



Hadar Jacobson

Art in Metal Clay

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Instruction Manual for Hadar's Clay™



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Instruction Manual for Hadar's Clay™

Storage and Shelf Life of the Clay

The powder clay does not require special storage. As long as it has not been mixed with water, it has an indefinite shelf life. Mixed clay should be refrigerated, wrapped with plastic food wrap inside a closed plastic box. It has been shown to last at least a few months when properly kept. If you don't intend to use the clay for a long period of time, it's best to freeze it.

The shelf life of **unfired** pieces is very long. There is no need to fire them right away.

Toxicity

None of the ingredients of Hadar's Clay™ is toxic. It may be unhealthy to inhale any powder of any kind. Use a protective mask and goggles when handling the powder, as well as when handling carbon.

Mixing Instructions

Also available as a video clip at www.youtube.com/artinsilver – select the video entitled “Hadar's Clay™ – Mixing.”

What you need:

- ☐ Small metal bowl or soup bowl
- ☐ Kitchen knife or any other mixing tool
- ☐ Distilled or filtered water in a spray bottle
- ☐ Olive oil in a spray bottle

Mixing the clay (just like cookie dough)

1. Shake the metal clay powder container.
2. Pour the desired amount of powder into the bowl.
3. Spray small amounts of water into the powder and mix with the knife. The powder will gradually form into crumbs.
4. Keep spraying and mixing until the crumbs separate from the walls of the bowl. Don't over-wet! If you accidentally over-wet, add more powder. When the crumbs have consolidated into one mass, oil your palms and knead it a little. Rolling the clay as shown in the video is optional but not necessary.

Consistency of the Clay

The mixed clay is soft, pliable, does not crack when bent, and sticks well to itself.

The photo on the right shows how readily the clay drapes without cracking when mixed to the right consistency.



Lubrication

The clay does not stick to the hands. As a release agent from texture plates use olive oil only (not from a spray can!). Other lubricants may contain ingredients that could react with the clay and damage its consistency.

Drying

Dry pieces directly on a heating pan at 220-250°F (95-120°C). Flat pieces of Traditional (Flex) clay powder and all types of steel tend to warp while drying, even when dried in the air. Once they start warping, keep flipping them over until they stay flat. This takes only a couple of minutes. Quick-fire copper, bronze, Brilliant Bronze, Rose Bronze, and White Bronze don't usually warp as much while drying, but flipping them is recommended.

If warping does occur with thin pieces, cool them in the refrigerator. They will become somewhat flexible. Gently flatten them down. You can also spray them with water and once they are soft, flatten them; then wrap them with a paper towel and leave them under a heavy book overnight.

Reconstituting

You can reconstitute solid pieces that have not been fired. Always use distilled or filtered water to reconstitute clay. It can be reconstituted by grinding the dry piece in a dedicated coffee grinder and repeating the mixing process as described above. It is not recommended to reconstitute clay powder that is derived from sanding and filing.

If the clay dries, roll it with a rolling pin into a thin layer, spray it with water, fold it a few times and roll it again to work the moisture in. Repeat until you are satisfied with the consistency.

Flexibility and Strength of Dried Clay

The surface of dried clay lends itself to carving, and is best sanded with 150-grit sandpaper or a fine-grit sponge sanding pad (do not use medium grit!). Cooling the dried clay in the refrigerator for 5 minutes will make it more flexible.

Traditional (Flex) clays and steel clays are a little tougher to carve and sand.

Shrinkage

The shrinkage of each clay depends on the firing schedule. At low-fire schedule, White Bronze shrinks by 10%. At mid-fire schedule, copper and Rose Bronze shrink by 10%, bronze and Bronze XT shrink by 15%, and Brilliant Bronze shrinks by 23.5%. At high-fire schedule, copper, Rose Bronze, Bronze XT and Low Shrinkage Steel XT shrink by 28%. See the document entitled "Shrinkage Chart for Hadar's Clay™, linked on the right-hand panel of my blog.

Firing with Core Material

It is possible to fire with core material – including cork clay. When firing the first phase (pre-firing), it is important to make sure that the core material has burnt off.

Some core materials, such as pasta and cardboard, will not burn off inside carbon, even with 2 hours' hold at the first phase.

Flexible (Traditional/Flex) Clay

Mixing Traditional (Flex) copper, bronze, Brilliant Bronze, Rose Bronze, and Pearl Grey Steel XT clay with glycerin makes clay that stay flexible after it has been dried. Flexible clay allows you to weave, fold, and knot with dried clay.

See instructions for making and using flexible clay in my book: *The Handbook of Metal Clay: Textures and Forms*, 2nd edition. To see a demo video clip, go to youtube.com/artinsilver, select the Videos tab, and click on the video entitled *Hadar's Clay™ - Mixing Instructions*.

Shrinkage: Flex copper, bronze, Brilliant Bronze and Rose Bronze, 25% at mid-fire schedule, Pearl Grey Steel XT, 28% at high-fire schedule.



Tip: Let the flexible sheet or wires dry in the air and store them in the refrigerator.

Repair

After firing, pieces can be repaired and re-fired. Unlike silver clay, base metal clays **cannot** be repaired with a torch. Repairing with small amounts of fresh clay does not require pre-firing and can be done in 1 hour.

Firing with Activated Carbon

Precious metals such as pure silver and gold can be fired in the air. They don't react with the oxygen under high temperature, and the oxygen ensures complete removal of the binder.

Base metal clays such as copper, bronze, Brilliant Bronze, White Bronze, Rose Bronze, Bronze XT, and steels do react with oxygen under high temperature to create oxides, which prevent proper sintering (the final bonding of the particles together). To help prevent this, they should be fired buried in activated carbon, which reduces the amount of oxygen in the kiln and inhibits this reaction. However, most organic binders used in metal clays need oxygen in order to burn off. If there is not enough oxygen (because it has been reduced by the carbon), the binder will not burn off and proper sintering will not be achieved. This problem can be solved by using a proper firing schedule.

For an extended discussion of the firing process see my article **Understanding Metal Clay and the Firing Process** on p. 26.

The Carbon

Use coconut shell-based carbon, acid-washed, size 12x40.

Important note: The same type of carbon may differ from one manufacturer to another. If sintering is not achieved using the firing schedules suggested below, try carbon with the same specifications from a different manufacturer.

Good carbon for sintering purposes does not produce a lot of ash and does not stay hot a long time after firing.

The Firing Box

The carbon is best contained in a round stainless steel mixing bowl, a pet dish or a silica crucible. Round vessels circulate the heat better than square ones.



Stainless Steel Mixing Bowl, Pet Dish, and Silica Crucible

The advantages of the mixing bowl and pet dish is that the circular shape allows for better distribution of heat. However, they oxidize and flake and cover the kiln floor with black dust (often mistaken for carbon). You can line the floor of the kiln with or a lava cloth (available from glass fusing suppliers) and vacuum the kiln after firing. Silica crucibles are resistant, do not suffer from thermal shock like ceramics, and do not flake.

The Firing Set-up

1. Line the inside of the box with a ½" layer of carbon.
2. Arrange your pieces on the carbon horizontally, in one layer only. (Hollow forms are better fired vertically to avoid slumping).
3. Place the box on the four 2" posts. Make sure there is space for air flow between the top of the box and the top of the kiln chamber.
4. Do not use a lid. The carbon will stay contained in the box. If there is black dust inside the kiln chamber after firing, it is because the metal container has oxidized and flaked.
5. Use a 2-phase firing schedule: phase 1 (pre-firing) and phase 2 (see below "Pre-firing").



6. After the second phase, some of the carbon will have turned into ash. To discard the ash after the first phase of firing, blow it away with a straw or a mini-fan.
7. To discard the ash after the second phase of firing, pour the content of the box, from high above, through a large-hole sieve into a metal container (a large mixing bowl) placed on a heatproof surface. Be sure to wear a mask. Most of the ash will blow in the air. The fired pieces will stay in the sieve and the leftover carbon can be re-used.



Test Firing

Each kiln fires a little differently, even kilns that are identical in model and age. There is no single firing schedule that will apply to all kilns. Whatever kiln you have, you need to do some test firing before firing actual pieces. By doing this simple test, you will make your kiln work for you.

Testing the kiln for mid-fire schedule:

Make a few pieces, as many as you would normally fit in your kiln. The pieces should be made from both Quick-fire copper and bronze (regular or Brilliant, not Bronze XT), non-textured. Here is how to make them:

- Roll a layer of copper clay at least 6 cards thick. Place a little ball of bronze on the layer.
- remove the cards, and roll the ball flush with the copper layer.



Make a few pieces with copper as the base and a few with bronze as the base.

Dry the pieces, and fire according to the following schedule:

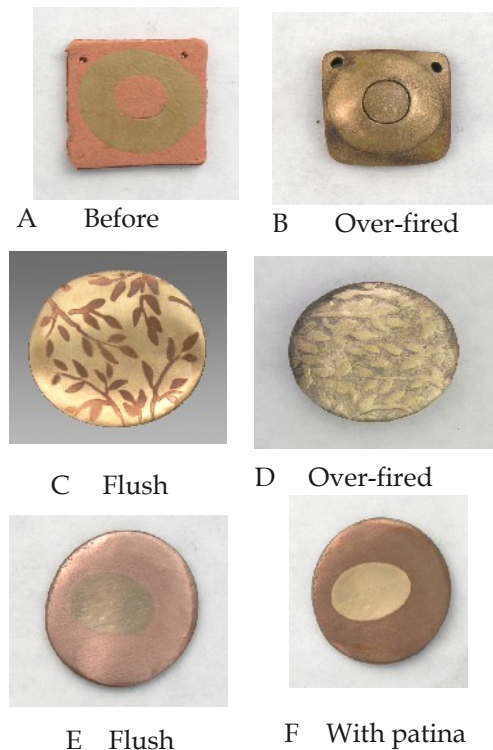


<p>Phase 1 (Pre-firing)</p> <p>Pre-fire on a stove top (see instruction below), or inside the kiln as described below. In both cases the pieces should be laid on a layer of carbon but not covered with carbon.</p>	<p>Phase 2</p> <p>Ramp at 1800°F/1000°C to:</p> <p>1460°F/793°C (brick kiln)</p> <p>1510°F/821°C (muffle kiln)</p> <p>Hold for 2 hours.</p>
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Check the results for over-firing or under-firing:

Over-firing

If the mixed pieces are curled, or a relief shows on pieces that were flush before firing, or the copper part has disappeared (photos B and D), the temperature was too high. Make new test pieces, and in the second phase fire them at a temperature lowered by 10°F/5°C. If you get a similar result, make new test pieces and lower the temperature by another 10°F/5°C. Repeat until the fired copper and bronze are flush as they were before firing. Photos C and E show the desired result (“married metals”). Photo F shows the same piece after patina was applied to highlight the contrast between the married metals.



Under-firing

Sand the copper part of the piece with 220-grit sandpaper. If the piece is fully sintered, the surface will look more metallic as you keep sanding. If you keep sanding and the copper becomes more pitted and dark (photo G) instead of becoming shiny metallic (photo H),



then it was under-fired. Make new test pieces and fire again at a temperature that is 10°F/5°C higher.

Note: it is important to fire new test pieces at a higher temperature. If you fire the same pieces, they may sinter only because you fired them twice. (Re-firing is actually a good way of repairing under-fired pieces.)

Testing the kiln for low-fire schedule

Fire test pieces of White Bronze at 1250°F/676°C (brick), 1325°F/718°C (muffle). No pre-firing is required. If there is no sintering, raise the temperature by 10°F/5°C at a time. If the pieces melt, lower the temperature by 10°F/5°C at a time. Perform each test with a new test piece.

Testing the kiln for high-fire schedule

Pre-fire a piece of Bronze XT. In the second phase, fire the piece at 1700°F/927°C (brick) 1780°F/971°C (muffle). If it blisters, lower the temperature by 10°F/5°C at a time.

Pre-firing (Phase 1)

Perform the first phase of firing on a stove top (propane camping stove or a kitchen stove). To see a demo video clip, go to [youtube.com/artinsilver](https://www.youtube.com/artinsilver), select the Videos tab, and click on the video entitled *Shortening the Firing Time for Base Metal Clay*.

Pour a 1" layer of carbon into a stainless steel bowl. Place your pieces on top of it without covering them in carbon. Put the bowl on the stove.



If you pre-fire outdoors, cover the bowl to keep the heat in. You can use a fiber board, the SpeedFire Metal Clay PreFire Cone from www.metalclaysupply.com, or Fiber Firing Container from www.pmcconnection.com.

Drill a pencil-size hole in the fiber board and the fiber container. To do this you can use a screwdriver. Just twist it in; the fiber is very soft.

Turn the flame on to full capacity. After a few minutes you will smell and see the smoke coming out of the holes in the lids. This is the binder burning. It is important that the binder burns slowly, without catching fire, or pieces will crack. If pieces catch fire, lower the flame. If you are not sure there is smoke, you can lift the lid with a glove or tweezers and look inside.



After the smoke stop, remove the lid with a glove and peek inside. The pieces should look black.

Pour more carbon into the bowl to cover the pieces and put them in the kiln for the **second phase** of firing. The whole process takes about 2:30 from beginning to end.

Note: at high altitude the stove-top firing may last longer. In general, there is no harm in firing on a stove top for up to 40 minutes.

All clays can be pre-fired on a stove top except for White Bronze. Clays that require pre-firing are quick-fire bronze, Brilliant Bronze, Bronze XT, Rose Bronze, and copper.

After pre-firing you can move on directly to phase 2. However, there is no need to hurry. The second phase can wait.

Pre-firing can also be done in a kiln, with the piece resting on carbon but not covered by it. Ramp at full speed to 1000°F/538°C (brick kiln) or 1100°F/593°C (muffle kiln). A few minutes after the kiln has reached the temperature, check the pieces. When they are all black and the smoke is gone, proceed to phase 2. For full binder burnout this process may take longer than pre-firing on a stove top.

Firing Schedules

The following firing schedules apply to two popular types of kilns, both 8"x8"x6":

Brick kiln (top and front loader), and front-loader muffle kiln. Use them as a starting point for testing your kilns.

These firing schedules have been shown to work with all currently existing brands of base metal clay.

Mid-Fire Schedule

**Traditional (Flex) Bronze; Brilliant Bronze; Quick-fire Bronze;
Combination of Quick-fire Copper, Bronze or Brilliant Bronze, and
small amount of Quick-fire Steels**

Phase 1

Pre-fire on a stove top or in the kiln at
1000°F/538°C (brick kiln) or
1100°F/593°C (muffle kiln) with pieces
not covered with carbon.



Phase 2

Ramp at full speed to:
1460°F/793°C (brick kiln)
1510°F/821°C (muffle kiln)
Hold for 2 hours.

High-fire Schedule

**Copper; Bronze XT; Rose Bronze; Steels, Combination of Bronze XT,
Copper, and Large Amounts of Steels**

Phase 1

Pre-fire on a stove top or in the kiln at
1000°F/538°C (brick kiln) or
1100°F/593°C (muffle kiln) with
pieces not covered with carbon.



Phase 2

Ramp at full speed to:
1700°F/927°C (brick kiln)
1780°F/971°C (muffle kiln)

Hold for 2:00 hours.

Copper and Rose Bronze
can be also fired on their
own at mid-fire schedule.
However, they will not be
as strong, and will not
reach their maximal
shrinkage.



Low Shrinkage Steel XT on its own does not require pre-firing; neither does Low Shrinkage Steel XT combined with low amounts of copper and Bronze XT.

Low-fire Schedule

White Bronze on its Own and Combined with Other Clays

Ramp at full speed to:

1250°F/677°C (brick kiln)
1325°F/718°C (muffle kiln)

Note: This is one-phase firing.
No pre-firing is required!

Hold for 2:00 hours. Optional: 1:30 hours
for less than 100 grams.

White Bronze has a narrow sintering range. It can quickly go from not sintering at all to melting or deforming. Therefore, **it is necessary to make test pieces before you begin firing actual pieces!** Use low-fire schedule as your starting point.

Post-firing

To delay tarnish and corrosion it is recommended to soak all types of fired clay in oil (preferably baby oil or scented oil) for an hour or so. Due to the porosity of the clay, pieces will hold the oil inside them and defy humidity.

Pieces can also be coated with long-lasting lacquer (such as Permalac) or wax. No form of sealing is permanent.

Copper and Bronzes

To highlight the contrast between copper and bronze in mixed, non-textured pieces, sand the pieces smooth, apply Baldwin's Patina, and rinse with warm water. See the video clip on YouTube (go to [youtube.com](https://www.youtube.com), click on the Videos tab, and select the clip entitled *Baldwin's Patina on Metal Clay*) and my books: *Mixed Metal Jewelry from Metal Clay*, and *Patterns of Color in Metal Clay*.



Baldwin's Patina is not meant to add color but to highlight the contrast between the married metals.

Brilliant bronzed can be polished to look like shiny gold. See the file “Finishing Fired Metal Clay,” linked on the right-hand panel of my blog.



Steels

All types of steel clays have a pearl gray, silvery color after firing. They are very strong when used on their own. Pearl Grey Steel XT and Quick-fire Steel XT shrink 28% by volume. Pearl Grey Steel shrinks less and is preferred for gradient surfaces. It is not recommended to fire it on its own. Low-Shrinkage Steel XT shrinks about 10% and is the only steel recommended to use as the main, structural part of a piece. It is malleable and can be hammered into shape after firing. Other steels can be used in combination with other metals or as accents.

All are magnetic!



Coloring Steel

There are many ways to blue steel and a continuing debate as to which way is best. Suggested here are two processes for bluing. If performed prior to sealing, both contribute to the sealing quality.

Cold Bluing

Blue color can be achieved by applying a little bit of Birchwood Casey Super Blue. After bluing, sealing should be done with or wax as described above.

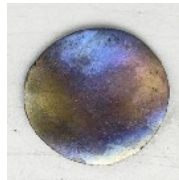


Hot Bluing (also called tempering)

Heat the piece with a torch. When the desired color appears, immediately dip in cold water. Repeat a few times until you reach the desired color. Polish by rubbing the piece with steel wool.



This rock was held by the wire and heated gradually with a torch until it turned dark blue. After quenching it looked like hematite.



Baldwin's Patina will darken steels when mixed with other metals in one piece. It will not darken them if they are fired in combination with Bronze XT.

The earring on the right was fired with Quick-fire bronze. The earring on the left was fired with Bronze XT.



To prevent steel from rusting, it is recommended to Seal it with a water resistant acrylic sealer such as PYM II.

White Bronze

White Bronze is a copper alloy powder which, after firing, yields a metal with a color very similar to that of silver. It is not to be confused with nickel silver (also known as German silver or alpaca). It contains no nickel.

Fully sintered pieces are hard, strong, and easy to sand. However, they are not flexible. **Do not try to bend them with pliers or to hammer them, or they will break!** Be sure to do all your fabrication before firing. White Bronze is most

suitable for combining with other metals in one piece. Thin pieces are brittle, but thick pieces of White Bronze and pieces from combinations of White Bronze are not.

White Bronze does not tarnish as readily as silver. It also reacts well to liver of sulfur and other patinas. It does not react to Baldwin's Patina, which makes it possible to highlight the contrast between White Bronze, copper, and steels in mixed pieces.



Firing Different Metals in one Piece

When different metals are fired in one piece, the firing schedule is determined by the lowest firing clay in the mix: any mix containing White Bronze has to be fired at the low-fire schedule; any mix containing bronze (not XT) and no White Bronze, has to be fired at the mid-fire schedule. Any mix of high-fire clays can be fired a high-firing schedule. For further details, please see my presentation *Introduction to Mixed Metal Clay*, which can be downloaded from the right-hand pane of my blog at hadarjacobson.com/blog.

A mix of copper, bronze, and steel that uses Quick-fire Bronze or Brilliant Bronze has to be fired at mid-fire schedule and allows only small amounts of steel to be included.

A mix of copper, bronze, and steel that uses Quick-fire Bronze XT can be fired at high-fire schedule and allows large amounts of steel to be included.

The following compatibility chart shows different possible mixes together with their firing schedules.

Compatibility Chart

Part 1. Which metal clays can be fired together in the same piece, in one firing, and at what schedule?

All clays are compatible with each other and will bond to each other if fired in one piece.

1. Traditional (Flex) copper and bronze or Brilliant Bronze
Mid-fire schedule



2. Quick-fire copper and bronze or Brilliant Bronze
Mid-fire schedule



3. Quick-fire copper and steels
High-fire schedule

The bronze color in the photo on the far right is a result of alloying between the steel and copper at the contact point.



4. Rose Bronze and Steels
Mid-fire schedule



Although both clays can be fired at the high-fire schedule, a better contrast is achieved at a lower temperature

5. Quick-fire Bronze or Brilliant Bronze and Steel
Mid-fire schedule



6. Quick-fire Copper, bronze or Brilliant Bronze, and steels
Mid-fire schedule



7. Quick fire Copper, steels, and Bronze
XT
High-fire schedule



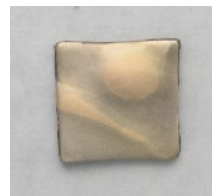
Bladwin's Patina will not blacken steel when Bronze *XT* is used in combination of copper and steel or just steel.



8. Bronze *XT* and Quick-fire Steel *XT*
High-fire schedule



9. Bronze or Brilliant Bronze and White Bronze
Low-fire schedule



10. Copper and White Bronze
Low-fire schedule
(may require repeating the second phase of firing for full sintering of the copper part)

The bronze color is created by the reaction between copper and White Bronze.



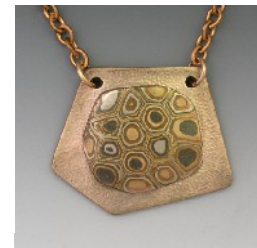
11. Copper, bronze or Brilliant bronze and White Bronze
Low-fire schedule
(may require repeating the second phase of firing for full sintering of the copper part)



12. White Bronze and Pearl Grey Steel
Low-fire Schedule
(may require repeating the second phase of firing for full sintering of the steel part)



13. Quick-fire copper, bronze, or Brilliant Bronze, White Bronze, and steels
Low-fire schedule
(may require repeating the second phase of firing for full sintering of the copper part*)



14. Low-shrinkage Steel XT, Bronze XT and copper
high-fire schedule with no pre-firing

15. Quick-fire Copper and low-shrinkage silver clay
Low-fire Schedule



* For canes, gradients, mokume-gane and striped designs as in the examples above, see my book: *Patterns of Color in Metal Clay: Canes, Gradients, Mokume-Gane*.

**Part 2. Which metal clays can be fired together in the same piece,
in more than one firing, and at what schedule?**

1. Fire copper first (High-fire Schedule) and add silver by torch-firing. Silver does not stick to copper, so a mechanical connection is required.*



2. Fire copper first (High-fire Schedule) and add White Bronze in the second firing (Low-fire schedule). White Bronze sticks to copper, so no mechanical connection is required. This type of inlay will not work with silver since the silver will shrink and fall out, while the White Bronze will stick to the copper.



3. Fire copper and bronze or Brilliant Bronze first (Mid-fire schedule) and add White Bronze in the second firing (Low-fire schedule). This will not work with silver – both because silver does not stick to copper and because of the reaction between silver and bronze.



4. Fire steel first (High-fire schedule) and add silver (torch), or bronze (mid-fire schedule), or White Bronze (low-fire schedule) at second firing.



5. Fire steel and copper first (high-fire schedule), and add bronze or Brilliant Bronze (mid-fire schedule), or White Bronze (low-fire schedule) at second firing.



* For mechanical connections see my book:
Mixed Metal Jewelry from Metal Clay.

How to Talk to Your Kiln

Programming Your Kiln

With 2-phase firing schedule

Phase I

On the control panel, press the left button until you reach a program that is not pre-set. If the kiln is not pre-set, press the “up” button until you reach PrO1 (Program 1). On pre-set kilns it may be program 6.



Press the left button again. The kiln will say: “Idle.”
Translation: “I am doing nothing. Tell me what to do.”



Press the left button again.

Translation: You are telling your kiln “Start asking.”

The kiln says:

“rA 1” (ramp 1).

Translation: “How quickly would you like me to reach the desired temperature the first time around?”

(1 means the first time around)



Your answer is “Full speed,” which means “Ramp up as quickly as you can.” (In most kilns this means 1800°F/1000°C per hour.) Press the up and down arrows until the display says “Full.”

Note: 1800°F/1000°C per hour is only the rate (“speed”) at which the temperature will rise. The kiln is not actually going to reach this temperature.



In some kilns, the speed is determined by time, not by temperature. For those kilns, ask the kiln to ramp in 1:00 hour.

Press the left button again.

Translation: You ask "What's your next question?"

The kiln says: "°F 1."

Translation: "What temperature would you like me to reach the first time around?"

Using the up and down arrows answer: "1000 (538°C)."

In a muffle kiln answer: 1100 (593°C).

In a very small kiln answer "1000 (538°C)."

Press the left button again.

The kiln asks: "HLd1" (hold 1).

Translation: "How long should I *hold* (stay) at that temperature?"

Your answer: "30 minutes" to "2:00 hours". (To say this, press the up and down arrows until the display reads 00:30 or 2:00, or anything in between).

Press the left button again.

Now the kiln asks: "rA 2" (ramp 2).

Translation: "How quickly would you like me to get to the desired temperature the second time around?"

(2 means the second time around).



Your answer is: "0 "

Translation: "I don't want a second time around."

If the kiln keeps asking questions keep pressing 0 until the kiln says "Strt" (Start).

Press the left button again. The kiln will say: "On."

Phase II

Press the "up" arrow to PrO2 (Program 2). If your kiln is pre-set, you will have to use program 6 again. Just press the left button, and change only the temperature and time as noted below.

As before, prompt the kiln for the next question by pressing the left button after each of your answers.

Kiln: "Ramp 1"?

You: "Full speed."

Kiln: "°F 1"?

You: "1460°F (793°C)."

In a muffle kiln the answer is 1510°F (821°C).

Kiln: Hold 1?

You: "2 hours."

If the kiln asks "Ramp 2" answer "0".
Press the left button until it says "On."



Checklist

Question	Correct Answer
<input type="checkbox"/> Did I shake the jar before mixing the clay?	Yes
<input type="checkbox"/> Did I use distilled water when mixing the clay?	Yes
<input type="checkbox"/> Did I use any lubricant other than olive oil?	No
<input type="checkbox"/> Did I use core material or glycerin?	If you did, hold 2:00 hours when firing phase 1 in kiln
<input type="checkbox"/> Does the thermocouple stick into the chamber?	Yes
<input type="checkbox"/> Is the thermocouple older than 3 years? Could it be rusty?	No
<input type="checkbox"/> Did I use a box other than a stainless steel mixing bowl?	Adjustment of the temp. may be required
<input type="checkbox"/> Did I use a square box?	Don't fire pieces in the middle of the kiln; in a front loader, avoid the front as well.
<input type="checkbox"/> Did I elevate the box to the top of the kiln?	Yes
<input type="checkbox"/> Did I use a lid?	No
<input type="checkbox"/> Did I leave enough space around the box for heat flow?	Yes
<input type="checkbox"/> Did I leave the venting hole open in the first phase?	Yes
<input type="checkbox"/> Did I overcrowd the box?	Longer hold time may be required
<input type="checkbox"/> Did I cool the kiln and the box after the 1 st phase?	Yes
<input type="checkbox"/> Was there silver in the box?	No
<input type="checkbox"/> Did I mix different brands of copper and bronze clay?	No
<input type="checkbox"/> Did I fire test pieces before firing actual pieces?	Yes
<input type="checkbox"/> Did I confuse bronze with White Bronze?	No
<input type="checkbox"/> Did I confuse bronze with Bronze XT?	No
<input type="checkbox"/> Did I start with a cold kiln after doing phase 1 in a kiln?	Yes
<input type="checkbox"/> Was the carbon on fire at the end of the first phase?	No
<input type="checkbox"/> Was there a lot of ash in the box at the end of each phase?	No
<input type="checkbox"/> Did the carbon and/or kiln stay hot long after firing?	No

Understanding Metal Clay and the Firing Process

When I started this blog, I predicted that within a year many brands of metal clay would be available. This has become true, and it seems to create a lot of confusion – different instructions, different firing schedules, etc. Different teachers use different brands and may not be fully aware of how to handle other brands.

To help clear up this confusion, I thought it might be best not necessarily to clarify the differences between the brands, but to establish what they have in common. Perhaps understanding the process of sintering metal powder will help individual users to find their own optimal firing schedule.

I am by no means a scientist, and all I am about to say is based on a lot of reading and experimentation. Reading material about the theory of sintering is not necessarily helpful, since practice rarely goes hand in hand with theory. However, things that I have read gave me ideas about what may be worth trying, and through trial and error I arrived at a certain level of understanding. That is what I have to share.

Sintering means the bonding of the loose metal particles together well below their melting point. The term sintering applies not only to metal powder but also to ceramics.

A metaphor that may be helpful in understanding the sintering process is ice cubes. Ice melts at 32°F/0°C. The temperature in the freezer is far below that. What happens if we raise this temperature without reaching the melting point? The ice cubes will start sticking to each other until we are able to pick them up as one solid unit. However, since they don't touch each other at every point of their surface, there are spaces between them and this whole mass is porous. If the metal is brought above its melting point it becomes liquid which flows and fills the pores.

The sintering process consists of 2 main phases:

1. Removal of the binder
2. Densification of the particles

Removal of the Binder

The role of the binder is to give the metal powder the consistency of clay, so we can shape it or press it into molds. For the clay to turn into pure metal, the binder needs to be removed completely before the sintering process begins. If it is not completely removed, whatever is left of it prevents the metal particles from adhering to each other.

If the binder is completely removed, it does not matter what type it is. The type may affect the working condition of the clay, but not the sintering results.

Densification

Once the binder is removed, the particles are allowed to get closer and closer. As the temperature rises, their contact areas grow, but since they don't reach their melting point and turn into liquid, they cannot flow and entirely fill the spaces between them.

Back in 2008, I posted a link on my blog to a video clip about powder metallurgy. From my blog, enter **Powder Metallurgy** in the search box, click **Go**, and then click on the title of the article appearing in the Search Results column. About halfway through the clip, you can see a good illustration of densification.

Also see my blog entry entitled "The Sintering Bracelet Project," originally posted on April 28, 2010. (From my blog, enter **The Sintering Bracelet Project** in the search box, click **Go**, and then click on the title of the article appearing in the Search Results column.)

And: *Introduction to Mixed Metal Clay* (Presentation), accessible from the right-hand pane of my blog.

What needs to happen in order for us to have successful firing?

Precious metals such as pure silver and gold are fired exposed to air. They don't react with the oxygen in the air, and the oxygen ensures the complete removal of the binder.

Base metal clays such as copper, bronze, and steel, when fired exposed to air, react with oxygen to create oxides, a third material which, like the residue of the binder, prevent the particles from bonding. Pure copper can be fired exposed to air for a very short time before it oxidizes internally. However, longer or repeated exposure to heat and air will enhance the oxidation and eventually the copper will disintegrate. This is true not only for copper clay but also for solid copper, such as plumbing parts and sheets.

Bronzes and steels cannot be fired exposed to air. If they are, a large chunk of them will come off, taking with it the texture and details.

Therefore, base metals are fired buried in activated carbon, which reduces the amount of oxygen in the kiln and inhibits this reaction. Gold granulation is done this way, since it involves the use of copper. The carbon creates a "reducing atmosphere"; when heated, carbon monoxide fumes are generated, which bond

with the oxygen present in the kiln. Carbon monoxide fumes can be also generated by burning gas such as propane or natural gas.

However, most organic binders used in metal clays need oxygen in order to burn off. If there is not enough oxygen (because it has been reduced by the carbon), the binder will not burn off completely. If the binder is not completely removed, there will be no proper sintering.

So in a way, the activated carbon is both a blessing and a curse. On the one hand it enables sintering; on the other it interferes with the removal of the binder. In industry, vacuum or gases are used to create a reducing atmosphere.

It is therefore recommended to burn off the binder outside the carbon. The easiest way to do this is on a stove top. The pieces to be fired are laid on a layer of carbon inside a round steel bowl, so they can easily be transferred to the kiln after the binder burns off. It is important that they don't catch fire or they may crack. When there is no more smoke and the pieces turn black, they are covered with another layer of carbon and carefully moved to a kiln for sintering.

The process may last between 10 to 40 minutes. No internal oxidation occurs during that period, and the thin outer layer of oxide can be easily removed after sintering.

If you choose to burn the binder inside carbon, it is important to burn it *before* the carbon catches fire.

From my experience, the binder burns at around 1000°F/538°C in a brick kiln or 1100°F/593°C in a muffle kiln. (I refer to the most popular kilns, that are about 8"x 8"x 6".) At this temperature the carbon does not burn yet. Some brands of clay have more binder in them than others and may need to stay at this temperature longer in order for the binder to burn off completely.

No matter which brand of clay you use, it is always a good idea to hold at this temperature about 2:00 hours before going on to the goal temperature. Then the firing should be stopped. Let the pieces cool down to room temperature, then ramp to the sintering temperature.

To make sure the carbon is not on fire in the first phase, open the kiln at the end of the cycle. If the carbon is on fire, lower the temperature next time.

See the section about firing high- and low-firing clays together in one piece in my presentation *Introduction to Mixed Metal Clay*, which can be downloaded from the right-hand pane of my blog at hadarjacobson.com/blog.

Firing Schedules – Quick Reference Table

<p style="text-align: center;">Mid-Fire Schedule</p> <p style="text-align: center;">Traditional (Flex); Quick-fire Bronze; Brilliant Bronze; Combinations of Quick- fire copper, bronze or Brilliant Bronze, and small amount of steels</p> <p>Phase 1</p> <p>Pre-fire on stove top or in the kiln at 1000°F/538°C (brick kiln) or 1100°F/593°C (muffle kiln) with pieces resting on carbon but not covered by it.</p> <p>Phase 2</p> <p>Ramp at full speed to:</p> <div style="display: flex; align-items: center;"> <div style="margin-right: 10px;"> 1460°F/793°C (brick) 1510°F/821°C (muffle) </div> <div style="border: 1px solid black; padding: 5px; font-size: 0.8em;"> The second phase of this schedule applies to silver clay as well. </div> </div> <p>Hold for 2:00 hours.</p>	<p style="text-align: center;">High-Fire Schedule</p> <p style="text-align: center;">Copper; Rose Bronze; Steels; Bronze XT</p> <p>Phase 1</p> <p>Pre-fire on stove top or in the kiln at 1000°F/538°C (brick kiln) or 1100°F/593°C (muffle kiln) with pieces resting on carbon but not covered by it.</p> <p>Phase 2</p> <p>Ramp at full speed to:</p> <p>1700°F/927°C (brick) 1780°F/971°C muffle)</p> <p>Hold for 2:00 hours.</p>
<p style="text-align: center;">High-Fire Schedule</p> <p style="text-align: center;">Low-Shrinkage Steel XT; Low-Shrinkage Steel XT combined with low amounts of copper and Bronze XT</p> <p>No pre-firing required.</p> <p>Ramp full speed to:</p> <p>1700°F/927°C (brick) 1780°F/971°C muffle)</p> <p>Hold for 2:00 hours.</p>	<p style="text-align: center;">Low-Fire Schedule</p> <p style="text-align: center;">White Bronze on its own, and combined with other clays</p> <p>No pre-firing required.</p> <p>Ramp at full speed to:</p> <p>1250°F/676°C (brick) 1325°F/718°C (muffle)</p> <p>Hold for 2:00 hours. Less than 100 grams cab be held 1:30 hours.</p>

Smart Bronze Firing Schedule

Brick kiln: Ramp at 1400°F/778°C per hour to 1440°F/782°C. Hold 2 hours.
Muffle kiln: Ramp at 1400°F/778°C per hour to 1495°F/810°C. Hold 2 hours.