Iron in China

Advanced

I don't know a thing about iron in China. I have never been there and seen anything myself (e.g. in a museum) so all I can do is to summarize what I have read. Since **Bennet Bronsons**'s article[1)] is relatively recent and rather illuminating (meaning it resonates with my own feelings or prejudices), most of what follows is based on his insights. We have met Bennet Bronson before; he also wrote the still best review about the history of wootz steel.
Otherwise it is always a good idea to consult the work of **Donald B. Wagner**, e.g. his book "Iron and steel in ancient China" (Leiden: Brill, 1993), and what Vincent E. Pigott has to say about that book. [3)]
Many articles on ancient Chinese metallurgy appear to be heavily biased towards "China was always ahead by definition", and I have a problem with this kind of view. Here are some random examples from the Internet:

> *During the Spring & Autumn Period of the Warring States Period, China invented many superior casting processes like the wrought iron technique, crude iron technique, wrought steel technique, cast iron technique, cast iron for decarburized steel technique, tempering technique and standardized iron casting technique.*"

First, "the Warring States period is a period in ancient China following the Spring and Autumn period (771 BC - 476 BC) and concluding with the victory of the state of Qin in 221 BC, creating a unified China under the Qin Dynasty." says Wikipedia. Second, wrought iron *casting* techniques and so on are certainly impressive, in particular because they are oxymorons, i.e. contradictions in terms.

> *"Iron was smelted in China by the 4th century BC, and steel was perfected by the 400's AD using coal as a high temperature fuel. By having good refractory clays for the construction of blast furnace walls, and the discovery of how to reduce the temperature at which iron melts by using phosphorus , the Chinese were able cast iron into ornamental and functional shapes.*"
> "*As early as the Fourth Century A.D., coal was used in China, in place of charcoal, as fuel to heat iron to rework the raw iron into finished products. Although sources on the use of coal in the Song Dynasty (960-1279 A.D.) are limited, the Chinese are reported to have developed the ability to use coal in the smelting of iron by the Ninth Century. The use of wood to make charcoal was causing deforestation*".

Maybe they did use coal as early as the 4th century AD, maybe they didn't (its disputed). Whenever they did it, they also made sure that they had all the phosphorous and sulfur problems coming with this "superior" technology. Easy casting of doubtful stuff - yes. Good steel - rather not!.

> *"The Chinese probably discovered copper-smelting and bronze-making independently of the West, because their pottery kilns were much superior."*

No, they didn't. It is far more likely that copper and bronze technology *diffused in* from the West.

> *"However, their advanced technologies of melting and casting made it unlikely that they would independently discover iron-working, because the technology of forging iron to purify the bloom was not part of their way of operating."*

Huh? Because they are so advanced they cannot discover a simple technology?

" *Sometime after 1000 BC, knowledge of iron-forging techniques reached China from the West. The Chinese then applied their superior furnace technology to take iron-working to new levels of expertise. They were the first to cast iron into useful objects, because they could routinely melt iron on a large scale*."

No. They did not cast *iron* into useful objects, they cast *cast-iron* into *some* useful objects but missed out on many other useful objects that needed to be made from *wrought iron* or *steel*

"About 300 - 400 BC, the Chinese learned that if a cast iron object is reheated to 800° or 900° in air, it is decarburized, that is, it essentially has some of the carbon burned out of the surface layer".

They certainly did not learn that. They had no idea about elements. They just learend that product properties improve somewhat by this process.

"This process forms a skin of lower-carbon iron (steel) over the cast iron core. The finished tool is hard and wear-resistant, and for most uses is comparable with the end product of Western forging, in which a skin of steel is formed over a core of wrought iron by forging."

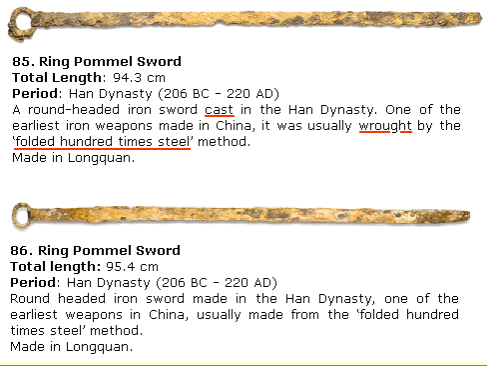
Complete and utter bull shit. A brittle material coated by a few micrometers of tough steel is still a brittle material, Coating your glass sword with some Scotch tape will no really make it much better.

"But the Chinese technology was far more efficient. The Chinese cast objects already had the precise shape required, whereas Western smiths had to produce the right shape by hammering wrought iron on a forge. The Chinese could effectively mass-produce cast steel-jacketed tools of all kinds, while Western smiths had to make them one at a time".

True. The stupid Western method had one slight advantage, however. Their products were often far superior!

"The Chinese were building cast iron suspension bridges from the 6th century, 1200 years before the Europeans."

Maybe. I haven't seen it beause it is not around anymore. The Hagia Sophia or the Pantheon, however, considerably more complex than a suspension bridge and built a bit earlier by the Europeans, is still around.



85. Ring Pommel Sword
Total Length: 94.3 cm
Period: Han Dynasty (206 BC - 220 AD)
A round-headed iron sword cast in the Han Dynasty. One of the earliest iron weapons made in China, it was usually wrought by the 'folded hundred times steel' method.
Made in Longquan.

86. Ring Pommel Sword
Total length: 95.4 cm
Period: Han Dynasty (206 BC - 220 AD)
Round headed iron sword made in the Han Dynasty, one of the earliest weapons in China, usually made from the 'folded hundred times steel' method.
Made in Longquan.

"Early" Chinese Swords

Source: Macao Museum of Arts; History of Steel in Eastern Asia

- A "cast - wrought" sword? Made from cast-iron, iron or steel? 200 BC is early? Compare to much older Luristan swords or somewhat older Celtic swords. The "folded hundred times steel" method presumably is a good thing? No - it simply tells us that the iron / steel used for sword forging was extremely inhomogeneous.

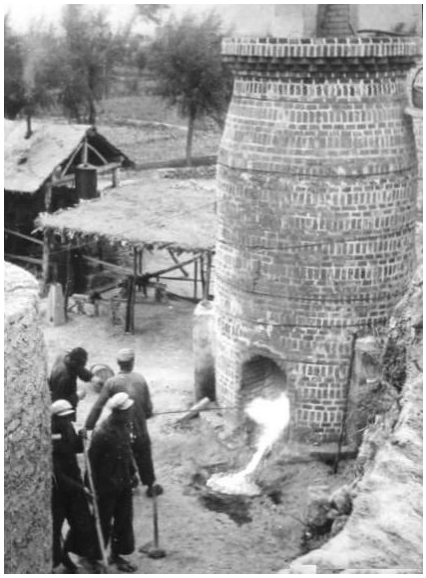
And so on ad infinitum or nauseatum.
I'm *not* saying that China isn't a very old culture that was superior to others in *some* aspects of civilization and technology *some* of the time. Be that as it may, as far as metal technologies in general, and iron technology in particular was concerned, they weren't all-out superior, they just were very different.
The art of making metals including iron actually arrived (or was discovered) rather late in China. That is also true for copper and bronze, but in particular for iron. After iron smelting was started, however, it developed very quickly and in a peculiar way. The Chinese, it appears, made almost exclusively *cast iron* in what one would call a blast furnace nowadays, essentially skipping the making of wrought iron in "bloomeries".
Steel was made by "fining", i.e. taking the carbon out of the cast iron by burning it off in air. That is the principle of steel-making today. The early Chinese techniques included a kind of puddling" process, which is similar to processes used in the West much later (let's say after 1500 AD). Does that mean that the Chinese were 1000 years or so ahead of the West? It's a matter if definition. If you prefer a bad steel made by an advanced method to good steel made in an old-fashioned way, the Chinese were ahead.

- Of course, iron objects from before 200 BC have also been found - just not very many. In a country the size of China, this simply must be expected. Some meteoric iron might have been used or the occasional bloomery might have produced some iron. I won't go into this because pretty much everything is disputed. The fact is that iron and steel technology only made a difference to people in general after, roughly, 400 BC. Even then, up to about the beginning of the Christian age, bronze objects (tools, weapons, adornments, ...) far outnumbered iron objects as grave goods. Iron objects were mostly found in garbage dumps. That doesn't necessarily mean that iron was cheap everyday stuff but that its use was mostly practical and not ceremonial / decorative. The kind of emotional attachment you entertain for your trusty and beautiful sword will usually not carry over to your rusty and broken shovel blade.

By 200 BC a large iron industry was in place, run by wealthy clans or the state. It was well-organized and thoroughly controlled. The primary product was cast iron, feeding a large and sophisticated secondary industry. Integrated "plants" ran, for example, "8 blast furnaces, 1 fining hearth for puddling, 1 annealing furnace for solid-state de-carburizing, 11 mold baking furnaces or kilns, 5 general purpose heating furnaces and 1 forge". I'm not sure if that beats what the Romans did in their "factories" around this time, but it is certainly impressive.
But only 1 forge? That indicates that the vast majority of the cast iron produced was indeed cast into molds for making tools (like digging implements), pots and anything else that can be made from brittle cast iron. Don't make the mistake of conisdering brittle = weak, useless, not strong. Your toilet is made from brittle material but easily takes your weight and other abuse for long times.
Steel making by "fining" or "puddling" the cast iron, followed by forging the steel, was not only a laborious process but could not have produced high-grade steel easily.

- The Chinese cast-iron industry certainly pre-dates "ours" by 1 500 years or so. The reason, however, is not that the Romans or others in the West couldn't make cast iron! They could, in fact, but *they didn't want to!* They simply had no use for the brittle stuff.
  The Chinese, to their everlasting credit, used their cast iron for making peaceful objects, including flower vases and (huge) sculptures. Western cast iron, when it was finally produced, went immediately into cannon making. So the Chinese certainly take the price for being the good guys. Our ancestors were the bad guys by comparison. That might be morally questionable but has its advantages. They easily conquered and subdued the good guys with their superior iron / steel weapons. Look up what the British did in the so-called "opium wars". Of course, nowadays they are really sorry for that, and acknowledge that the Chinese had the moral superiority then. (Haha, good joke, huh?). Some of our German (good) guys around this time wrote the music that the Chinese (and everybody else on this planet) like to listen to ever since, by the way.
  While the Chinese cast-iron industry was far ahead of the rest of the world around 200 BC, there is also another side to this: The technology hardly changed during the next 2 000 years or so. Here are pictures from smelting

cast iron and **"puddling" steel** from *1958*:

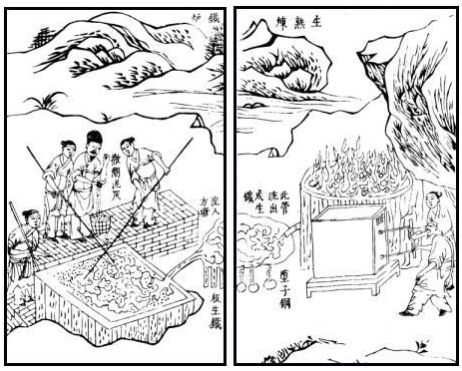


Tapping of a blast furnace in Wushan, Gansu, 1958

Puddling steel around 1958
"Operation of a traditional type of fining hearth in Shanxi"

Source: Alley, Rewi 1961b "Together they learnt how to make iron and steel. Some early types of furnaces used in 1958-9, in China". Collection of the Needham Research Institute, Cambridge.

- Now look at how that was done around 1600 and quite likely also 1800 years earlier.



Making cast iron (right) and puddling steel (left) in the old times

Source: "Furnaces for refining cast and wrought iron", illustration in Tian gong kai wu (reproduced from 1637 ed). All over the Net

Note the "bellows", operating on the principle of a bicycle pump, and delivering air in *both* strokes, in and out. That was rather advanced in comparison to a single-stroke accordion bellows.

Of course, making steel can't be done exactly like shown here. Liquid cast iron kept in a square pool as shown above would solidify far too quickly, not allowing the removal of a large part of the carbon by reacting with the oxygen from the air. Well, as one of the top experts on Chinese Iron History, Donald B. Wagner remarks: [2]
"The description and illustration are so precise that there is no real doubt that Song Yingxing, or the author of his source, had seen something very like this process. But it is very difficult to explain. Anyone who has worked with molten cast iron, as I have, will immediately object that the cast iron from the blast furnace, flowing into such a large open hearth, without thermal insulation, fuel, or any sort of air blast, will solidify before any significant amount of carbon has been removed.
Most translators and commentators seem unaware of this objection. They explain the passage and illustration in terms of modern open-hearth steelmaking processes, and state that the curious "wuchaoni" (some sort of earth used in the process) would contain iron oxide, FeO, to help remove carbon by the reaction FeO + C = Fe + CO, but this would not solve the problem.
The only commentator, as far as I know, who has been aware of the problem was one of the first, the German metallurgist Adolph Ledebur, more than a century ago, and he also proposed a solution. A Japanese friend had shown him a copy of Tian gong kai wu and translated the metallurgical sections for him. In his article about it he suggests that the wuchaoni spread on the iron contained saltpetre (potassium nitrate, KNO_3). It is a powerful oxidizing agent (this is its function in gunpowder), and might very well be able to accelerate the oxidization of the carbon in the iron sufficiently to keep the temperature up until the carbon is exhausted and the cast iron has been converted to wrought iron."

Be that as it may, one thing is quite clear. You may get de-carburized iron this way - but certainly not very good steel .

There is a bigger mystery, however, than exactly how the puddling process worked: How could the old Chinese furnaces produce cast iron? It's not so much a question of the temperature but of the chemistry inside a furnace. Eutectic cast iron at 4.3 wt% carbon melts at a mere 1130 ^{o}C (2066 ^{o}F), easily achieved in any kind of charcoal-run furnace with some air blown in. The problem is to get the carbon inside the *pure* iron that is initially produced by a solid-state process at this temperature.
It's a matter of creating a "self-amplifying" process. You must allow enough time at temperature as high as possible in the reduction zone in your smelter, so that iron + carbon monoxide succeed to move enough carbon into the still solid iron in order to decrease the melting point to a temperature where the steel thus produced becomes *liquid*. The liquid stuff then can dissolve carbon easily and stay liquid even at the lower-down parts of the furnace, where it might be colder.

Nothing helps: your furnace must get very hot, far hotter than a normal bloomery producing wrought iron. It was clear how to do that - to the Chinese *and* to their counterparts in the West: Increase the charcoal to ore ratio and supply more air. The Chinese smelters had double-action "bellows" (actually more a kind of air-pump akin to what you know from your bicycle) that provided a continuous airstream at the forward *and* the backstroke of the pistons, so they might have had an advantage in the air supply department. The price to pay for that is money. Your costs go up - more manual labor and more charcoal compared to making solid iron in a bloomery.
It essentially boils down to the simple question: do you want to make cast iron? The Chines said: yes, the West said: no.

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[1] Bennet Bronson: "The transition to iron in ancient China" in "The Archeometallurgy of the Asian Old World", editor V.C. Pigott, Uni. Museum Monograph 89; University of Pennsylvania, 1999

[2] D. B. Wagner, "Iron production in three Ming texts" Third International Symposium on Ancient Chinese Texts and Records on Science and Technology, Tübingen, 31 March - 3 April, 2003.

[3] Vincent E. Pigott: "The Study of Ancient Metallurgical Technology; A Review", Asian Perspectives, Vol. 35, No.1 (1996) p-89