MetalClay Australasia Pty Ltd

PO Box 63
Kippax
ACT 2615
Tele 02 62597237
Mobile 0402 912 961
Facsimile 02 61616214
metalclay@plaspress.com.au
www.metalclay.com.au

ABN 47 116 747 776

Appointed Australasian Distributor Makin's Clay, BRONZclay™
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BRONZclay – Drying and Firing Bronze Clay - An Improved Schedule

With appreciation and grateful thanks to Mardel Rein for generously sharing these results with the Metal Clay Community.

BRONZclay - Drying Bronze Clay
by Mardel Rein - Updated 27/10/08

Drying is a very important part of working with BRONZclay, and how it is done can make a big difference in the fired product.

Bill Struve of Metal Adventures, Inc (inventor of BRONZclay) tells me that the binder he uses in the clay stiffens when its warmed and softens when cooled. That explains why cracks appear in thick pieces (3mm or more) that have been dried on a heat source. The outside begins to harden as it warms (because the binder stiffens from the heat) but the inside is still cool. The difference in temperature and moisture creates internal stress, and cracks are the result.

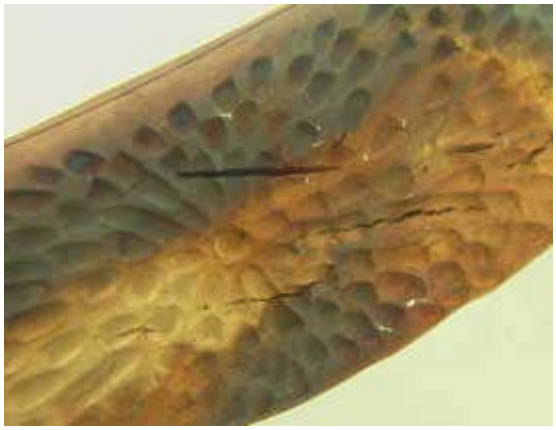
Sometimes stress cracks cannot be seen with the naked eye. In the photo below, a 6mm slab of clay was air dried for 1 hour, then moved to a cup warmer at a very low temperature. After drying I observed that hairline cracks had formed on the surface. The cracks were so fine I could not see them

Sample of a heat dried piece. Very fine stress cracks developed during drying. The sample was chip carved to see if it had any affect on the opening of the cracks during sintering.

The internal stress of uneven drying also causes warping of the item being dried. Thin pieces are more susceptible to warping, but all BRONZclay pieces can warp when dried un-evenly.

Drying Options
The metal clay drying paradigm tells me to add heat to drive off the moisture. More and more I am learning that with BRONZclay I don't want heat at all. I want cold. So, I've been experimenting with different ways of drying the clay and I've made some very exciting discoveries.

All along BRONZclay has been telling me it doesn't like heat. It gets stiff when it warms and softer when it's cooled. So, as I was standing in my kitchen with my head in the freezer thinking about how cold contracts and heat expands, it dawned on me. Cold air dries just as well as warm. So, now I am using cold to dry, store, and work with BRONZclay. I have found that chillng the clay allows me more working time, a better consistency to the clay, less cracking and a better surface finish. I am currently still experimenting with this idea, and hopefully other will try my methods and push them further.



The hairline cracks observed before firing have opened up during sintering. Chip carving the surface had no effect in deterring the cracks.

No-Dry Method
BRONZclay can be fired at any stage of wetness. I can take a piece of clay directly from the package, totally wet, drop it in the activated carbon and fire it. As long as the schedule is correct for the thickness and the kiln being used, the clay will sinter beautifully.

Freezer/Refrigerator Drying
Refrigerators and freezers are cold, dry places....perfect for drying BRONZclay. Place items to be dried on a project card and place in the refrigerator or freezer to dry. Turn after about 5 minutes, then turn again after another 5 minutes. Drying time is dependent upon the thickness. Up to 3mm pieces will dry in the freezer overnight or within a few hours in the refrigerator.

Be sure to read the section on Cold Forming BRONZclay. This is another exciting development in chilling, forming and working with BRONZclay.

Other Drying Options
Here are some other methods for drying BRONZclay. Any combination of these methods can be used to accomplish the task at hand. As you become more adept at working with BRONZclay, you will know when to apply heat, when to use cold, etc.

The 3 rods at the right were fired completely wet. The slab on the left was frozen before firing.

Air Dry: Place pieces on a project card and set aside to dry. Turn regularly for faster, more even drying and to minimize distortion. Drying can be accelerated by placing in a warm location with good air circulation (27C is ideal). The warm top of a refrigerator makes a good spot to dry BRONZclay. Drying time is completely dependent on humidity and temperature conditions. If you are in a warm, dry climate, drying will be faster than what we experience in the Midwest. That also means that you'll be rehydrating more often as well.

Food/Cup/Candle Warmer/Electric Frying Pan: BRONZclay drying can be speeded by gently warming the clay on a heat source. Notice the word "gently" in the previous sentence. The temperature of your heat source is very important with BRONZclay. If the temperature is too high, pieces distort. Thin pieces heated too quickly can end up looking like a potato chip.

To avoid distortion, dry slowly and turn every minute or so for the first few minutes to allow for even evaporation of the moisture throughout the clay.

There are many types of **warming surfaces,** but the most popular for metal clay in the USA is the cup or candle warmer. For the studio artist, these inexpensive warmers dry metal clay quickly and efficiently. BRONZclay should not be placed directly on the heating surface. Direct heat can cause distortion and cracks because the initial drying temperature is too high. The surface temperature of the small warmers that I have measured varied between 140F to 200F. Those temperatures, as low as they sound, are high enough to cause quite a bit of distortion in the BRONZclay during drying, and crack thicker pieces.

I've recycled worn-out 6mm thick Cordierite kiln shelves as heat-reducers for my cup warmer. I broke one shelf into 25mm square pieces and used those as risers for a large kiln shelf to sit on. Elevating the shelf cools the air between the warmer and the shelf. Add additional layers to lower the temperature further. A stack of 3 would work well as a temperature regulator. Corrugated plastic also works as does cardboard and foam core. Whatever you use as a heat reducer on your cup/candle warmer/Electric frying pan test it first to be sure it won't warp.

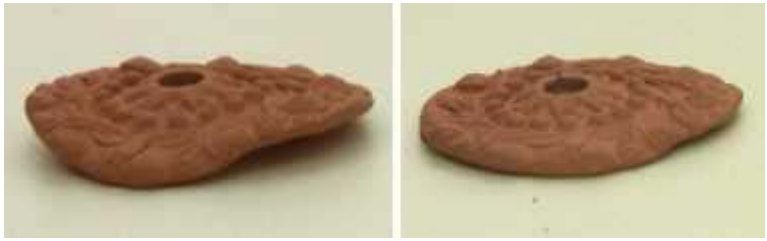
Dehydrator: A food dehydrator is an efficient way to dry BRONZclay and has given me excellent results with large pieces. Do not rush drying. Drying too fast will cause cracks that will not heal during firing. BRONZclay will dry most thoroughly and evenly when placed directly on the drying racks. If drying on project cards, turn the pieces after about 5 minutes for even drying.

Example of a heat dried piece that developed stress cracks. The photo shows the sample after firing. Before firing, the sample had only hairline cracks barely visible on the surface

Cold Forming & Distortion Repair
I have found a way to reform dry BRONZclay pieces. Since cold relaxes the binder and makes it more flexible, and heat stiffens it, I used these two characteristics to force warped clay back into the shape I want it to be.

To form dried BRONZclay, first chill the piece to make it flexible, reform it, then heat rapidly to set new the shape.

The sample shown in the photo below is the same piece before and after cold forming. The sample on the left was dried on a cup warmer and ended up looking like a potato chip. To reform it, I placed it in the freezer for about 10 minutes. Removed the item from the freezer and immediately placed it on a cup warmer, put a car-polishing pad on top of that and a then added a steel bench block on for even pressure. I pressed it flat as quickly as it hit the heated surface and held it there until for about 30 seconds. I then turned off the cup warmer and allowed the piece to cool with the weight in place. The polishing pad protects the surface of the clay and helps to spread the weight of whatever you are using to flatten your piece so you don't break it.



The sample above left was dried on a cup warmer. The photo at the right shows the same piece after cold forming.

The weight is not actually necessary. I used it so I could get even pressure on the piece and so I didn't have to stand there and wait for it to set. I have reformed links using just the heat of my fingers, but it's much faster and more reliable to use a warmer to get the shape to hold. It will want to spring back to it's old shape if you do not get it hot enough after forming.

If you don't get all the movement you want on the first round, re-chill and go at it again.

Crack Repair
If you see hairline cracks in your BRONZclay before you fire it, you will see hairline (or larger) cracks after you fire it. Before the clay is fired, you can fill the cracks with lump clay, and in some cases you can burnish out the crack. BRONZclay can be burnished before firing if the surface lends itself to burnishing. After the clay is fired, it is possible to burnish out some hairline cracks. Some designs will be impossible to repair, so the best course of action is to allow the clay to dry very slowly and avoid cracks. Alternatively, to explore the idea of cracking, you might want to deliberately dry a piece very fast to allow cracks to form. The cracks could be inlaid or stones could be set in the spaces

Firing Bronze Clay - An Improved Schedule

Changed to suit Australian conditions – original text by Mardel Rein - Updated 03/11/08

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 for most people, but takes 5 hours. I wanted to see if that 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. Some pieces 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. I would like to share the results of these tests with you.

The firing schedules I am suggesting in this article have been tested in the following kilns: Paragon SC2 (1440 watt model), Paragon SC2 (1680 watt model), Paragon E9A-/x and Caldera digital kilns, and an Evenheat Sierra E360 kiln*. (*Evenheat tested by Bill Struve of Metal Adventures, Inc).

Firing BRONZclay

My 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 a fast heating. It was only when the thickness was more than 3mm that the splitting became an issue. With those two 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: Divide the target temperature by the thickness of the clay to get the rate of heat per hour. The length of time of firing is automatically set when you enter in the rate of heat. The time will end up being approximately equal in hours to the thickness of the clay in millimetres. For instance, a piece 7mm thick takes a little under 7 hours. I have fired thicknesses up to 24mm thick using this formula. Bill Struve has successfully fired a 50mm diameter solid sphere with my formula. I sawed chunks from my pieces to determine complete sintering. Bill saws his pieces in half with a band saw.

I was hoping to find a shorter firing schedule for all BRONZclay firings, but it looks like thick pieces are just going to take time. The good news is: if your pieces are thin, your firing time will be fairly short.

Filling the Firing Pan

I leave at least 14mm of airspace at the top of my firing container. I believe that filling the container to the top may be the cause of what appears to be random sintering failures, and that it may have to do with the amount of oxygen needed for combustion of the binder in the clay.

My thinking goes like this: if there are more pieces, there is more binder to combust. Combustion requires oxygen. If there is a huge load of clay, then there is a lot of binder that needs to be combusted. If the pan is packed with carbon and green ware pieces and the lid is on tight, what happens when the oxygen is used up inside the container? My idea is that combustion of the binder does not happen completely when oxygen is short.

So, if you think about it, it would happen like this…..the container is totally packed. The BRONZclay pieces on the outside are getting hot first because they are closer to the elements. Pieces on the sides of the container reach combustion temperature before the pieces in the centre. The pieces on the outside use up whatever oxygen they need for complete combustion, and then the centre of the container gets hot enough and if there is still enough oxygen to combust, those pieces combust. So it makes total sense to me that the pieces on the inside would not sinter while those on the outside do.

More evidence: How do you make carbon? Burn a fuel in an oxygen deprived environment, The slow burning creates carbon (or charcoal). So, if there is not enough oxygen, and if all the conditions are right, the result can be that the binder burns to carbon and the result is a brittle piece that is often pure black or near black.

BRONZclay Firing Schedules
The firing schedule for BRONZclay is determined by these factors:

* Clay thickness determines firing duration
* Kiln wattage determines target temperature
* Kiln type determines cooling method

Clay Thickness - 1 Hour per Millimetre
To find the length of time needed to sinter BRONZclay, measure the piece at its thickest point in millimetres. That number is about how long it will take to sinter the clay all the way through. If the piece to be fired is hollow, the thickness of the clay used to create the hollow piece should be measured, not the size of the hollow piece itself. All firing schedules are based on the thickness of the clay measured in millimetres.

For a thickness of 3mm and less, use the 3-Hour Firing Schedule
For a thickness over 3mm, calculate the firing

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 15mm wide, how long should it be fired? The answer is 4 hours. It might be 20mm long, but it's only 4mm thick. It might be 15mm wide, but it's only 4mm 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 8mm 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.

Kiln Wattage Determines Temperature
Look at the electrical data plate on your kiln and find the wattage, listed as WATTS. Your target temperature, if your kiln is 1440 Watts, will be 843C. For 1500+ watt kilns, your target temperature is 810C.

Kiln Wattage	Target Temperature
1100-1490	843C
1500-2000	810C
2000+	untested

Please note that these schedules have been tested on the following kilns: Paragon SC2 1440 Watt, SC2 1680 Watt, E9A-X 1110 Watt, E360 kiln. Larger interior kilns may need temperature adjustment.

BRONZclay Heating Chart
To calculate the rate of heating, divide your target temperature by the thickness of the clay in millimetres. The result will be the rate of heat per hour in degrees Centigrade. Or, use the chart below to find the rate of heat for your clay thickness and kiln wattage.

BRONZclay Heating Chart

To calculate the rate of heating, divide your target temperature by the thickness of the clay in millimetres. The result will be the rate of heat per hour in degrees Centigrade. Or, use the chart below to find the rate of heat for your clay thickness and kiln wattage.

Target Temperature	Thickness in Millimetres Heating Rate in Degrees Centigrade (per hour)														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
810C	Use the 3-Hour Firing Schedule			189	148	120	100	86	74	65	57	51	46	41	37	34
843C				197	154	126	105	89	78	68	60	54	48	43	39	36

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Let's find the rate of heating for a 6mm thick object fired in a Paragon SC2 1440 watt kiln. Since the wattage is 1440, the target temperature is 843C. The thickness is 6mm, so divide 843C by 6 and you get 141. So the rate of heat is 141C per hour.

To program the kiln for the 6mm thick BRONZclay firing, set the rate of heat to 141C per hour, the target temperature to 843C and the hold time to 0. That is not a typo. The hold time is zero. With this program, the kiln will heat at a rate of 141 degrees Centigrade per hour until it reaches 843C, then the program will end and the kiln will begin to cool. A 6-millimeter firing takes a little under 6 hours.

3-Hour Firing Schedule
The 3-hour program is for pieces 3mm or thinner. Program the kiln to heat at full speed to your target temperature. Hold the target temperature for 2 hours. Then cool.

To fire an object whose thickness is 3.5mm, use the 4 hour heating rate. Measurements should be rounded up to the next whole number when calculating the heating rate.

Cooling Theories
It is well known in bronze casting that cooling too quickly or, oddly enough, too slowly can result in brittleness. Experiments are ongoing, but test firings with a long, slow cooling have resulted in a brittle product, as did test firings that were cooled extremely fast. Identical firings with a controlled cooling were not brittle. My idea, based on bronze-casting wisdom, is that BRONZclay should be cooled in a controlled manner to avoid brittleness. This idea may prove to be incorrect, but it might be one of the reasons some pieces come out of the kiln brittle. There may be other factors that should be accounted for, too. The thickness might need to be considered in cooling. Maybe none of it makes any difference. The thing is, the clay is so sensitive going up in temperature; it makes sense that it would be just as cranky going back down. Based on this information, and my cooling experiments, I now treat cooling as a part of the firing process.

Cooling
Ceramic fibre kilns cool very quickly, and I have not had much problem with leaving firings to cool in a ceramic fibre (muffle) kiln. Brick kilns cool more slowly than ceramic fibre kilns. Kilns with exposed bricks cool faster than those enclosed in a case. Every kiln will cool at a different rate, and opening the door or removing the pan to cool outside the kiln will have a huge affect on how fast the metal inside the pan cools. Ideally, the metal should cool rapidly to 538C, then more slowly to room temperature. This cooling process is called crash cooling.

On a front loading kiln, open the door about an inch and wait until the temperature reads below 538C 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. 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 a long time, so do not attempt to use your fingers. Obviously, you need to use extreme caution when working with hot kilns and firing pans. 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 538C, then remove the kiln lid completely and finish cooling the pan in the firing chamber.

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 316C, 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
From my observations, every detail is important when firing BRONZclay. The firing temperature and rate of heat must be adjusted for the kiln, the firing container, and the thickness of the clay. While test firing BRONZclay, I experimented with several different firing containers.

Stainless steel is a good choice because it can withstand high heat and is very inexpensive and easy to find. 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". Don't worry that your container turns black and burnt looking once it's been fired. This is normal.

Avoid plated stainless steel. The plating will pop off in a million little shards, contaminating your carbon and 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. It's definitely not good to have oxidized metal inside the kiln. You'll hear the snap and crackle of the plating popping off as the kiln heats and cools. If you use a container that flakes like crazy, just vacuum your kiln and find one that isn't plated.

Tins and other steel containers can be used, but you must be sure it's not made of aluminium. Aluminium melts at about 660C. In addition to the square firing pans, I've test fired in small stainless steel bowls in various sizes, tin containers, fused silica melting dishes, and stainless steel foil. All of these containers work, but the firing would have to be adjusted to accommodate the container used. The heat of the kiln will get through foil much more quickly than the thicker firing pans. Use my firing schedules as a starting point and you'll most likely have to slow the rate of heat or lower the temperature.

When firing in a small stainless steel mixing bowl, I used a hard ceramic kiln shelf as a lid. I've fired without a lid at all, but that eats up a lot of carbon.

I used stainless steel foil to make a little pouch to fire test pieces. The pouch was a little hard to make while there were delicate goods inside. I next folded the foil into a small square pan, filled it with activated carbon and put a foil top on that and fired test pieces at the 3-Hour schedule. I did not test anything thicker than 3mm in the stainless steel foil, so I don't know what rate of heating should be used. Start by firing 3mm using the 3-Hour schedule and adjust as needed.

NOT ALUMINIUM FOIL I do not use aluminium foil. I don't want anyone to get this wrong. You cannot use aluminium foil in the kiln. Aluminium melts at about 660C, and aluminium alloys melt at even lower temperatures. We fire to 810C at the least with BRONZclay, so please do not make the mistake of putting aluminium in your kiln. Using aluminium utensils to take your pans out of the kiln is just fine. You have to dwell at that temperature for the metal to melt.....like chocolate. It is also perfectly safe to use aluminium utensils to remove items from the firing pan.

Of all the containers I tried, the square stainless steel firing pans ended up being 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 square firing pans. We offer the firing pans with activated carbon and other tools here.

Activated Carbon

BRONZclay is fired in activated carbon, the same stuff used in a water filter. Firing in the coconut-derived carbon available in Australia gives the metal a colourful, but somewhat unpredictable patina. The patina is the result of metallic impurities in the coal, and I believe the specific colours are influenced by temperature.

There is one more detail about carbon types in addition to the coconut derived carbon, some carbons are acid-washed. 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 activated carbon from a pet store because there is no guarantee what type of carbon it is. We offer the firing pans, activated carbon and other tools here.

Activated carbon is made by slow heating a fuel in an oxygen-free environment. To make carbon from coconut, coconut shells are heated to high temperatures and all but the carbon is burned out of the coconut, leaving pure carbon. 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 & Setup

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 155mm to a wall. Choose a place where you'll have plenty of space for tools and cooling tiles. A table top 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. Enamelled 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.

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 25mm thick bed of activated carbon, and then covered over with additional carbon, filling the container 14mm from 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 14mm 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 to do with either the temperature, or the carbon dioxide that pools at the bottom of the container. Whatever the reason, it’s a durable and 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.

I usually push or wriggle the pieces into the carbon bed, and cover with carbon if there is just a handful. 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. At first I worried that I might scratch pieces by just thrusting them into the carbon, but they seem to hold up just fine. I regularly plunge my dry pieces into the pan with my fingers. The carbon is very loose and fluffy. Multiple pieces can be fired at once. It's easiest to pack the container in layers and pour carbon over them so you know exactly where each piece is and you don't accidentally allow pieces to touch and fuse together. If you fire a full container, you may need to increase your kilns temperature to account for the greater volume.

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 fibre 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 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 in thickness 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 fibre blanket can be used to plug an area that you do not want filled with carbon.

Witness Strips

Make and keep handy small strips of dried bronze clay about 3mm wide by 50mm long and in typical thicknesses used in your work. Include a witness strip in the same thickness as the thickest piece in your pan of BRONZclay firings. The witness strip will serve as your "done-ness indicator". Try to break the fired witness strip with two pairs of pliers. If the bronze is fully sintered, you should not be able to break it, only bend it. If it breaks easily, something went wrong. The problem can be determined by what the fired piece looks like, and I'll have a separate article up dealing with troubleshooting soon. However, for now I can say I eliminated brittle firings when I started leaving some air space in the container.

Placement in the Kiln
The firing pan should be centred 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.

In a brick kiln, there are single elements in a groove several inches apart. Boost your firing pan up to have the centre of it aligned with one of these elements if you have a brick kiln. In the Caldera, I use 12mm kiln posts and centre the container as much as possible. In the E9A-X I place the pan directly on the kiln floor, centred left and right and about 12mm from the thermocouple to the back.

In a ceramic fibre (muffle) kiln, the elements are embedded in the wall and run back and forth on the sides and back wall. In an SC2, I set my firing pan, whether it's tall or short, on 12mm kiln posts, and centre it left and right, pulled as much to the front as possible.

Gemstones & Inclusions
Many 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 silver clay. Testing has shown that any stone that can be fired in silver clay can survive a BRONZclay firing as well....if not better.

I have fired a very heat sensitive tanzanite CZ twice for 9 hour each time and the colour is as brilliant as an unfired control sample. I have also fired a natural peridot for 6 hours and it also survived beautifully. It’s the oxygen that was the problem in the kiln with silver clay. Incidentally, I’ve tried firing silver clay in the carbon (and sterling silver with metal clay). It can be done if you fire it twice. For silver clay only, first fire to 900C, hold for 2 hours and cool. Then fire again, fast ramp to your target temperature and hold for 3 hours. So far in tests, sterling silver has alloyed with the fine silver during sintering, but may not do so at lower temperatures. This will have to be tested.

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 jewellers' 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.

* Glass **cannot** be co-fired with BRONZclay. The firings are too long and too hot.
* 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
How much does BRONZclay shrink? From what I have seen, it depends on its shape, thickness, placement in the kiln, and the firing schedule used. 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. These were not closed circles. They both came out having shrunk 0% in width. Both pieces were tested to assure complete sintering. Other items shrank from 16 to 20% in various directions. I think the clay is like anything else, it will take the easiest way out so it shrinks first in the thinnest places and last in the thickest or the place that’s the hardest to move.

To test shrinkage, I measure length, width, thickness and weight before firing. I also note the position in the container, what container was used, the kiln used, firing schedule, etc.

Pieces positioned nearer to the heating elements shrink more in thickness than those in other parts because they get hotter. Activated carbon is a poor conductor of heat, so pieces on the inside of the container will never get as hot as those on the outside. What’s interesting is that the length and width were the same on my test pieces regardless of where they were located in the firing pan, but those on the sides adjacent to a heating element shrank more in thickness only.

Carbon can hold a lot of heat, but it’s not a good conductor of heat. It takes about 30 minutes for the inside of the container to equal the outside of the container in temperature.

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. They were much thinner than identical pieces fired only once, but their width and lengths were the same.

Make lavender paste to “glue” sintered bronze pieces together. Make a very thick paste, but instead of mixing it with lavender water use straight lavender essential oil. 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 time. I have cocktail straws I cut short to form bails and that works great as a pipette for picking up a drop of oil or water. Add a drop at a time to the clay and mix with a palette knife. To use, abrade the surfaces to be joined. 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 oil paste. Allow to dry at 90F for 24 hours. Use the firing schedule for the unfired components thickness.

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.