Understanding Metal Clay and the Firing Process

When I started my 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.

Here is a link to a short video clip that I linked a while ago on my blog. About halfway through the clip, you can see a good illustration of densification.

www.hadarjacobson.com/blog/2009/03/08/powder-metallurgy/

Also see: "The Sintering Bracelet Project": www.hadarjacobson.com/blog/2010/04/28/the-sintering-bracelet-project/

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 and bronze, 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 pipes and sheets.

Bronze, White Bronze, Rose Bronze, 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" by burning; while burning, it consumes the oxygen present in the kiln chamber.

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 gasses are used to create a reducing atmosphere.

If we manage to burn the binder *before* the carbon catches fire,
we increase our chances of successful sintering.

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 between 0:30 and 2:00 hours before going on to the goal temperature. Large and thick pieces have a lot of binder to burn, so holding at this temperature will always be helpful. Holding at this temperature will not affect thin or small pieces that may be present in the batch. Then the firing should be **s**topped. 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.

Firing high-fire and low-fire clays together

Bronze will blister and warp if you fire it at over 1470°F/800°C (brick kiln) or 1550°/843°C (muffle kiln). White Bronze will swell, warp or melt at above 1250°F/677°C (brick kiln) or 1325°F/718°C (muffle kiln).

Copper clay and Pearl Grey Steel reach their full density at high temperatures. However, when combined with other clays in small amounts they can sinter at lower temperatures; although they don't reach their maximum density, they are sintered, and the bronze and White Bronze give strength to the fired piece.

If larger amounts of copper and Pearl Grey Steel are combined with low-fire clays, the copper and steel should be fired first. The other clays are added to the fired copper or steel, and the piece is fired again at the low temperatures.

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June 2011