Firing BRONZclay – An improved schedule

By Mardel Rein – Updated 1/5/09

Quick Start BRONZclay Firing
At the end of this article is our Quick Start BRONZclay Firing Guide to get you up and firing. If you want to know more about the technical aspects of firing BRONZclay, the rest of this article explores those areas in detail.

B**RONZclay Firing Schedules**
Inside each pouch of BRONZclay is an insert that contains 2 firing schedules. Which one you use is determined by the thickness of the item being fired. There is a "thin" firing schedule for a thickness of 6 cards (3mm) and less, and a "thick" firing schedule for clay thicker than 3mm.

The "thin" schedule seems to work well for most people, but takes 5 hours. I wanted to see if that time could be shortened. The "thick" schedule gave me some problems in sintering over 5mm in thickness. Some pieces only formed a thin shell of metal with powdered bronze in the core, and some came out brittle. I wanted to find out why those things happened and figure out a firing schedule that would work for every BRONZclay firing.

My firing schedules are based on some very simple observations. While experimenting with torch firing, I noticed that BRONZclay splits from the inside when heated too quickly. Another observation was that thin pieces, 3mm and less, didn't seem to be bothered by rapid heating. It was only when the thickness was more than 3mm that splitting occured. With those ideas in mind, I realized I could heat thin pieces at full ramp speed, saving 2 hours in the total firing time.

I have also found a way to determine the time required to sinter any given clay thickness by using a simple formula: Divide your kilns target temperature by the thickness of the clay and you get the rate of heat per hour. The firing duration is automatically set when you enter in the rate of heat. The duration is roughly equivalent in hours to the thickness of the clay in millimeters. For instance, an item 7 millimeters thick takes a little under 7 hours to fire from start to finish.

I have successfully sintered pieces up to 1 inch thick using this formula, and Bill Struve (inventor of BRONZclay) has successfully fired a 2 inch diameter solid sphere with my formula.

How to Calculate a BRONZclay Firing Schedule
Here are the factors that determine the firing schedule for a particular kiln, assuming you are firing in the standard 2-3/4" (short) firing pan or 4" (tall) firing pan:

- Kiln wattage and size determines target temperature & hold time
- Clay thickness determines heating rate
- Kiln type determines cooling method

Kiln Wattage & Size Determines Target Temperature and Hold Time
Look at the electrical data plate on your kiln and find the wattage, listed as WATTS. Your target temperature, if your kiln is an SC2 1440 Watt model, will be 1550F. For the SC2 1680 watt model, your target temperature would be 1490F.

Target Temperature & Hold Chart

Kiln Model	Wattage	Target Temperature	Hold Time	
			Short Pan	Tall Pan
E9AX	1100	1550F	0	2 hrs
Firefly	1680	1490F	0	2 hrs
Caldera	1680	1490F	0	2 hrs
SC2	1440	1550F	0	2 hrs
SC2	1680	1490F	0	2 hrs
E360	1500	1550F	0	2 hrs
E450	1800	1490F	2 hrs	2 hrs
SC3	1680	1550F	2 hrs	2 hrs
SC3	2000	1490F	2 hrs	2 hrs
Xpress E14A	3120	1490F	2 hrs	2 hrs
Home Artist	1800	1490F	2 hrs	2 hrs

Hold Times
Some firings require a hold time for proper sintering. Using a 4” tall pan will always require a hold time, regardless of the kiln wattage and size. Only the short pans can be fired without the hold time. Since it is always safe to add a 2 hour hold time to the end of a program to assure full sintering, if you have the time, it's a good idea.

If your kiln is not listed here, you can easily find your target temperature. Click here for instructions on finding your kilns target temperature.

Clay Thickness Determines Heating Rate
When programming a kiln for a firing, the rate of heat is set first. The rate of heat is how fast, in degrees per hour, the kiln heats to it's target temperature. For a BRONZclay firing, the rate of heat is determined by the thickness of the clay.

Use a millimeter gauge to measure the item to be fired at its thickest point, always rounding up to the next whole number. Divide that number by your kilns target temperature. The result will be the rate of heat per hour. It is not necessary to use a precision instrument for measuring. A simple plastic or brass gauge is sufficient.

I've calculated the rate of heat for firings up to 16mm thick in the chart below.

Heating Rate for a Given BRONZClay Thickness

Target Temperature	Thickness in Millimeters Heating Rate in Degrees Fahrenheit (per hour)															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1490F	Full Speed to target temp			372	298	248	212	186	165	149	135	124	114	106	99	93
1550F				387	310	258	221	193	172	155	140	129	119	110	103	96

To program the kiln for the 6mm thick BRONZclay firing, set the rate of heat to 248F per hour, the target temperature to 1550F and the hold time at 2 hours. With this program, the kiln will heat at a rate of 248 degrees Fahrenheit per hour until it reaches 1550F, then the program will hold this temperature for 2 hours. After the hold time, the kiln will signal completion and begin to cool. If your kiln has a small interior

and you are using the small firing pan, the hold time would not be necessary. (For simplicity, you could always add the 2 hour hold time to the end of a firing for good measure).

What is Thickness?
Keep in mind that width is not the same as thickness. For instance, if you roll out a slab that is 4mm thick, 20mm long and 15 millimeters wide, how long should it be fired? The answer is 4 hours. It might be 20 millimeters long, but it's only 4 millimeters thick. It might be 15 millimeters wide, but it's only 4 millimeters thick. We measure only the thickness to determine firing duration. If 2 strips, each 4mm thick are attached together with paste, the assembly would then measure 8 millimeters thick and would require the 8 hour firing schedule. Be certain to measure at the thickest part of your clay for complete sintering. For a firing that contains a variety of thicknesses, use the program for the thickest portion of the piece. Firing thin pieces longer will not hurt them.

Kiln type determines cooling method
The rate at which BRONZclay is cooled can affect the final product. If the metal is cooled too slowly, it can become brittle. If it is quenched in water when it is too hot, it can also become brittle.

Brick kilns can hold heat in long enough to cause brittleness in the metal when it's left to cool in the kiln. If you have a brick kiln, it is recommended that you crash cool the kiln. If you have a ceramic fiber kiln, the kiln can be left until it returns to room temperature or it can be crash cooled.

Crash Cooling
To cool your pieces quickly without inducing brittleness, follow this procedure after the firing program has completed: On a front loading kiln, open the door about an inch and wait until the temperature reads below 1000F before opening the door all the way for maximum cooling. At this point, the pan can be left to cool inside the kiln with the door open, or the pan can be removed and cooled on a trivet. Use a pan fork to remove the firing pan. Remove the lid and allow the pan to cool for about 15 or 20 minutes before digging up the treasure with a sifting spoon. The carbon is going to be very hot for several hours, so do not attempt to use your fingers. Obviously, you need to use extreme caution when working with hot kilns and firing pans, so be smart and take all precautions to stay safe.

To crash cool a top loading kiln, slide the kiln lid off to one side by 2 or 3 inches for the heat to escape. Allow the kiln to cool to 1000F, then remove the kiln lid completely and finish cooling the pan in the firing chamber.

Once the kiln has been crash-cooled, and the firing container lid removed, You can cool BRONZclay pieces rapidly by quenching in water if there are no stones embedded. I often remove BRONZclay pieces from the carbon when the metal is still too hot for my fingers. I use a slotted spoon to sift my pieces out of the carbon. As long as the bronze is not hot enough to burn paper, it is safe to quench in water to cool, however quenching BRONZclay at temperatures above 1000F may result in brittleness. Do not quench BRONZclay pieces with embedded cubic zirconia, lab or natural gemstones.

If you remove the pieces when they are more than 600F, the metal will oxidize instantly in the air. I've gotten some lovely antique finishes this way. You can also plunge the piece back into the hot carbon to change the patina. Use tongs of course!

Bronze Clay Firing Container Options
Stainless steel is a good choice for BRONZclay firing because it can withstand high heat without melting. Any stainless steel container that can hold a volume of activated carbon can be used to fire BRONZclay as long as it is marked “stainless steel”. Of all the containers I tried, the square stainless steel firing pans are the most convenient, roomy and easiest to deal with. Since most people are firing in these pans, the firing chart and temperatures given here apply to the 22 gauge stainless steel 4” high and 2.75” high square firing pans. We offer the firing pans in kits with activated carbon and other tools in our online store.

I’ve test fired in small stainless steel bowls of various sizes, tin containers, fused silica melting dishes, and stainless steel foil (not aluminum). All of these containers work, but the firing schedule have to be adjusted to accommodate the particular container used.

Avoid plated stainless steel. Some stainless steel is plated to make it more brilliant and shiny. If you use a plated container, you'll hear the snap and crackle of the plating popping off as the kiln heats and cools, making a big mess inside the kiln. I'm not sure if it's good or bad to have this burned plating mixed into the carbon, but my guess is it's not. If you use a container that flakes like crazy, vacuum your kiln, clean your carbon (instructions below) and find a container that isn't plated.

Do not fire in an aluminum container or in aluminum foil. Stainless steel foil is NOT the same as aluminum foil. Aluminum melts at about 1220F. The lowest temperature that BRONZclay is fired at is 1490F, so an aluminum container would melt during the firing. Using aluminum utensils to take your pans out of the kiln is just fine. In order for an aluminum tool to melt, it would have to be placed in the kiln long enough to reach the melting point. Just taking a firing pan in and out using an aluminum utensil is not a problem. It is also perfectly safe to use aluminum utensils to remove items from the firing pan itself. The first sifter I used to dig up my treasures was an old aluminum slotted spoon.

Activated Carbon Choices
BRONZclay is fired in activated carbon, the same stuff used in water filters. There are 2 kinds of activated carbon that can be used: coal and coconut. Firing in the coconut-derived carbon is supposed to give a clean bronze color to the metal, but I've almost always ended up with some coloration, and the coal-based carbon gives the metal a colorful, but somewhat unpredictable patina. The patina is the result of metallic impurities in the coal, and the specific colors are influenced by temperature.

While it seems easy to skip down to the store to buy some activated carbon, I do not recommend buying off-the-shelf carbon. It's important to know what type of activated carbon you are buying. Some carbons are acid washed as part of the activation process. Acid-washed coal carbon is okay, but acid-washed coconut carbon is unsafe because when heated, toxic fumes are released. Resist the temptation to buy generic activated carbon because there is no guarantee what type of carbon it is. We offer the firing pans in kits with activated carbon and other tools in our online store.

Activated carbon is made by slow heating a fuel in an oxygen-free environment. To make carbon from coal, coal is heated to high temperatures and all but the carbon is burned out of the coal, leaving pure carbon. To make carbon from coconut, coconut shells are heated in the same manner. To "activate" the carbon, it is exposed to oxygen or gasses and sometimes chemicals, depending on the characteristics desired.

Carbon is the 4th most abundant element in the universe by mass. Every living thing has carbon as one of its building blocks

Kiln Location
Locate your kiln where it can be observed frequently, and where children and animals cannot get to it. There should be no shelves or cabinets above the kiln, and the back of the kiln should be no closer than 6" to a wall. Choose a place where you'll have plenty of space for tools and cooling tiles. A tabletop or portion of a counter can be covered with ceramic tiles to protect from burns. A wood workbench makes a sturdy firing station, and a wood cutting board with an iron trivet set on top makes an excellent cooling rack for kiln shelves and firing pans. Enameled surfaces are another very good surface for a kiln, and many people have discovered that the top of their dryers offer prime kiln real estate. The top of a dryer doesn't leave a lot of room for tools, though, and you'll probably find yourself wanting to spread out to the washer as well.

Your firing station should include a pair of heavy leather gloves, a pan fork, and a sifting spoon to remove items from the carbon. Keep a bucket and a mesh sifter on hand. You'll use it to sift the carbon for small parts and for occasionally cleaning the ash that will accumulate in the carbon.

If your firing station is inside a room with carpeting, put a safety mat in front of the station in case of accidents. Keep a fire extinguisher at the ready for emergencies.

Loading the Firing Container
It is recommended that the clay is placed on a 1" thick bed of activated carbon, and then covered over with additional carbon, filling the container to the top. I don't find it necessary to fill the container to the top with carbon, and I believe packing the container may lead to firing failures. I leave at least ½" of air space between the level of the carbon and the top of the pan.

Pieces can be located at the bottom of the pan, but there must be some carbon between the bottom of the container and the BRONZclay. Pieces fired at the bottom often come out with a solid pale yellow, gold or green patina. This may have to do with either the temperature or the carbon dioxide that pools at the bottom of the container. Whatever the reason, it's a beautiful patina.

Situate the pieces in the carbon to work with gravity. The carbon makes a good firing support for many items, but some pieces can deform or slump from the downward force of gravity during firing. Counteract gravity by placing domed items face down in the carbon. Position hollow shapes vertically in the pan. Look at the piece and imagine gravity pressing down on it. Situate the piece in the pan in such a way that it has the most strength against gravity.

If I have just a few pieces to fire, I usually push or wriggle the pieces into the carbon bed. At first I worried that I might scratch pieces by just thrusting them into the carbon, but they seem to hold up just fine. For delicate pieces, I dig a little hole and place the piece in gently, making sure it is fully supported from below before covering it over with carbon. I have also found that I can just place my pieces on the surface and shake the container. The pieces then sink into the carbon like they are in quicksand.

Multiple pieces can be fired at once. For larger loads, it's easiest to pack the container in layers and pour carbon over each layer so you know exactly where each piece is and you don't accidentally allow pieces to touch and fuse together.

Pieces that are touching during firing may fuse together. If you do not want pieces to fuse, do not allow them to touch during firing. In firing pieces that are interlocking, such as chain links, small pieces of fiber paper can be used to separate the parts during firing.

The position of your clay pieces in the firing pan can make a difference in the outcome of your work. If you have a front-loading kiln, there are no heating elements in the door. That means the front of the kiln is going to be cooler than the sides and the back. In firing experiments, identical pieces were placed inside a firing pan and their positions noted. A piece positioned at the cooler front of the kiln did not shrink as much as one located in the hotter back of the kiln. Both pieces were very strong and could not be bent by hand, but they did not sinter equally due to the cooler temperature in the front of the kiln. Keep this in mind if you need all your pieces to sinter equally and locate them strategically. In a front-loading kiln, there are no elements in the door, the floor or the roof. A top-loading kiln has heating elements all the way around the chamber. If you are using a top-loading kiln, you can distribute your pieces evenly in the firing pan, noting that your cool spots will be at the bottom of the pan.

Activated carbon particles can get into nooks and crannies and inhibit shrinkage or leave marks. A small bit of fiber blanket can be used to plug an area that you do not want filled with carbon, such as a bail.

Witness Strips
Make and keep handy small strips of dried bronze clay about ¼" wide by 3" long and in typical thicknesses used in your work. Include a witness strip in the same thickness as the thickest piece in your BRONZclay firing. The witness strip will serve as your "done-ness indicator".

After firing, try to break the fired witness strip with using two pairs of pliers for pieces 5mm thick and less, or for thicker pieces, hammer the heck out of it and see if you can break it. I use an old ball peen hammer to test my thick pieces. I place the strip on a steel bench block and whack the living daylights out of it. If

the BRONZclay is fully sintered, it will distort but not break. If it breaks easily, something went wrong. The problem can be determined by what the broken piece looks like. Be sure to view my article on troubleshooting to determine the problem and find the solution.

I have recently discovered that I can write on BRONZclay and the writing actually survives the firing. Pencil, ink pen, india ink, and felt pen all survive the firing. The writing can be polished off, but for making notes for firing, it's good to know that you can write directly on the unfired clay and it will not burn off. This is also a great technique for identifying who's is who's when firing for a classroom.

Placement in the Kiln
The firing pan should be centered in the kiln as much as possible. Do not allow the thermocouple to touch the firing pan as it can cause incorrect temperature readings and result in over or under-firing. It's best to elevate the firing pan on kiln posts, even if they are only ½" tall. This allows the heated air to circulate around the container during firing and provides a more even temperature to the container.

In a brick kiln, there are single elements in a groove several inches apart. Boost your firing pan up on kiln posts to have the center of it aligned with one of these elements if you have a brick kiln. In the Caldera, I use ½" kiln posts and center the container as much as possible. In the E9A-X I place the pan directly on the kiln floor, centered left and right and about ½" from the thermocouple to the back.

In a ceramic fiber (muffle) kiln, the elements are embedded in the wall and run back and forth on the sides. In an SC2, I set my firing pan, whether it's tall or short, on 1" kiln posts, and center it left and right, pulled as much to the front as possible.

Gemstones & Inclusions
Natural and lab created gemstones and most cubic zirconia can be embedded directly in BRONZclay and fired in place. Check out our Gemstones in Metal Clay firing guide to see which stones can be fired in BRONZclay. Testing has shown that any stone that can be fired in silver clay can survive a BRONZclay firing for longer times and at higher temperatures than in silver clay.

Tanzanite cubic zirconia is a heat sensitive stone. It's so sensitive in fact that it can only be heated to 1110F for a maximum of 10 minutes before it starts to darken. But I fired this stone for 9 hours in 2 separate firings for a total of 18 hours in the kiln at 1550F in activated carbon. After each firing the color was as brilliant as an unfired control sample. So, it's oxygen that causes the problem in heating this type of stone, not the actual heat itself.

I've also tested several other heat sensitive stones and they have also survived better in the carbon than in an open air firing. Diamonds are a stone that do not survive in a silver clay firing, but can survive when buried in activated carbon.

Natural gemstones must be louped to be sure they are safe to fire. If you can see little cracks or spots in a stone with your naked eye, the stone probably is not safe to fire. The pressure imposed on an embedded gemstone stone by sintering metal (which shrinks about 25%), can be enough to shatter an already fractured stone. Examine each gem with a 10-power jewelers' loupe. If you see cracks or little particles inside the stone, firing it may be a gamble. At the very least, leave some space around the stone for the clay to shrink so there is not so much pressure on it.

- Most glass cannot be co-fired with BRONZclay. The firings are too long and too hot, however according to one glass artist borosilicate glass can be fired in place. I have not tested this claim.
- Sterling silver and fine silver cannot be co-fired with the BRONZclay. The metals will attempt to alloy (mix) with each other in an unattractive way.
- Precious metal clay cannot be co-fired with BRONZclay. These two clays can be combined, but not during the sintering phase of BRONZclay
- Copper, Brass and Bronze can be embedded in the clay and co-fired

Shrinkage
Overall shrinkage is probably about 25%, but that's not 25% in every direction necessarily. Strangely enough, closed circles don't seem to shrink much. I formed a ring at size 9-1/2. After firing the ring still measured 9-1/2. Another ring shrank from an 8 to a 7-1/2. The same thing happened with 2 cuff bracelets which did not shrink in overall width, but substantially in length and thickness. Other items shrank from 16% to 20% in various dimensions. In general, thinner pieces shrink more in length and width than thick pieces.

Where an item is located in the firing container can have an impact on the total shrinkage of the item. Items located near heating elements shrink more than those in other parts because they get hotter sooner than those in the center of the container. Activated carbon is a poor conductor of heat, so pieces in the inside of the container will reach temperature about 30 minutes later than those near the outside edges

Refiring BRONZclay
BRONZclay can be re-fired. I have fired some pieces several times by accident because I lost them in the carbon and found them only when I sifted the carbon to clean out the dust. Once an item has been fired, additional firings do not harm the metal.

Attaching fired BRONZclay
If you have fired pieces that you'd like to combine, they can be pasted together and fired. First clean the items to be attached very well. Give them a rough satin finish in the areas to be attached. Make lavender paste to "glue" the sintered bronze pieces together. Make a very thick paste, but instead of mixing it with lavender water use straight

Mix the paste to the consistency of soft peanut butter (a tiny bit softer than normal paste). Use a dropper as a dipper to pick up the oil a drop at at time. I have cocktail straws I cut short to form bails which work great as pipettes for picking up a drop of oil or water. Add a drop at a time to the clay and mix with a palette knife. Attach parts with the paste and dry at 90F for 24 hours. Fire at the 3-Hour Schedule. If you add unfired components to pre-fire bronze, scratch brush the bronze and attach the component with lavender oil paste. Allow to dry at 90F for 24 hours. Use the firing schedule for the unfired components thickness.

Tip: We ship our Lavender Essential Oil with a plastic cap and include a glass and rubber dropper. Keep the original cap and reserve the dropper for use as needed. Do not store the dropper on the bottle. The lavender oil is very strong and will break down the rubber over time, ruining the dropper

Kiln Maintenance
Whether you have a brick or muffle kiln, be prepared to step up maintenance when you fire BRONZclay. Oxides will build up on the outside of your firing pan. These oxides will flake off and accumulate at the bottom of the kiln. Vacuum the inside of your kiln regularly to keep it clean. Wipe the thermocouple with a damp rag or sponge whenever you vacuum to keep your kiln in top shape. A thermocouple will not read as accurately as it ages (an older thermocouple will fire hotter than it reads), so test fire your kiln every 75 firings using cones to verify the accuracy of the firings.

Sign up for our mailing list if you'd like us to keep you posted on the latest information on working with BRONZclay. We send email only when there is something really pertinent to your interests, so you can safely subscribe. Be sure to read the other articles on BRONZclay.

Quick Start BRONZclay Firing Guide

1. Find your Target Temperature

Find your kiln model from the chart below. Check the electrical data plate on your kiln and match it to your model. Circle your target temperature. This is the target temperature you will always use to fire BRONZclay in your kiln. Circle the hold time needed for your firing pan size. (It's okay to use a 2 hour hold time on all firings).

Target Temperature & Hold Chart

Kiln Model	Wattage	Target Temperature	Hold Time	
			Short Pan	Tall Pan
E9AX	1100	1550F	0	2 hrs
Firefly	1680	1490F	0	2 hrs
Caldera	1680	1490F	0	2 hrs
SC2	1440	1550F	0	2 hrs
SC2	1680	1490F	0	2 hrs
E360	1500	1550F	0	2 hrs
E450	1800	1490F	2 hrs	2 hrs
SC3	1680	1550F	2 hrs	2 hrs
SC3	2000	1490F	2 hrs	2 hrs
Xpress E14A	3120	1490F	2 hrs	2 hrs
Home Artist	1800	1490F	2 hrs	2 hrs

2. Measure your clay

Measure the thickest place on your BRONZclay using a millimeter gauge, rounding up to the next whole number. Find the rate of heating that corresponds to your thickness and target temperature.

Heating Rate for a Given BRONZClay Thickness

Target Temperature	Thickness in Millimeters Heating Rate in Degrees Fahrenheit (per hour)															
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1490F	Full Speed to target temp			372	298	248	212	186	165	149	135	124	114	106	99	93
1550F				387	310	258	221	193	172	155	140	129	119	110	103	96

3. Program your kiln

Program your kiln to heat at the rate found in the chart above for your thickness.
Set the target temperature to your kilns target temperature.
Set the hold time.

4. Load the firing pan

Bury your pieces in the activated carbon.
Load into the kiln.
Start the program.

5. After Firing

The kiln can be left to cool to room temperature or the pan can be removed hot.
To remove the hot pan, crash cool the kiln to 1000F, then remove the firing pan to a trivet and remove the lid.
Allow the container to sit at least 30 minutes.
Sift out the treasures using a sifting spoon.
Finish as desired.