in the form of splatter guards from the kitchen section of many stores (maybe around 30 mesh), otherwise, you will likely be shopping online at a specialty supplier (see Appendix 2, Resources).

It's worth taking the time to make a good setup for sieving sand — this may be as simple as cutting the bottom out of a bucket and gluing mesh in (construction adhesive is good for this), but it usually involves making an angled wood frame. For anything but small, occasional sieving jobs, it's worth investing time in a good setup. Build the frame to fit on a slope over a Rubbermaid, or whatever bin you find most convenient. Leave the lower end open for coarse aggregate to exit and hook a bag over the end so that it bags itself. Try out some different angles (you can start with 45) until you find the one that works best for you.

Most sand is primarily made up of silica, so avoid breathing the fine dust — always wear a respirator to sieve sand.

Fiber

Fiber is used in many, but not all plasters. The role of fiber is to increase tensile strength and ductility — meaning it helps plaster resist stretching, compression, and deformation. It can also play an important role in reducing shrinkage cracking.

Types of Fiber

Natural fibers used in plasters include straw, hemp, animal hair, coconut, sisal, flax, cattails, wild rice hulls … and many other fibers. Straw is the most commonly used fiber, and it can be used in a wide variety of plasters. It can be cut at different lengths to use in base coats or finish coats. It's not as commonly used in finish plasters unless they will be applied thick or the look is desired — fine straw in a finish can be very beautiful.

Fiber has several function in earth plasters:

- It allows for increased depth of application. Plasters that are meant to be applied very thick

Fig. 2.10: *A small selection of the many possible fibers that have been used in plasters: 1) coarse chopped straw 2) mulched straw processed with a wood chipper 3) hemp sliver 4) textile flax 5) wild rice hulls 6) polypropylene fiber (synthetic).*
Credit: Michael Henry

will have a lot of fiber, whereas many thinner finish plasters have no fiber.

- It compensates for substrates that are prone to movement, and also helps the plaster bridge a change in substrate without cracking along the transition.
- It allows for changes in depth, filling hollows in the wall, and building raised sculptures or other structural elements on the wall.
- The amount of fiber in a plaster usually ranges from 0–30%, but it can be more. Generally, the thicker a plaster will be applied, the coarser the fiber that will be used in it.

Straw

The fiber of choice for most earth plaster base coats, and some finish coats, is chopped straw. Where the base coat will be very thick (to level uneven walls or fill voids, for example), the straw is usually chopped to 2–6 inches in length. However, coarse straw reduces workability of the plaster, so for thinner base coats, or where a relatively fine finish is desired, straw can be chopped to as little as 1–2 inches in length. Finely chopped straw will contribute less to the strength of the plaster, and it may be more prone to cracking when applied very thick, but adding a larger amount of fine straw to a recipe can often substitute for a smaller quantity of long straw, with better workability. A *mix* of different lengths of straw often produces the best results.

In straw bale homes, floor sweepings from window trimming or weed whacking the walls can be a good source of fine to medium-length chopped straw for plaster. Bag them in contractor-grade garbage bags and save them for later. Or, to make coarse chopped straw, simply carve up a bale with a chainsaw: with at least one string still tied, cut the bale down the entire length, carving off 2–4 inch strips. You may be tempted to cut with the top of the bar to avoid pulling too much straw into the mechanism. If you do this, just keep yourself, and everyone else, well clear of the saw — in case it kicks back. When you use the top of the bar, many of the chainsaw's safety features can't help you. Proper chainsaw safety gear should be worn.

Finer straw usually needs to be screened. Using a wood chipper is often the most efficient way to process a lot of fine straw. Otherwise, you can use a leaf mulcher, or improvise a mulcher using a weed whacker and a tub. Cut the bottom out of the tub (leave a rim), and duct tape metal screening or fencing with the desired opening size into the hole. Half-inch to one-inch fencing will screen a nice fine-chopped straw. Cover the top of the tub with plastic, with a slit to feed in straw and accommodate the shaft of the trimmer. You'll find that the trimmer mulches the straw and at the same time pushes it through the screen much more efficiently than you could do it by hand. Set the mulching tub in another tub with a spacer to leave a cavity where the straw can land. A half hour invested making this contraption can save hours of labor on a job. Use a trimmer that has its motor on the back — if the motor is inside the mulching container, it will burn out right away.

Tom Rijven uses a lawnmower to mulch straw. This involves running a mower (without a side-chute, or bag) over the straw a few times, in a long wood frame with a plywood base.

Straw contains significant amounts of silica (wheat straw is 3–5% silica, rice straw has more), so a respirator should always be worn when working with dry straw that could create dust.

Hemp

Hemp fibers vary a lot in their properties depending on what part of the plant they come from and how they are processed. Hemp hurd, or shiv (the core of the stem), is a coarse material that is typically used in sculpting and for building structure, but it is otherwise not very useful in plasters. Hemp *sliver* is a fine fiber that can be used in finish coats or as an addition to thicker coats. It may be subtly visible in finer finish coats. These fibers tend to collect on the paddles of most types of mixers unless they are cut fairly short, usually ½ inch. This type of fiber may be available from paper-making suppliers or other online retailers.

Flax

Flax (*Linum usitatissimum*) is the plant from which linen is made, and its seed is the source of linseed oil. Flax is an underrated plant that can play a very valuable role in natural building. Flax can be purchased in a variety of qualities and types from paper-making supply shops. The most useful for finish plasters are *textile flax* or flax *noils* (the leftovers from combing machines), which can be used as very fine fiber in finish plasters.

Cattail fluff

Cattail fluff can be used as a very fine fiber in finish plasters. It should be collected when it is loose and dry on the stalks, and a little of it can go a surprisingly long way. It is a very short fiber, so is not suitable for plaster that will be built to any significant depth. However, because it essentially vanishes into a plaster, it allows for fine finishes.

While some of the fibers in this section don't appear in recipes in this book (cattail, coconut, and flax), we have successfully used cattail fluff and flax in recipes in the past. Feel free to experiment with substitutions of fibers in your mix, to make sure they have the desired effect. Locally available fibers are cost effective and easily obtained.

Synthetic fiber

Synthetic fibers used in plaster are primarily either fiberglass or polypropylene. Synthetic fibers are commonly used in lime and cement-lime plasters, but they can be used in earth plaster, too. Polypropylene is the most likely choice because it works amazingly well in small quantities and is readily available from most masonry supply stores. However, while it doesn't show at all in a troweled finish, it typically shows when a sponge finish is used (because it lifts out and leaves little hairs on the plaster surface). This is a problem, especially in unpainted finish plasters. Natural fibers such as fine hemp, flax, or cattail fluff are comparable to synthetic fibers, but using them means you avoid putting plastic into your lovely earth plaster, and the surface can be sponged without having the fiber lift out of the plaster. All things being equal, go natural — but in a pinch, or for certain applications, synthetic works well with very little material.

Pigments

Pigments are mixed into many fine finish plasters, as well as natural paints and alis (clay paint). Many natural pigments are simply clays that have high proportions of iron oxide or other minerals that lend their characteristic color. Pigments vary in their toxicity, UV-stability, and lime (alkali) stability.

Types of Pigment

Earth pigments

Earth pigments are rocks, minerals, or clays that are dug directly from the earth. If they are not already a fine powder, they are ground into one. Ochre is a very well-known earth pigment with a color that comes mostly from hydrated iron oxide (limonite). Umber and sienna derive their color from hydrated iron oxide and manganese oxide.

When umber and sienna are heated, the limonite is dehydrated, converting some of it to a much redder hematite. The resulting pigments, which are darker and more reddish-brown than the raw forms, are known as burnt umber and burnt sienna.

In many cases, earth pigments have been mined from the same areas for centuries and can have historical and cultural significance.

Synthetic pigments

Synthetic pigments may emulate pigments that were traditionally derived from natural sources, or they may be novel inventions. Many of the pigments of interest to plasterers are inorganic pigments; however, some organic pigments can also be used in plaster and can offer extremely stable, vibrant colors.

Mars was originally a brand name in the late 18th century, but the term is now often used for any synthetic iron oxide pigment. Mars yellow is a synthetic yellow ochre; when heated, it transforms to a wide variety of other colors including Mars orange, violet, and black. Even though they are synthetic pigments, Mars colors are usually grouped with earth pigments, to which they are closely related.

Many of the other synthetic inorganic pigments are oxides of other metals. Chromium oxide green is a common pigment that is quite beautiful. Chromium oxides have a bad reputation because of chromium trioxide, a toxic form of chromium used in electroplating. The form of chromium oxide used as a pigment is considered safe and nontoxic.

Naples yellow is a lead-based pigment and is therefore highly toxic and should be avoided. However, there are replacement pigments that may use the name Naples yellow (e.g. *Naples yellow deep*) but contain no lead — these have the pigment number Pbr24. This pigment group includes some beautiful yellow and yellow-orange colors.

Pigment Stability

Some pigments break down quickly in the presence of lime (they are not *lime-fast*). For example Prussian blue, a deep blue pigment, turns almost completely white within minutes of being mixed with lime. Artists who work with

Table 2.8: Pigment Characteristics

Some Common Pigments and Pigment Groups	Lime Stable?	UV Stable?	Toxicity	Notes
Earthtones including ochre, umber, sienna, iron oxides Py42,43 Pr101,102 Pbr6,7,9 etc.	Yes	Yes	Low	May contain silica, otherwise nontoxic. Affordable, widely available.
Cobalt colors Pb26,28,36,50	Yes	Yes	Low	Expensive.
Chromium oxide green Pg17	Yes	Yes	Low	Safe and stable oxidation state of chromium.
Pbr24 (range of colors)	Yes	Yes	Low	Chrome antimony titanate. Naples yellow alternative.
Mayan pigments	Yes	Yes	Low	Organic dyes chemically bonded to clays.
Hansa yellow Py3,74	Yes	Yes	Low	Synthetic organic pigment.
Indanthrone blue Pb60	Yes	Yes	Low	Synthetic organic pigment, very stable but expensive.
Naphthol reds Pr170	Yes	Variable	Low	Synthetic organic pigment.
Pigments with Some Toxicity				
Ultramarine blue Pb29	Variable	Yes	Low-moderate	Some ultramarine blues are marketed as limefast.
Cadmium colors	Yes	No	Low-moderate	Reports of toxicity vary from nontoxic to carcinogenic.
Titanium dioxide	Yes	Yes	Low-moderate	Possible carcinogen if inhaled. Nano-sized particles may be more toxic than larger ones.
Phthalo colors	Yes	Yes	Low-moderate	May damage kidney and liver at moderate doses, but this is not clear. MSDS sheets vary in reporting toxicity.

fresco know which pigments they can use with lime, and they often post good information on the internet. To test for yourself, mix the pigment with lime putty and leave it mixed wet in a jar for a few weeks to see if it fades.

Some pigments fade in sunlight (they are not UV stable). For instance, cadmium colors are stable in lime, but not UV. Mural painters have lists of colors that are very stable outdoors.

Maximum Quantities

The maximum pigment that should be used in plasters is often given as 5–10% of the binder by weight. Just to confuse things, the same ratio by volume is often cited as a maximum; in reality, it will vary a little depending on the type of pigment. Regardless, if you're aiming for the higher end of the range, evaluate your plaster tests — weak or dusty plaster may have too much pigment. Three to five percent often gives a nice color.

Toxicity

Don't assume pigments are safe. Make sure of it by checking the safety data sheet (SDS or MSDS) for every pigment you work with. Even pigments that are considered to have low toxicity should never be inhaled, as they may contain small amounts of silica or other products that can be dangerous as a very fine powder.

Mixing Pigments

Pigments need to be properly mixed in order to avoid streaking. Some pigments (e.g. ochres) can be mixed into the dry mixture before adding water. However the best way to mix any pigment is as follows:

- Blend the pigment with a small amount of water, roughly an equal volume to the pigment.
- Stir this mixture well; it should be a workable paste — if it's too thick, add water.
- After stirring well, slowly stir in more water until it's the consistency of thin paint.
- Add the pigment to the mix.

To mix the pigment evenly into the plaster:

- Mix half the dry ingredients into the water.
- Add the pigment slurry and mix well.
- Add the remaining dry ingredients and mix again.

Blending Pigments: Color Theory

An understanding of color theory is beyond the scope of this book (a good reference is *The Keys to Color* by Dean Sickler), but if you work with pigmented plasters, you'll have to confront color mixing. A useful concept is *modifying color by adding complementary colors.* Complementary colors are opposite each other on the color wheel, and when they are combined in a paint or a plaster they cancel each other out — so it's a subtractive approach to using color rather than the additive one that one normally thinks of.

For example, if you want to shift a blue-green toward the green, rather than adding green, you could add orange, the complement of blue, to cancel it out. However, if you wanted to tip it more toward blue, you would add red, which would cancel some of the green. This trick is especially useful when working with natural pigments, where the color palette is limited (maybe the hue of green you want to add doesn't exist). Of course, sometimes the best way to get more green is to add green!