High-fire Stoneware and Porcelain

by David Beumée

I think it's time that potters were given more tools and information to find out about the stoneware and porcelain clay bodies that they use. My own bias is toward making one's own clay, because in the process the artist becomes close to the source of their materials when changes need to be made. This cannot be the case with a commercial clay body, because commercially-prepared recipes are proprietary information. I want to present a process by which potters are able to generate their own clay bodies, because clay is the most important material we use. I understand all too well the time constraints placed on all of us who wish to make a living from sales of our work, and that tools presented for testing procedures are also applicable to commercially-prepared clays. If problems are recognized, recommendations to the manufacturer can be made, and I sincerely hope that you will do so. We want to be able to use high-fire stoneware and porcelain clay bodies on the wheel that are highly plastic and workable, have low shrinkage and are of a low percentage of water absorption, exhibit no warping, cracking or slumping, have a desirable texture and fired color, fit a wide variety of glazes, and are safe for use in the oven.

WORKABILITY

As it pertains to a clay body, the term "workability" is a more complete definition than plasticity, because it includes the concepts of strength and thixotropy. I'll try to define the terms one at a time.

PLASTICITY

For porcelain and stoneware throwing bodies, I want the maximum amount of plasticity I can get from the clays that are the main constituent of the recipe. I use a wet-mix method that produces a throwing body of excellent plasticity, because by such a method, as great a proportion of the clay particles as possible is allowed to become wet. This method is particularly applicable to what I call "true" porcelain: a clay body which contains no ball clay, and which may fire to a truly white color. Such bodies contain only kaolin clay, and I have tested as many kaolins as possible to find those that fire white. There are many excellent choices of kaolin clays to be found domestically in the United States at a far more reasonable price than imported English kaolins. (See chart "Best Of Individual Clays" pages 48-49). White-burning kaolin clays, unfortunately, are quite short (non-plastic) in comparison to many fire-clays, stoneware, and ball clays that are available commercially, and this is the reason I go to such trouble to wet mix a porcelain body. (See directions and illustrations under Mixing Procedures.) By mixing the clay body as a slurry, I am allowing as much water as possible to penetrate between the flat clay particles, and this is the mechanism that allows for maximum plasticity. As I complete this research, I am using a commercial porcelain clay body called P-60-S, made by Mile Hi Ceramics in Denver, originated by Herb Schumaker. This is a true porcelain because it fires very white at cone 10 and 11, contains no ball clay, and has excellent glaze fit. But like almost all commercially -prepared clays in the U.S. and Canada, it is a "dry-mixed" clay body. The process works like this: A normal batch of approximately 1500 pounds of clays, feldspar, silica, and perhaps a plasticizer, are put into a gigantic mixing machine, and just enough water is added to turn the batch into a moist clay, a procedure that wets about 60% of the mixture, leaving about 40% of the clay particles still dry. In the case of stoneware bodies, which use far more plastic clays than porcelains, dry mixing may produce a body that has good or even very good workability on the wheel. But it makes an enormous difference when the only type of clay in a porcelain mixture is kaolin, which is by nature of relatively large particle size and therefore quite short. P-60-S throws OK for a "dry-mixed" body, but I wonder how it would handle on the wheel were it wet-mixed and filter pressed, as is the case with Southern Ice, a porcelain body imported from Australia by Laguna.

STRENGTH AND THIXOTROPY

In the context of porcelain and stoneware bodies for wheel work, one of the ways I use the term "strength" is the ability of a clay to stand up on the wheel, to have a kind of springy, resilient quality that allows for repeated working of the clay without collapse. For this quality, a lot of plasticity is needed of course, and usually a good and effective flocculant is a welcome addition to the mixture to keep your clay from becoming deflocculated, either from the water used to mix the clay or from release of alkalis from the use of sodium-based feldspars such as Kona F-4, Minspar, or Nepheline Syenite. In my area of eastern Boulder County, sodium hydroxide is added to the hard mountain water to make it feel soft. But sodium hydroxide acts as a deflocculant, exactly what you do NOT want in your clay body, and for this reason I add a flocculant such as calcium chloride to the water used for mixing the clay. Deflocculation of a clay body defeats strength and makes the clay flabby and weak as it is thrown on the wheel. (See "Mixing Procedures" to find out when and how to use calcium chloride to flocculate your clay, whether it is a porcelain or stoneware body.) Choice of clays used in the body mixture make an enormous difference in the ability of a clay body to exhibit strength on the wheel. 50-mesh Hawthorn Bond fire clay, and New Foundry Hill Creme stoneware clay both have a wonderful "dense" feel for stoneware clay body mixtures.

I am using porcelain on the wheel, a type of clay that has only fine ingredients in the recipe. No addition of grog or sand is used, and this can mean that certain size constraints are placed on the pieces I am able to make. Far larger pieces can be thrown from some stoneware clay bodies, not only because of the plasticity of clays that are used in comparison to porcelain, but because the clays have much larger particles to stand on, namely grog and/or sand added to the recipe, or the use of coarser clays, such as 35-mesh Hawthorn Bond fire clay or C-1 clay, available from Laguna. If you want a clay body that fires somewhat "white" like porcelain that has great strength on the wheel to stand up to the making of larger forms, you will need to sacrifice ultimate whiteness of fired color (porcelain) in favor of a white stoneware body that contains (relatively) white-burning ball clays, such as 54-S, Old Hickory #5 or HCS #5, and perhaps a Grolleg-based grog such as Molochite. (See "Best Of Individual Clays.")

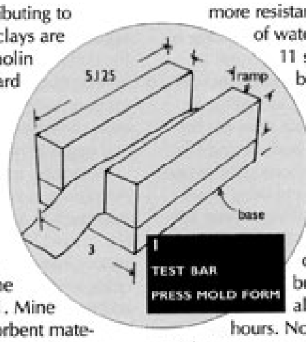
Also included in the term "workability" is the concept of thixotropy, referring in one sense to the ability of the clay to stay where it's put as it is being worked on the wheel. Anyone who has opened a bag of commercially-prepared porcelain has probably noticed what seems to be a stiff clay that becomes soft and workable as it is wedged and kneaded in preparation for wheelwork. This is thixotropy at work, and I have come to realize that a bit of it is a good thing for the ability of a porcelain clay to stay where it is put as it is being thrown on the wheel. Highly thixotropic clay is another matter entirely, and is deflocculated clay that is impossible for use on the wheel. Good plasticity and strength, and a bit of thixotropy, combine to add up to good or very good workability in a porcelain body for use on the wheel. (Note: Throwing with as little water as possible is particularly important for porcelain, because the larger particle size of kaolin clay makes porcelain "thirsty," meaning that water is soaked up fast, greatly contributing to early collapse. Lucie Rie was particularly good at "dry-throwing," enabling her to throw extremely thin porcelain and stoneware pots using a bare minimum of water, a technique which no doubt allowed her to work the pots for extended periods of time.) As yet, no porcelain clay I have made or used can compare to a commercial body imported from Australia by Laguna, known as Southern Ice. If you want to treat yourself and feel what a wet-mixed, filter-pressed porcelain throws like on the wheel, try this porcelain. It fires to a translucent blue-white color the like of which I have never seen in twenty-two years of testing and throwing porcelain clay bodies. The drawback is its very high expense. When throwing tall porcelain cylinders in preparation for covered jar or vase forms, I wet the inside of the cylinder only, using slurry from the previous pull to lubricate the outside of the pot.

HOW WHITE IS WHITE?

Only if you are interested in getting a great degree of clarity from clear, white, celadon, copper red or other transparent or translucent glazes, is the ultimate degree of whiteness from a porcelain clay body necessary. If you want translucency from your clay body, that is, a fired porcelain you can see light through, a true porcelain that contains no ball clay is what you want, provided it's thrown or carved thin, has a transparent or translucent glaze on it, and is fired to a high enough temperature to allow the body to become vitrified completely. But if translucency and ultimate clarity of glazes are not so important, there are many white stoneware clay bodies that are a lot more fun to throw and handle. Invariably, these bodies contain ball clay and, therefore, can be quite plastic and workable on the wheel, which can mean a big increase in the fun factor as the clay is used. It means, for instance, that handles and knobs can be attached with much greater ease and much less attention to timing in comparison to a true porcelain body. But the price paid for increased plasticity is little or no translucency of the fired clay and less clarity for your glazes, because ball clay contains iron, darkening the fired body and giving a darker background for your glazes to be reflected against. The plasticizer used to make a true porcelain body is crucial. All the bentonites I have tested (using fusion buttons) fire chocolate brown, including those sold as light or "white" bentonite. Fortunately, Macaloid, Bentone MA, and Veegum T are commercially available and all fire very white, but must be mixed wet to release their amazing plasticizing qualities.

SHRINKAGE

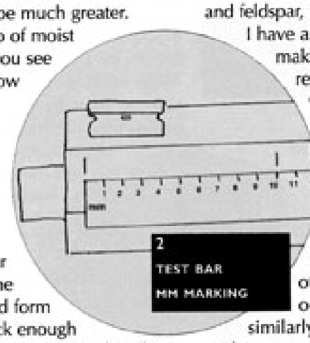
Many factors contribute to a relatively high shrinkage rate of porcelain clay bodies. I wet-mix all my bodies, so the water content is higher than with commercially-prepared clays, and this contributes to a higher shrinkage rate, more on the order of 16 to 18% for a porcelain, and 14 or 15% for stoneware bodies. Porcelains are composed of all fine materials, usually 200 mesh or finer, so the melt is closer to glass than for a stoneware body, which also contributes to higher shrinkage. I fire to a hard cone 10, and porcelain clay bodies contain a relatively high percentage of flux in comparison to stoneware bodies, also contributing to higher shrinkage. Most importantly, kaolin clays are high shrinkage by nature. All my favorite kaolin clays (Helmer, 6 Tile, EPK, DB Float, Standard Porcelain [from England], and Macnamee) are all between 17 and 20% shrinkage as individual clays (wet mixed). I have long since compensated by over-sizing my pots, but it never fails to surprise how a tightly packed kiln can have so much empty space when the door is finally opened.



1
TEST BAR
PRESS MOLD FORM

Here is how to find out how much your clay body shrinks: You will need to build the press mold form described in Illustration #1. Mine are made of wood, which provides an absorbent material that the press-molded clay will shrink away from, so that the test bar can be lifted out of the form using a strip of canvas that I lay down in the bottom of the form. Be sure to screw and glue your rails onto the base with the toughest epoxy you can find, and use clamps or a vise to glue your rails in place. Be sure not to seal the wood in any way, or put lacquer or Varathane on it. If the grain of the wood for your base goes in the same direction as the grain of the wood you use to make your rails, your chances of building a form that will stand up to use will be much greater.

To test a body, use a pound or two of moist clay and press it into the form until you see the clay squirt out the open sides. Now wire off the excess clay and smooth the top and sides with a stiff rib, and immediately mark off 100 mm (10 cm) into your test bar, using a razor blade for accuracy. (Illustration #2) Write into the clay which body you are testing, so it can be identified after the firing. Next day your test bar should be stiff enough to lift out of the press mold. The particular press mold form that I use makes a test bar that is thick enough so that repeated turnings are not necessary as the bar dries. Just lift or pick the bar out of the form and set aside to dry completely. Biscuit- and high-fire your test bars in between your pots, and after firing, carefully measure between the razor blade marks with a ruler that has a millimeter scale on it. If the measurement is 82, for instance, your porcelain clay body shrinks 18% at the temperature you have fired your kiln. (100 – 82 = 18% shrinkage). At cone 10 or 11, your hope should be to produce a stoneware body with a smaller amount of shrinkage, more like 11–15%.



2
TEST BAR
MM MARKING

ABSORPTION AND THERMAL SHOCK

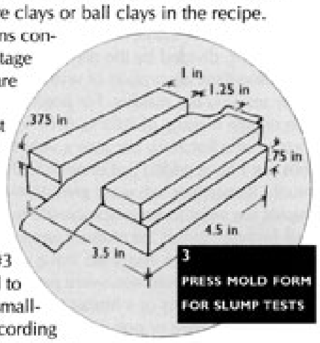
For porcelain clay bodies, I expect 0% absorption at cone 10, but I think a little porosity in a stoneware body may be a good thing because it may make the stoneware clay body more resistant to thermal shock. I think up to 2% of water absorption is fine for a cone 10 or 11 stoneware clay body. Use your fired test bars (Illustration #1) to make this test. While the bars are still warm from the firing, weigh them carefully to the nearest tenth of a gram and record your numbers. I use a triple beam Ohaus scale for all my weight measurements. Now boil your test bars for two hours and allow them to soak overnight. I pressure cook my test bars but, whatever method is used, be sure to allow the bars to soak for at least eight hours. Now pat dry to remove excess water and weigh your tests again. The formula is: wet weight minus dry weight, divided by the dry weight, times 100, will give the percentage absorption of water for the particular clay body test you are making. For porcelains, I like to get a percentage reading of 0.05%, 0.15%, or some such thing, instead of a flat zero, because a very tiny bit of absorption tells me I have added just enough feldspar and not too much. Remember, we want great throwing bodies. That means we want to keep non-plastic materials, such as silica and feldspar, to just the amount needed, and no more.

I have always imagined that a cone 04 earthenware makes great ovenware precisely because the clay remains of a higher porosity than fired stoneware or porcelain. This means that when such a body is (thermally) heat-shocked, such as taking a plate out of the oven and putting it in water, an earthenware plate of 10% water absorption (porosity), may be more likely to survive cracking because the shock can be dissipated by the porosity of the clay. Such would not be the case with a porcelain body of 0% absorption, where the body is "tight," or completely vitrified. If such a piece were similarly shocked, the shock would have nowhere to go because complete or nearly complete vitrification has taken place, hence the 0% absorption, and the pot breaks. But the highly fluxed nature of a porcelain body also means that the possibility of cristobalite formation is very low, and I have never had trouble using porcelain bodies as ovenware, and have never had a call from an angry customer. I regularly put my porcelain pots in preheated ovens, but that is not to say that I take hot porcelain pots out of the oven and dunk them in water, or that I take porcelain casseroles out of the freezer and put them directly in a preheated oven.

WARPING, CRACKING, AND SLUMPING

According to Dr. Carty's lecture at the 2002 NCECA conference, "Holistic Approach to Defect Reduction," warping and cracking in a clay body are two sides of the same problem. Warping is due to compression, and cracking is due to tension, and both problems develop because of non-uniform particle packing in the body. On a practical basis, I have tried to solve this problem by including as much variety of individual clays as possible from my list of "Best Of" individual clays in any clay body recipe I formulate. I try my best to mix the body as thoroughly as possible. Much can be learned from testing and firing small batches under similar procedures and looking at fired test bars side by side. If I see a stoneware clay body test that exhibits severe warping or cracking, I add some coarse grog to the clay body mixture or substitute coarser clays such as C-1 or 35-mesh Hawthorn Bond for some of the finer-mesh stoneware clays or ball clays in the recipe.

Because porcelains contain a higher percentage of flux than stoneware clay bodies, I may conduct a slump test on a new porcelain body, particularly if I see a porcelain test bar come from the firing slightly shiny. (Illustrations #3 and #4.) You'll need to make a similar but smaller wooden form, according to the measurements given in Illustration #3. Press mold clay into this form just as you would for the shrinkage bar, wire off the excess clay, smooth with a stiff rib, and write into the moist clay which body you are testing. You will need to watch this test bar closely as it dries, as a bar of such thinness will curl, and needs to be turned as it dries to come out flat. Then biscuit- and high-fire your test bars on a cut soft brick. (Illustration #4) Dip the top edges of the brick in kiln wash so the test bars can slide as they shrink in the firing. The bars that stay nearly flat at the temperature and in the time cycle in which you fire are the porcelain clay bodies to pursue.

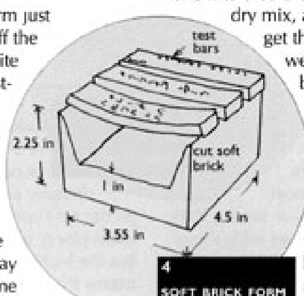


3
PRESS MOLD FORM
FOR SLUMP TESTS

TEXTURE AND FIRED COLOR

One of the benefits of doing your own clay body testing is that you get to choose exactly the texture and fired color that are right for you. 1500 gram tests leave you enough moist clay to throw a small pot (see Mixing Procedures), and if the texture or plasticity are not just the way you like, you can make a change. Perhaps the body will have a certain feel that I can only describe as "dense and just right," or perhaps it will be rough from too great a percentage of added grog, or have a sticky, overly smooth feel. Perhaps the color of the fired test is too dark from an addition of iron-bearing clay or iron oxide, or not dark or light enough for your taste. With the familiarity gained by mixing your own clays, you can begin to take control of your own fate and begin to make changes with confidence.

A note on adding iron oxide to stoneware clay bodies: According to Jim Robinson's article, "Fear of Silica: An Approach to Stable Stoneware," (STUDIO POTTER, Vol. 9, No.2, June 1981), if you add red or black iron oxide, yellow iron oxide, yellow ochre or any other form of iron oxide to a clay body to improve fired color, keep your addition to 1% or less. Iron is a flux, and beneficial mullite, which forms in the body during the firing as an important source of strength to the clay, can be dissolved by the glasses that are formed by an overabundance of iron, meaning that your fired body may become brittle. Without the addition of iron, your stoneware body may end up being more of a gray color than the beautiful tan or brown color we all know and love, but this gives the opportunity to begin to use colored slips. My tests reveal that 1/2% Blackbird/ Barnard slip, added to a slurry made of your stoneware clay body, gives a very nice tan color as a slip added over the leather-hard clay. For medium brown, 1% Blackbird/ Barnard seems to be about right, and for dark brown, try 1/2% yellow ochre or 1/2 to 1% red iron oxide. Allow some of your trimmings to dry out completely so you can get a dry weight to add a percentage of iron to make into a colored slip. Add the percentage of iron to the dry mix, and add the mix to just enough water to get the entire mix soaked. Mix the slip very well and screen through a 60-mesh sieve before use on wet or leather-hard ware. This will give you a thick slip to which a small amount of sodium silicate can be added if it is too thick for your liking. This will thin the slip without adding any water, which would contribute to cracking of the slip as it dries. If you want to add iron to your body, remember that if possible, adding an iron-rich refractory clay in a small percentage to a stoneware mix, rather than adding straight iron oxide, will mean much less staining of your hands, clothes, and everything else in your studio. (Newman Red, available from Laguna, is a highly refractory iron-bearing clay. 10% or less added to a stoneware clay body mixture is my recommendation.)



4
SOFT BRICK FORM
FOR SLUMP TESTS

THERMAL SHOCK, GLAZE FIT, AND CRISTOBALITE

In creating oven-safe stoneware and porcelain bodies, there are many potential difficulties. First, creating a body that is balanced in terms of its expansion and contraction, neither too high, or too low, seems of obvious importance. In the absence of a dilatometer, using Jim Robinson's Glaze Test Series (STUDIO POTTER, Vol.16, No.2, page 74), we are creating clay bodies that expand and contract in a way that will fit a wide variety of glazes from low to high expansion, which helps in the effort to create clay bodies that are safe for use in the oven.

Second, try to eliminate cristobalite from forming in a high-fire clay body, also done through the use of the 10 glazes of high to low expansion in the Glaze Test Series, as feldspar is gradually added to the mixture. My recommendation is that a potash-based feldspar is best for high-fire clay bodies, because there is less chance of soluble alkalis leaching into the clay, and therefore less chance for deflocculation to occur. My fusion button tests show G-200 feldspar having a slightly greater melting capacity and also a more translucent melt than Custer feldspar. Both products melt very clean with no hint of contamination, but I prefer G-200 because I can use less of it to achieve the same absorption percentages in the clay bodies that I create.

Third, is choice of materials for the clay body, and it is gradually becoming obvious that a choice of coarser materials that leave a clay body slightly "open," with a slight percentage of absorption of water after the firing may be a key in creating stoneware clay bodies that are safe for use in the oven. In general, as Jim Robinson states in "Body Building for Potters," you can consider that for a stoneware clay body, an average of 20% non-plastic materials (feldspar and silica) will need to be added to a blend of clays "to stabilize and give it good glaze fit characteristics." From my experience, that average increases to a 35% addition of feldspar and silica added to kaolin clay for porcelain clay bodies.

Thermal shock has to do with the ability of a fired clay body to withstand the rigors of daily use in the kitchen by customers who may pay no attention to that card you may have sent along at the time of sale. Mine says: "This pottery is intended for daily use, and is suitable for use in the oven, but all stoneware and porcelain pottery is vulnerable to sudden temperature change. Don't use over direct heat. Don't pour cold water into hot vessels, or put a hot vessel into water. Don't put a cold vessel into a hot oven, and don't use for dry roasting or broiling. The pots are dishwasher safe and contain no toxic materials." This always has seemed overly punitive, and I have wondered if a stoneware or porcelain body could be created that is resistant enough to thermal shock that my care card wouldn't scare people away from using my casseroles for their intended purpose.

There are clay bodies that are relatively high in expansion (and contraction) in relation to the glazes that cover them, and clay bodies that are of low expansion. In the absence of specific testing, such as taking pots made from both high and low expansion materials, putting them in a hot oven, letting them heat to say 425°F, taking them out of the oven and plunging them in cold water, I make an assumption that clay bodies of relatively low expansion will survive where those of high expansion may not. But how do I know about the relative high, low or balanced expansion of a clay body? I know by having tested 10 test mice of each body with a set of glazes that range from very high to very low expansion. (See Jim Robinson's Glaze Test Series from his groundbreaking article "Body Building for Potters: A Clay Blending Formulary," published in STUDIO POTTER, Vol.16, No.2, June 1988.)

If a clay body is of LOW expansion because of the particular materials chosen for its recipe, then it will fit the low expansion glazes in the GTS (Glaze Test Series) without the glazes shivering (GTS number 7 and 8, and especially numbers 9 and 10). But it will be found that the high expansion glazes in the Series, numbers 1, 2, and 3, will have crazed, and very possibly numbers 4, 5, and 6, and sometimes even numbers 7 and 8 as well, on bodies of extremely low expansion.

If a body is of HIGH expansion, then it will be found that the high expansion glazes in the GTS, numbers 1, 2, and 3, will fit the body without crazing, but that the low expansion glazes in the series, numbers 9 and 10, and possibly numbers 4, 5, 6 and 7 as well, will have shivered over the high expansion body.

The mechanism works like this: If the clay expands (and contracts) MORE than the glaze (we use the term expansion to mean both expansion and contraction), then the GLAZE is put in compression by a high expansion clay body, and the BODY is put in tension. The body may put such a squeeze on the glaze that the glaze will pop off the pot after the firing, in shards so sharp that to compare them to a razor doesn't even come close. This is called shivering of the glaze. But a small amount of compression by the clay onto the glaze is actually very helpful, because the whole pot is strengthened. A similar situation is a glaze that expands and contracts LESS than the clay, like a shino glaze with low expansion materials in the recipe like spodumene or petalite. This situation also puts the clay body in tension, and it can mean that the pot will crack, even though the fired clay is of much greater thickness than the glaze, because fired ceramic materials don't stand being pulled apart (being put in tension) very well.

If, on the other hand, the clay expands (and contracts) LESS than the glaze, or the glaze contracts MORE than the clay as the kiln cools, then the glaze is put in tension and the clay body is put in compression. The glaze cracks open because it's being pulled apart. You can imagine what happens to a cooled form of glass that's being made to stretch over a fired clay that is contracting at a slower rate. If the expansion rates are nearly the same, and the glaze is contracting only slightly faster than the clay, you get great big crackles in the glaze. If the glaze is contracting at a much faster rate than the clay, you get little tiny crackles, and the glaze continues to crackle weeks or months after the firing. This can be used to great decorative effect, coloring crackles with one color of ink after the firing, and another color at a later time. But functionally you have greatly weakened a pot by having a glaze on it that is crazed or crackled. You can consider that the overall strength of your pot has doubled with uncrazed, or non-crackled, glazes surrounding it inside and out, and that you have cut the strength of your pot in half by the use of crazed glazes. Also, customers don't understand functional pots that have crazed glazes on them. They are used to seeing pots manufactured by industry, which has long since known what potters need to know and apply to pots that are to be used in the kitchen and on the table. It is possible (although not particularly likely) that bacteria could grow in the glaze crackles that are stained on the inside of a coffee or teacup, for instance. When you've chosen the clay bodies that you want, test and adjust your existing glazes so they fit your bodies without crazing. Save crackle glazes for use on decorative-type ware.

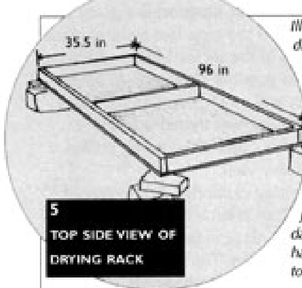
CRISTOBALITE AND SILICA

In the context of producing oven-safe stoneware and porcelain clay bodies at high fire temperatures of cone 9 to 12 and in the context of talking about thermal expansion and thermal shock it's important to understand that silica (SiO_2) is the main influence. What I have been accustomed to using as an addition to a clay body recipe is 200-mesh quartz silica – a product which is ground to a very fine powder that I assume is passed through a 200-mesh screen. The problem is that 75 to 85% of "200-mesh" silica is much finer than 200 mesh, all of which also falls through the screen. Here is a quote from author teacher and potter Peter Sohngen writer of a superb article in Vol. 28 No. 1 of STUDIO POTTER, Dec. 1999 called "Cristobalite: The Hump. New Data on Silica at Cone 10." "The fact is (that) a lot of the silica you've added and most of the free silica in the clays will change to cristobalite when fired to cone 10 if it is not fluxed by the feldspar." So why is the formation of cristobalite in your clay body a problem? It's a problem because it can cause your pots or your customers' pots to crack at oven temperatures meaning that you not only lose a customer but you likely lose all your customers' friends as well.

Another potential source of silica that can turn into dangerous cristobalite is the silica contained in clay itself. A theoretical formula for kaolinite (clay) is $Al_2O_3.2SiO_2.2H_2O$, so you can see that clay contains a very high amount of silica in relation to the amount of alumina; theoretically twice as much. As clay is fired, some of the silica is ejected, and this extremely fine silica will also change to cristobalite, if it is not soaked up in the melt by a sufficient amount of added feldspar to the clay body recipe. Though it is chemically identical to silica, cristobalite has a much higher coefficient of expansion, meaning that its inner crystalline structure "gives it a high 3% discontinuous expansion on heating at 220°C (ovenware temperature) and is the cause of most ware failure from thermal shock, especially on kiln cooling, or in oven use." (Jim Robinson, "Body Building for Potters," STUDIO POTTER, Vol. 16 No. 2, page 74). 220°C is about 350°F, right at the temperature that would be used to cook food on that platter or in that casserole you sold. BANG! Someone's dinner party is ruined, there's a heck of a mess to clean up, and you have angry customers on your hands that will never buy a pot from you again.

Thermal shock, glaze fit, and growth of cristobalite in your clay body are all interconnected, and Jim Robinson's Glaze Test Series can give you a good indication that no cristobalite has formed in your clay body, and will also allow you to know that your clay body will fit a wide variety of glazes. It is an excellent article and has formed the

HERE'S HOW TO BUILD A DRYING RACK

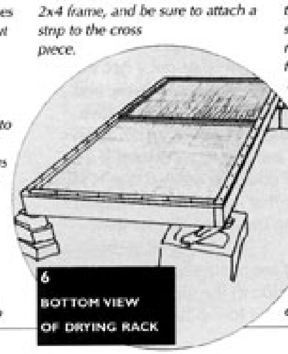


5
TOP SIDE VIEW OF DRYING RACK

Illustration #5 shows the overall dimensions of the rack which uses 2x4 construction. Be sure to put in a cross brace as shown in the middle of the form, and screw and glue your frame together very securely. Use quarter-inch hardware cloth to form the base of the frame.

The overall width of the rack is just wide enough to accommodate a three-foot-wide piece of hardware cloth, without having to do any cutting of the metal.

Now look at Illustration #6, which is a drawing of a rack turned over to reveal the underside. Use 1x2 hardwood strips to attach the hardware cloth to the 2x4 frame, and be sure to attach a strip to the cross piece.



6
BOTTOM VIEW OF DRYING RACK

Screw the strips very securely to the 2x4 frame. I use screws every six inches. (Illustration #7) Set the rack right side up. As you can see from the drawings, I set the racks up off the ground about a foot, and when the rack is full of clay body slurry, I place another thinner cloth on top of the wet slurry to keep out bugs. Be sure to support your rack by placing a block under the center of the middle brace. Illustration #9 shows the roof I put on top of each rack. I place half bricks on top of the rack, just in the middle of each end of the frame, and one on basis of my understanding about the dynamics of high-fire clays.

You will notice in my handout of "Best Of Individual Clays For Throwing Bodies," that I have included the silica to alumina ratio for each clay. (Si/Al). As you use Jim Robinson's program of testing individual clays, you will notice that clays of low Si/Al ratio, such as kaolin clays, will cause many of the glazes in the GTS to craze, but that if substitutions of individual clays to the all-clay blends are made which have a higher Si/Al ratio, such as C-l clay, crazing will diminish. If you look at page 379 of the fourth edition of The Potters Dictionary by Frank and Janet Hamer, you will see Table 26, "Table of thermal expansion and contraction." Our capricious friend silica appears twice on the table, in its crystalline form near the top of the scale (high expansion), and near the bottom of the scale in its fused form in bodies or glazes (low expansion). Quartz silica added to a clay body means its expansion will be raised, because in a clay body not all of the silica is taken into the melt, meaning that crystalline quartz would still be present (high expansion). The more silica, the higher the expansion of the clay body, putting a greater number of the GTS, and probably some of the glazes in your studio, into compressive fit, meaning that crazing is diminished. Adding silica to a glaze will lower the expansion of the glaze in relation to the clay body, because in the case of a glaze the silica is taken into a fused state (melted), meaning the silica has become a fired substance of very low expansion, which means once again that crazing is diminished. Silica that survives the firing intact in a clay body is of high expansion, and silica that is taken into the melt in a glaze is of very low expansion, so adding silica either to your clay or glaze will diminish crazing.

BODY BUILDING

Jim Robinson's article isn't called "Body Building for Potters" for nothing. It is a very involved process. He asks that you begin by testing the 10 glazes of high (8.4) to low (5.05) expansion in the Glaze Test Series on each of the individual clays that you might use in a clay body blend. Here I've shortened your task considerably. (Refer to "Best Of Individual Clays.")

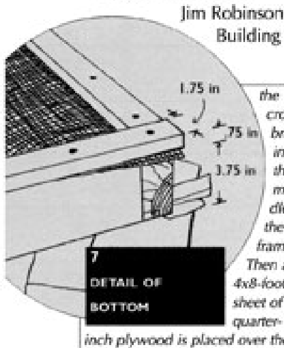
Next you are asked to prepare an "all clay" blend, and run the GTS (Glaze Test Series) on each of the blends of clays that you think might work as clay bodies. Next he asks that you make incremental additions of feldspar, and run the GTS in each incremental change, until GTS numbers 9 and 10 fit the blend without shivering. This gives a good indication that no cristobalite has been able to form, and means that your clay body will likely be safe from at least one form of potential shock, that of a sudden expansion and contraction of your pot at ovenware temperatures due to an excess of cristobalite growth in your clay. (*Note:* This is an indication only. Dilatometry performed on your fired clay body is the only way to really know.)

Now that you have lowered the expansion of your clay-feldspar blend to eliminate growth of cristobalite, you are now asked to raise the expansion of your blend by the addition of silica to achieve good glaze fit, meaning that your clay body will fit a wide variety of glazes from low to high expansion, namely GTS 3–10. (GTS number 1 and 2 are of such high expansion that they will craze over a balanced clay-body blend).

VOILA! You have a clay body that is very likely safe for use in the oven and also fits a wide variety of glazes.

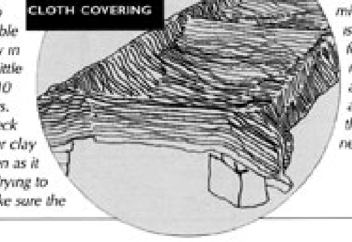
MIXING PROCEDURES

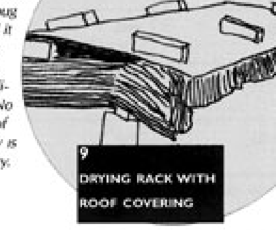
For testing new prospective clay bodies, I mix 1500-gram batches. After weighing out the dry ingredients, I mix them together dry inside a small 17 x 18-inch plastic garbage bag. Leave some air in the bag and close tightly with a twist tie. I use one gallon buckets, and I use the proportions one milliliter water to one gram clay body mix, or 1500 ml water to 1500 grams clay body. Pour the dry mix into the



7 DETAIL OF BOTTOM

the cross brace in the middle of the frame. Then a 4x8-foot sheet of quarter-inch plywood is placed over the rack, so that when the plywood is set on top of the rack, a roof is formed that will shed water. (Illustration #9) Now put some bricks on top of the plywood to hold it down. In the middle of the summer in Colorado I have had a full rack of wet slurry dry into usable clay in as little as 10 days. Check your clay often as it is drying to make sure the clay closest to each end is not getting too hard. I use slightly stiffer clay for taller forms, and save softer clay for plates and platters. I put the clay through my small de-airing pug mill, and it is ready for use immediately. No aging of the clay is necessary.


8 TOP VIEW WITH CLOTH COVERING


9 DRYING RACK WITH ROOF COVERING

BEST OF INDIVIDUAL CLAYS FOR THROWING BODIES

NAME	TYPE OF CLAY	CONE	PLASTICITY	SHRINKAGE	ABSORPTION	WARPING
HELMER	KAOLIN	10 REDUCTION	VERY GOOD	20 %	2.4 %	NONE
6 TILE	KAOLIN	10 REDUCTION	VERY GOOD	18 %	5.5 %	NONE
DB FLOAT	KAOLIN	10 REDUCTION	VERY GOOD	19 %	4 %	NONE
MACNAMEE	KAOLIN	10 REDUCTION	VERY GOOD	18.5 %	8.8 %	NONE
EPK EDGAR PLASTIC KAOLIN	KAOLIN	10 REDUCTION	GOOD	20.5 %	6.7 %	NONE
STANDARD PORCELAIN	KAOLIN	10 REDUCTION	GOOD	17 %	3.8 %	SLIGHT
HAWTHORNE BOND	FIRE	10 REDUCTION	GOOD	16 %	0.9 %	NONE
GOLDART	STONEWARE	10 REDUCTION	VERY GOOD	16.5 %	0.2 %	NONE
NEW FOUNDRY HILL CREAM	STONEWARE	10 REDUCTION	VERY GOOD	17 %	3 %	SLIGHT
CI-MARBLE MIX	"FILLER"	10 REDUCTION	GOOD	11 %	5.2 %	NONE
CHAMPION	BALL	10 REDUCTION	EXCELLENT	17 %	1.36 %	SLIGHT
TI-21	BALL	10 REDUCTION	EXCELLENT	16.5%	1.8 %	NONE
GOLD LABEL	BALL	10 REDUCTION	EXCELLENT	15.5 %	0.4 %	NONE
TAYLOR	BALL	10 REDUCTION	EXCELLENT	15 %	4.6 %	NONE
XX SAGGER	BALL	10 REDUCTION	FAIR TO GOOD	17 %	4.4 %	NONE
54-S	BALL	10 REDUCTION	EXCELLENT	14 %	5.1 %	NONE
M-23	BALL	10 REDUCTION	EXCELLENT	17 %	3.3 %	NONE
OLD HICKORY #5	BALL	10 REDUCTION	VERY GOOD	18 %	3.6 %	SOME
HCS #5	BALL	10 REDUCTION	VERY GOOD	17 %	6.4 %	VERY SLIGHT
RANGER RED	EARTHENWARE	04 OXIDATION	GOOD	13 %	6.4 %	NONE

CRACKING	TEXTURE	SI/AI	FIRED COLOR	SOURCE	COMMENTS
NONE	GRAINY	2.22:1	OFF WHITE, CREAM W/BLACK SPECKS	IDAHO CLAY & GLAZE 208.746.3724	THE MOST PLASTIC KAOLIN I HAVE TESTED. HELMER NEEDS EXTRA TIME TO SLAKE.
DEFINITE	SMOOTH	2.03:1	OFF WHITE, CREAM	IMERYS 800.325.2529	EXCELLENT CHOICE FOR PORCELAIN BODY IF ULTIMATE WHITENESS NOT IMPORTANT.
DEFINITE	SMOOTH		VERY LIGHT OFF WHITE	IMERYS DRY BRANCH 800.277.9636	INEXPENSIVE AND PLENTIFUL DOMESTIC KAOLIN.
SOME	SMOOTH		WHITE	R.T. VANDERBUILT	EXCELLENT WHITENESS. FAIR PLASTICITY.
DEFINITE	VERY SMOOTH	2.08:1	WHITE	THE FELDSPAR CORP.	WHITEST BURNING DOMESTIC KAOLIN. GOOD PLASTICITY.
DEFINITE	SMOOTH AND DENSE	2.24:1	VERY LIGHT GRAY WHITE	HAMILL & GILLESPIE 973.994.3650	BETTER PLASTICITY AND LOWER SHRINKAGE THAN GROLLEG. VERY EXPENSIVE.
NONE	GRAINY AND DENSE	2.51:1	LIGHT ORANGE W/IRON SPECKS	R.T. VANDERBUILT CHRISTY MINERALS	EXCELLENT WHITENESS. EXCELLENT FIRE CLAY FOR USE IN STONEWARE BODIES. I USE 50 MESH BOND.
SOME	SMOOTH AND DENSE	3.26:1	TAN GRAY W/IRON SPECKS	RESCO CEDAR HEIGHTS 740.682.7794	SULPHUR CONTENT. SLOW BISQUIT IN OXIDATION NEEDED. MANY GOOD QUALITIES.
NONE	VERY FINE	3.94:1	LIGHT TAN	H.C. SPINKS 901.642.5414	EXCELLENT DENSE FEEL. VERY PLASTIC FOR STONEWARE BODIES.
NONE	FINE	8.13:1	LIGHT GRAY TAN	LAGUNA CLAY CO. 626.330.0631	SUPER LOW SHRINKAGE. GOOD PLASTICITY. EXCELLENT ADDITION FOR STONEWARE.
SOME	VERY SMOOTH	3.87:1	TAN CREAM	H.C. SPINKS 901.642.5414	EXCELLENT ADDITION TO STONEWARE BODY TO INCREASE PLASTICITY.
VERY SLIGHT	VERY FINE	3.55:1	DARK TAN CREAM	OLD HICKORY CLAY CO. 270.247.3042	SPECIFICALLY BLENDED FOR PLASTIC FORMING TECHNIQUES. SUPERB FOR STONEWARE.
NONE	VERY FINE	3.44:1	MOTTLED GRAY	OLD HICKORY CLAY CO. 270.247.3042	LOW SHRINKAGE BALL CLAY. EXCELLENT ADDITION TO STONEWARE BODY.
NONE	VERY FINE	4.18:1	VERY LIGHT CREAM TAN	OLD HICKORY CLAY CO. 270.247.3042	EXCELLENT ADDITION TO A CLASSROOM WHITE STONEWARE RECIPE.
NONE	SMOOTH	3.37:1	VERY LIGHT CREAM TAN	KT CLAYS 800.343.4205	GOOD CHOICE, BUT LOW PLASTICITY FOR A BALL CLAY.
NONE	VERY FINE	3.28:1	LIGHT CREAM	OLD HICKORY CLAY CO. 270.247.3042	LOWEST SHRINKAGE OF ANY BALL CLAY TESTED. EXCELLENT ADDITION TO A WHITE STONEWARE.
VERY SLIGHT	VERY FINE	3.60:1	LIGHT CREAM	OLD HICKORY CLAY CO. 270.247.3042	SO-CALLED PORCELAIN GRADE BALL CLAY. EXCELLENT ADDITION TO A WHITE STONEWARE.
VERY SLIGHT	VERY SMOOTH	3.52:1	VERY LIGHT CREAM	OLD HICKORY CLAY CO. 270.247.3042	GOOD ADDITION TO ADD PLASTICITY TO A WHITE STONEWARE BODY.
VERY SLIGHT	VERY FINE	3.81:1	VERY LIGHT CREAM	H.C. SPINKS 901.642.5414	SLIGHTLY WHITER BURNING THAN OLD HICKORY #5. FOR WHITE STONEWARE.
NONE	FINE	6.84:1	BRICK RED	BRACKER'S GOOD EARTH CLAY 888.822.1982	THE ONLY PLASTIC EARTHENWARE CLAY I HAVE FOUND.

water, never the other way around. I always wear a mask for this part, and do it close to an outlet fan, which pulls the dust away. Allow the mix to settle into the water, cover and leave overnight. Next morning, mix thoroughly, screen and pour into a drying bat. If the body contains grog I skip the screening. Otherwise I use a 40-mesh and pour the wet mix into plaster bats. Mine measure 17 inches round by 4 inches high, with a well in the center 13 inches by 2 inches deep. The original form was thrown, and plaster castings were made from it. When the clay body test has dried to workable consistency, I wedge the clay, roll out a coil to wrap around my finger to test plasticity, and press clay into my press mold form (see Illustration #1) to make a test bar for shrinkage, absorption and fired color testing.

So let's say that you've determined that a particular clay body is a good one, and now you want to mix a quantity and begin to use it. For mixing quantities of a proven clay body, I start with 30-gallon plastic barrels, and I try to find ones that have flat bottoms. I fill the barrels about 3/4 full of warm water for each 100 pounds of dry mix and add 2% Macaloid, Bentone MA or VeegumT plasticizer to the water as it is being stirred to mix a porcelain clay body, if it is a mixture that contains only low-plasticity kaolin clays such as DB Float or Standard Porcelain. (908 grams Macaloid per 100 pounds of dry mix). If the recipe is a white stoneware, or is a porcelain body that calls for more plastic kaolins such as Helmer or 6 Tile, I add 1% plasticizer (454 grams per 100 pounds of dry mix). If the water is warm and is being stirred, the dry plasticizer should mix into the water if it is added slowly. Now mix thoroughly with a drill mixer and allow the mixture to soak overnight. This is key, because the water breaks down the plasticizer to a kind of gel, and adds an astonishing amount of plasticity and workability to a porcelain body for use on the wheel. Now add the dry kaolin, allowing it to settle naturally into the water/plasticizer mixture. Don't rush it! Once again, leave overnight to allow the clay to slake properly. (Helmer kaolin takes at least an extra day to slake).

Now mix the clay and plasticizer together thoroughly trying to avoid creating a vortex as you mix, which would pull air into your clay. I use a commercial Jiffler mixer, powered by a Dewalt 3/8 inch drill that will give up to 2500 rpm, and I have modified the shaft to a longer length so it will reach to the bottom of the barrel. Whatever brand of drill is used, try to buy one that gives the highest rpm possible, above 2000 rpm is good. Now add your non-plastic ingredients, the feldspar and silica, and again mix thoroughly. As a last step, I add the flocculant to the mixture. I use 0.4% calcium chloride, a chemical that does a wonderful job of flocculation of the clay body mixture. 0.4% equals 181.6 grams calcium chloride for each 100 pounds of dry mix. Always add the calcium chloride to a small amount of warm water and allow it to go into solution before adding it to the barrel. I always screen my clay, so I mix the slurry thin enough to drop easily through a 40-mesh screen. Now line the inside of your drying rack with cloth (I use heavy cotton ticking material) and pour in the clay body slurry even with the top of the frame. (Illustration #8) The excess water drips through the cotton, and water evaporates off the top, leaving superb throwing clay for your use.

If you're in the Denver area and don't want to bother with mixing your own clay or don't have time, there are some commercially mixed clay bodies from Mile Hi Ceramics in Denver that I have tested and can recommend. For stoneware clay bodies for cone 10 and 11 reduction, Mountain Stone, Huckleberry, Cedar, Biz Bod, Dover, and 4010 all have shown good to excellent workability, low shrinkage, acceptable absorption percentage, no warping, cracking, or slumping, good textural feel and fired color, and good glaze fit. At the present time, I use a Mile Hi porcelain known as P-60-S, a body of excellent white-fired color and glaze fit when fired to cone 10 in reduction.

At the present stage of this research, many questions about thermal shock resistance remain. According to Jim Robinson's article "Body Building For Potters," what is the relationship between excellence of glaze fit for a clay body and resistance to thermal shock? Are low-expansion bodies really more resistant to thermal shock than high-expansion bodies, and how resistant to various sorts of thermal shock does a clay body need to be? Time and testing will provide answers. I hope if you begin this journey, we can help each other along the way.

I would like to acknowledge, with a great debt of gratitude, the articles by Jim Robinson and Peter Sohngen, published in STUDIO POTTER. Thanks to Jonathan Kaplan, Ron Roy, Tim Frederich, Russ Fish of Old Hickory Clays, Michael Wendt of Idaho Clay and Glaze, and to the continued encouragement of Mel Jacobson. Special thanks to Gerry Williams of STUDIO POTTER for permission to reprint sections from the Robinson and Sohngen articles.

David Beumée
Earth Alchemy Pottery
806 East Baseline Road,
Lafayette, CO 80026
David Beumee hotpots@att.net
www.bouldercountyartists.com

David Beumée grew up in Billings and Red Lodge, MT, and completed his education in 1979 with a B.A. in Art from Montana State University, Bozeman, Montana. He moved to Lafayette, CO in 1983 where he continues to produce wheel-thrown porcelain as a sole means of support. He fires his porcelain to cone 10-11 in a reducing atmosphere.