THE BASICS OF BLOOMERY SMELTING

Deep in my January reading binge of 1998, inspired by accounts of African iron smelting and an account of the 19^{th} century iron industry in my home county, I hatched the notion to smelt my own iron from local ore, and make a sculpture with it. Until I read about the African bloomery furnace, I had never considered the possibility of iron being smelted on a small scale. It was one of those deadly ideas that once surfaced, would not leave, so I enlisted the help of my fellow eccentric Skip Williams. We thought a little ironmaking would be a fun way to spend a few chilly weekends. Fourteen months later, after many attempts and building two furnaces, we finally succeeded in smelting a 42-lb chunk of iron.

So what I'm going to do here is try to tell you how I made it work, trying mightily not to spin too deeply into Digression Land. But first I must warn you here: one lesson I learned in this project was not to put too much stock in what I have read. So if you're crazy enough to try this don't blindly trust what anyone tells you. Trust your eyes and your experience and your instinct.

WHAT IS A BLOOMERY?

For those who don't know, the bloomery process (also referred to as direct reduction) is the original method of producing iron. Operating on a small scale and at relatively low temperatures, it produced a sponge of malleable iron and slag that was forged directly into a wrought iron bar or billet. The furnaces varied greatly in form from shallow hearths to tall shafts. Beginning in medieval times, the bloomery was gradually supplanted by the blast furnace process, also referred to as indirect reduction. The blast furnace operated on a larger scale and at higher temperatures, and produced molten cast iron, which had to be further refined by eliminating carbon and reintroducing slag to create wrought iron. The blast furnace's advantages of producing large quantities and removing a higher percentage of iron from the ore outweighed the difficulty of this extra step.

A BRIEF THEORY OF THE PROCESS

Here's the basic theory of how the bloomery works. As we all know from our lifelong battles with rust, iron and oxygen really love each other, and are constantly trying to unite. Iron oxide is the dominant form in which iron occurs out here on the skin of the planet, and that's what most iron ore is composed of. Luckily for us, at elevated temperatures, the oxygen prefers other partnerships, most handily with carbon. So simply put, we want to put iron oxide in a charcoal fire above 900° C with lots of carbon monoxide. The carbon monoxide will grab oxygen from the iron oxide to create carbon dioxide, leaving behind bits of pure iron. These particles of iron will fall into a bath of liquid slag in the bottom of the furnace, and float around until they stick together into a bloom. The slag is largely composed of iron, silicon (the major impurity in most iron ore) and oxygen combined into a substance called fayalite. This slag has a relatively low melting point of 1200ºC, and a nice liquid slag is necessary to keep everything moving and to protect the reduced iron from burning. It also has a chemical function, as we shall see later. If our slag has too low an iron content, it's melting point will rise and the furnace will freeze up.

Many things you might read would lead you to believe that's about it. But a problem rapidly presents itself. If you have enough carbon fuel to produce enough heat and carbon monoxide to reduce much iron from the ore, you tend to have enough available carbon to combine with the iron to make it unforgeable. Most of the European experimenters I've read about, such as Tylecote and Crew, have dealt with this by reducing the amount of charcoal, so there is little carbon beyond that required for reduction, and blowing the fire very gently, so the ore spends a long time in the reducing area of the fire and the hot zone remains down near 1200ºC (carbon absorption increases with temperature). The problem with that is they'd spend 12 hrs to smelt a 4 lb. bloom that forged down to a 1 ½ lb. bar.

We discovered a better way when we went ahead and <u>tried</u> to make cast iron. By throwing in plenty of charcoal and running the furnace hotter, we get optimal reducing conditions in the stack of the furnace. Yes, the carbon particles that fall to the hearth are cast iron, but the slag bath decarburizes them (at least this is what I <u>think</u> happens). Besides fayalite, the slag also contains wustite (FeO). When the wustite comes in contact with the carburized iron, the carbon and oxygen combine, simultaneously decarburizing the existing metal and contributing more pure iron to the bloom. In this way we've progressed from 5 lb. slaggy blooms to 20-40 lb. dense blooms.

So much for theories. Here's how to do it. There are lots of variables to fool with in this process; remember to treat the following as a starting point.

FURNACE CONSTRUCTION

To build our furnaces, Skip & I used old hot water heaters lined with castable refractory. Besides being a convenient form, the steel skin is handy for welding on legs, tuyeres, handles and such. Inside the shell is a layer of insulation, and then the 3200ºF castable inside that. Leave an opening to insert the tuyere 8 or 10" above the bottom of the furnace and another opening at the level of the furnace floor to form a slag tapping arch. The interior diameter of our first furnace was 12", and of the second 14". The first shaft was cast in a single piece, but removing the hot bloom through the top proved an ugly chore. We built the second furnace in sections that could be lifted of with an overhead hoist (tip o' the hat to Wally Yater for this idea) so the contents could be more easily removed, to allow further experimental changes, and to improve portability.

We tried several sorts of tuyeres. The first tuyere was cast iron, and melted immediately (Duhh!). Then we cast refractory tubes, which worked OK but had to be replaced every other smelt or so. We finally built a water-cooled tuyere, which works great. The hollow tuyere opens directly into a water reservoir. Weld all those seams carefully to avoid nasty steam explosions! We've had best luck so far with an interior diameter of 1 ½". This dimension is one of the primary determinants of air flow, especially if you use a low pressure air source like a squirrel cage blower. Our current tuyere is 14º from horizontal. A removable peephole in line with the tuyere is entertaining, as well as vital for monitoring temperature and cleaning occasional blockages.

We are currently using a 150 CFM squirrel cage blower, which seems about right with this furnace. You also need an air gate to adjust flow. Bellows should work well if you've got lots of free labor. Probably the optimal set-up would be a variable speed/stroke piston. If you're really ambitious, some provision for pre-heating your blast will save some charcoal.

RAW MATERIALS

First we need iron ore. This planet is mostly made of iron, so you should be able to find <u>some</u>. We have gotten ours by picking through the tailings of old iron mines in our area. You can find these places by asking local geologists and rockhounds. Our state Division of Mineral Resources was also helpful. If you're not fortunate enough to live in an old mining district, you may be able to find bog ore (iron oxide precipitated out of water in current or ancient swamps). I guess if worse came to worst, you could buy some.

Before smelting, the ore should be roasted. You can roast ore in a wood fire or a gas forge. Bring the ore to a nice red or low orange heat, and try to keep it there a while. If you get it hot enough to start melting, you've screwed up. You can cool it down with water to help the ore to shatter into smaller pieces, or just let it cool. The ore will now be more friable. Bust it up so that most of the pieces are fine to pea size. You'll see that the ore is now shot through with fissures that will be accessible to the furnace gases. It will probably also have changed color to red and hammer-scale gray, making any other bits of sandstone etc. easier to see and remove. If you got the heat just right, non-magnetic ores may convert to magnetite, allowing you to pick out the good stuff with a strong magnet.

Obviously, the better your ore, the better your results will be. If you're not getting iron in your furnace, look to your ore first. The fayalite slag contains two iron molecules for every silicon molecule, so if there's too much silicon there won't be any iron leftover for the bloom.

Next we need charcoal. This is really the biggest part of the whole job if you're making it yourself. In my furnace, I'm burning 10- 12 feed sacks of charcoal for every smelt. I've tried lots of ways of making charcoal, and I'm telling you now, don't bother with any thing but the retort method. Your charcoal will be better, and so will your relations with your neighbors, since the retort burns some of the noxious fumes. For info on charcoal making in a retort get <u>Making Charcoal and Coke</u> by Barrie Howard (available from Norm Larsen). You can buy charcoal also, but it's not quite as good as you can make, as it tends to be a bit damp and under-cooked. You need real chunk charcoal, not briquettes, which will not work because of their fillers and their lousy structural characteristics. Bust the charcoal up so the average piece is 1-2" across, and sift out the fines.

A flux is optional. About ten percent of the iron in the slag can be replaced with calcium without altering the slag's melting temperature, so you might as well get that 10%. Limestone or oyster shells are the traditional sources of calcium. Manganese can also replace iron in fayalite, if you found any manganese ore in your travels.

FURNACE OPERATION

At this point, I feel compelled to follow the time honored Anvil's Ring tradition of The Safety Lecture. You will be dealing here with a very large and hot fire. I'm sure you all know the attire required for such occasions. Take special care of those eyes and hands! In addition, if you have hair you feel strongly about keeping, you'd better cover it up when charging the furnace.

First, get the furnace hot. To save charcoal, I stick the gas burner from my pipe forge into the slag tapping arch for about an hour before starting the charcoal. You can also start the preheat with wood. Then, leaving the tap arch open for draft, add the charcoal slowly until the fire burns up to tuyere level. Start the blast and add charcoal gradually until the furnace is full, and keep it near full during the entire preheat. Our preheat time has been 4-5 hours in our furnace, and uses the majority of the day's charcoal. When the smoke stops and the gases at the top of the furnace start to burn, you're ready for the first ore charge.

Fuel:ore ratio is one of the important variables, affecting temperature, efficiency of reduction, rate of burn, and carburization. A ratio of 1:1 (by weight) is a good place to start. As the furnace burns down enough to allow a charge, add in the charcoal, followed by the ore. We have been adding ore in 15 lb. charges. At this early stage, we tend to use a fairly gentle blast, increasing it during the course of the smelt. There is a limit to the total ore you can charge in your bloomery. In ours it seems to be about 60-80 lbs. The charging sequence could last anywhere from two to four hours. As your bloom and slag bath grow up to the level of the tuyere, you can prolong things by tapping some slag out. Spectators (and believe me you'll have some) really like this part, but try to refrain from doing it too early or too often. Remember, slag is your friend. Of late, we have often found it unnecessary to block the tap arch at all, simply poking through the charcoal and cooled slag that accumulates there to tap, but have a firebrick handy to stop it up if need be.

Happy slag is very black and very liquid at a bright orange heat (seen outdoors). Other colors, especially olive green, and high viscosity indicate low iron content.

At a certain point, you may find the furnace's temperature will begin falling, and you'll have difficulty keeping the tuyere cleared. You've reached the charge limit of the furnace. Try to stop just short of that next time. In any case, at the end of the charging sequence, add another bucket or so of charcoal, and burn the furnace burden on down to the bloom, which we hope has formed just below the tuyere. This post heat can take an hour or two.

The bloom will be an irregular spongy mass firmly attached to the furnace wall directly below the tuyere and extending most of the way across the furnace. Pry it loose however you can and pull it out. If Vulcan, Ogun, and their compadres feel you have approached the project with the proper reverential attitude, you will find your bloom is spongy iron with slag in it. Celebrate. If not, it will be mostly spongy slag with little bits of iron in it. Try again.

BLOOM FORGING

When we've examined our blooms by spark testing, we have usually found a wide range of carbon content. The portion of the bloom nearest the tuyere is denser and higher in carbon content, receding to spongier, lower carbon iron towards the periphery. If you want to make a knife or tool with this you may want to try removing the high carbon section now so you can work it separately (I have not tried this). Spark testing may lead you to believe you've made cast iron, but don't panic yet. The cast may only be skin deep, and the included slag and the more oxidizing environment of forging will continue decarburizing the bloom with each heat.

We often begin working up the bloom immediately after smelting, using our bloomery with the top sections removed as a forge, moving later to the gas or coal forge for welding. At this stage, your object is compaction rather than forging. If you take a welding heat now, all your slag will run out of the bloom, leaving you with lots of separate pieces of sponge iron. Rather, take a series of orange heats and compact the bloom, beginning with fairly gentle blows. Watch out, slag will be squirting all over the place. You will note that the spongy character of the bloom causes it to neither conduct nor hold heat very well, requiring many short heats to work it. When it's compact enough to heat like iron and return energy to the hammer like iron, take a welding heat and go for it.

Now remember, all of the above is not gospel, it's merely what I think and see now. I've also left out a lot in order to write an article rather than a book. You'll find some other information on our web site at http://iron.wlu.edu/, and we certainly welcome questions or discussion by phone, letter or e-mail.

Of course, the big question remains: Why? I reckon that would take a book. But I will say I see a lot of sculptural possibilities in the grain and crystal structures of the iron, and the potential for true escape from bar forms. And this process has definitely deepened and intensified my understanding, appreciation and love for this material I've built my life around.

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