

BINTIE: THE WOOTZ STEEL IN ANCIENT CHINA

WILLIAM LOX*

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Bintie was a highly-praised steel in ancient China similar to Wootz in ancient India. It was either imported from India or Central Asia or produced in China. Some have asserted that it was nothing else but Indian Wootz steel, others that it was a special steel produced locally with an indigenous origin. The brief history, appearance, and property of *Bintie* are described here, and three possible methods to produce it are discussed. *Bintie* was most likely a co-fusion crucible steel that was both imported from Indo-Persia and produced by the ancient Chinese at the same time.

Key words: Appearance, *Bintie*, Co-fusion, Crucible Process, History, Iron, Metallurgy.

China has a long history of iron-smelting and steel-making, and developed an isolated, unique system of iron metallurgy in ancient times, especially in technologies of cast iron production. In the various types of ancient Chinese Fe-C alloys, a high carbon steel called “*Bintie*” or “*Pin t’ieh*” became famous. The nature and the production of *Bintie* has been a mystery from early times until now, and it attracts more attention than even the cast iron of ancient China.

1. A BRIEF HISTORY OF *BINTIE* IN ANCIENT CHINA

The term “*Bintie*” firstly appeared in historical documents of the Beiwei Dynasty (386 AD - 534 AD), and was mentioned in official history books such as *Wei Shu*, *Zhou Shu*, *Bei Shi* and *Sui Shu* many times. According to the records, in this period (4th-7th Century AD), *Bintie* was a special product of Persia, and ingots of this iron were frequently sent by Persian kings to Chinese Emperors as rare presents.

* International Centre for Bamboo and Rattan, No. 8, Futong East Street, Wangjing Area, Chaoyang District, Beijing 100102, P. R. China; e-mail: wilox95@hotmail.com

On the origin of the name given to this iron “*Bin 斌*”, there are several opinions. The first is that, it derives from Iranian language “*Spaina*”, which probably means “iron” in Persian. This idea is accepted by scholars like Zhang Zigao¹, Yang Kuan², etc in China. The second is, that it derives from the name of its production area “*Ji Bin 罽宾*”, which was the ancient Chinese appellation of Kashmir and North India. So here, “*Bintie*” means the iron from *Ji Bin*. The third is, “*Bin 斌*” also written as “*Bin 賓*” in Chinese which means “guest”, so “*Bintie 斌铁*” here means “an iron from foreign countries”.

In the Tang Dynasty (618~907 AD), *Bintie* frequently appears in historical documents, poems and books. In “*Xi Yu 西域*” the western territory of the Chinese Empire, now called Xinjiang 新疆, *Bintie* was produced locally. The price of a *Bintie* sword was nearly three times that of a common steel sword, and equal to 3 months salary of an official.

After the Tang Dynasty, *Bintie* was even more frequently mentioned in various kinds of documents. The production sites of *Bintie* became diversified to regions such as Xi Yu in Northeast China and Sichuan Province, etc. During the 10th~13th Century, China was divided into three empires, Song 宋, Liao 辽 and Xixia 西夏. The Liao Dynasty (916~1125 AD), was founded by the Kitans, or Cathay people, an alliance of Mongol-Tungus tribes in Northeast China. The Kitans conquered many peoples around them, and created a vast empire in Northeast Asia, and they traded with countries in Central Asia frequently. This was the first time that many countries had contact with China lying to their East and so they called all the people of China “Kitan”. For example, in Russian vocabulary, China is still called “Cathay”. The Kitans could have been making *Bintie*, after all they even named their Empire after *Bintie*, “Liao 辽”, in their language, just means “*Bintie*”. As the Kitans were both brave and brawny, they were said to be as strong as *Bintie* by their neighbors. At the New Year, *Bintie* was presented by the Emperor of Liao to the Emperor of Song as one of the top grade gifts. A production site of *Bintie* in the Liao Empire was in the “Yunnei Prefecture 云内州” located in Inner Mongolia. In 1125 AD, Liao was conquered by the “Jin 金”, the empire of Nuzhen. The Jin inherited the production of *Bintie* from the Liao, and the swords made of *Bintie* continued to be awarded to meritorious persons by the emperor as an honor.

Later, the Song and Jin Empires were all destroyed by Genghis Khan's grandson Kublai, and a large empire spanning from Asia to Europe named "Yuan 元" was founded. In the Yuan Dynasty (1271 ~ 1368 AD), the government set up a special bureau to control the production of *Bintie*, administered by Muslims. Blacksmiths from Central Asia and the Kitan tribes were all called up to the empire's capital "Dadu 大都" (present day Beijing) to service the conquerors and their army. Even now there is still a place called "Weigongcun 魏公村" in the Haidian District of Beijing, where the Uigur *Bintie* smelters from the Chaghatai Khandom lived during the Yuan period. In that time, *Bintie* was made into swords, knives, household utensils and musical instruments. They were more expensive than gold, and only the top officials and the body guards of the emperor could have them³. Also in the Yuan Dynasty, nearly all of the Kitans who had previously lived in Northeast China, joined the Mongol army, and migrated throughout the whole empire. They were assimilated gradually into the local people where they resided and the Kitans as a separate people disappeared, together with the techniques of *Bintie*-making.

In the Ming and Qing Period (1368-1912 AD), the Mongolians were driven back to their homelands, the grasslands of North China, and took with them the secrets of *Bintie* production and which was subsequently again forgotten. However, *Bintie* continued to be produced in Shanxi 山西 and Xinjiang during this period. A type of sword known as "*Mixi Dao* 米昔刀" which combined a Chinese-style blade with an Indo-Persian style hilt was made by the Muslims during the Ming Dynasty (Fig. 1.). The Muslims may have adopted the crucible

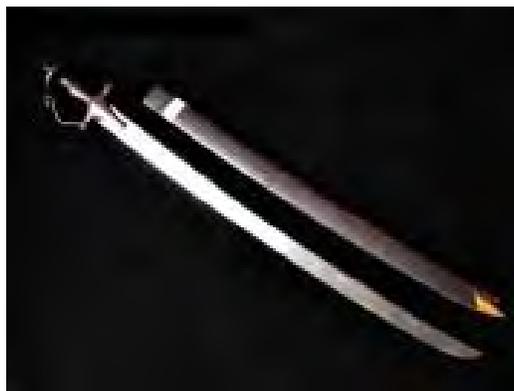


Fig. 1. A '*Mixi Dao*' made by Muslim swordsmiths in the Ming Dynasty. Photograph from the internet forum "Hang Long Ya Ji".

steel process. So-called *Bintie* ingots were still paid by remote tribes to the emperor as tributes uninterruptedly during Ming period, but for some reason, they seemed to be of a more inferior in quality than the common steels, and not too much attention was paid to them by the Chinese. There were also some Wootz swords made in “Hindustan 痕都斯坦” which were presented to the Emperor Qianlong, who was a connoisseur of swords, in the Qing Dynasty, and they still exist in good condition (Fig. 2).



Fig. 2. A Qing Dynasty short Wootz sword with white jade hilt, was made in ‘Hindustan’ (India), now in a private collection. Photograph from internet forum “HF Sword Forum”.

In more recent times after 1912, the production of *Bintie* in China declined sharply, and few *Bintie* items have survived the destruction of wars and the Cultural Revolution. The technology of *Bintie*-making is now completely lost and *Bintie* has become no more than a legend. Also, in common usage now in China, “*Bintie*” had changed its meaning as refined wrought iron or galvanized sheet iron, with few people knowing the original meaning of this term.

2. THE APPEARANCE AND PROPERTIES OF *BINTIE*

Bintie has a watered or snowflake-like patterning on its surface, which forms naturally by smelting instead of pattern-welding. A collector called Zhang Shouyi who lived during the South Song Dynasty (1127~1279), got a *Bintie* sword with hair-like patterning all over the surface. People in his times were confused, someone guessed it was made by forging-welding threads of iron and silver together, then folding repeatedly⁴. In the book “*Ge Gu Yao Lun* 格古要论” (*The Essential Criteria of Antiquities*, 1368), Cao Zhao said:

“*Bintie* is produced in the Xinjiang area. Some have a spiral patterning, while others have a sesame-seed or snowflake patterning. Polish the knife or sword made of *Bintie*, etch them with ‘gold thread’ alum (Zig Zag, ferric sulfate), and the pattern will appear. Its value is greater than silver...The patterning on fake *Bintie* is black...”

As *Bintie* swords were rare in ancient times, and to pass them down from generation to generation was not easy, very few have survived (Figs. 3 and 4).

Bintie has outstanding properties, being both sharp, strong, hard and tough. ‘It is hard enough to cut gold and jade.’⁵ Yuan Zhen (779~831), a poet



Fig. 3. A *Bintie* sword with watered blade made by the government of the Ming Dynasty (1368~1644 AD), now owned by a Muslim collector in Hebei Province. Photograph from “Huizu Forum Online”.



Fig. 4. A sword found in a pasturing area (probably Mongolia) with Wootz-like patterning, it seems to have been dug out of the ground. Photograph from internet forum “HF Sword Forum”.

of the Tang Dynasty described a *Bintie* sword, stating that ‘it could cut hairs blown to it’.

“*Bintie* is harder and tougher than common steels, it could cut iron armors without any hurt to the blade, and it was also as flexible as the branches of a willow tree.”⁶

The Liao Emperor’s successor, the first Emperor of Jin, once said: “Liao means *Bintie*, and is similar, although it is strong, one day it will rot away completely.”⁷ In folktales, *Bintie* swords are often used by heroes. One of Liangshan heroes, Yangzhi, a Chinese Robin Hood of the Song Dynasty, had taken a superior sword with him. The sword could cut iron as easily as cutting a clay billet and it could cut hairs blown to it. It could also kill a person without any blood adhering to the blade⁸. It was probably made of *Bintie* steel.

3. POSSIBLE PRODUCTION METHODS OF BINTIE

As there is neither a still-practicing production nor any documentary records of *Bintie* steel technology, how *Bintie* was made is a real mystery. Scholars in modern China are arguing unceasingly about its origin but have not come to a conclusion. Some assert that *Bintie* was Indian Wootz steel traded to China, some claim that they were of Damascus steel or *Bulat* steel from Central Asia, while others think they were indigenously developed. But all of them agree

that *Bintie* was made by a crucible process. When asked by which crucible process, they again stick to their own views. Three methods could have been adopted to make *Bintie*.

3.1. In situ Carburizing Process

The elder scholars in China such as Yang Kuan and Zhang Zigao are prone to believe that *Bintie* was an imported steel from Southern India. Yang Kuan:

“*Bintie* was made from an Indian steel called ‘Wootz’. To make Wootz, a sponge iron made from magnetite in a bloomery furnace was used. The sponge iron was sealed in a crucible with dry wood, fresh leaves or the stalks of plants as carbonaceous materials. The crucibles were heated by a fire of wood charcoal, and after 4~5 hours’ blowing by big bellows made of an animal’s whole hide, wootz was attained. Because the wrought iron was porous, when heated in a sealed crucible with dry wood, the surface layer of it was carburized into cast iron, which melted and flowed into the holes in the iron. At last, it became a medium or high carbon steel. The ingots should be forged for many times and quenched. This process had been popular in China for a long time, and has been transformed into a new process called ‘Men Gang, 焖钢’”²

Yang Kuan’s Wootz process seems probably be the process of Mysore steel in practiced in Southern India.

Zhang Zigao etc. stated that: “This pretty artwork came from Persia, but it was made from steel named Wootz which came from India. P. Ray had described the process: Steel was produced in ancient India by a process resembling the modern cementation or crucible process. Wrought iron prepared directly from magnetic iron ore, as already stated, formed the starting material. This was heated in closed crucibles with dry wood chips, stems and leaves of plants over a charcoal fire maintained by blowing air with large bellows. The operation was completed in 4-5 hours, whereas the modern cementation process takes 6-7 days. The steel first obtained was heated again in closed crucibles whereby the excess of carbon was burnt off. Sometimes water was poured onto the hot metal, which was thus hardened on being quenched.”¹ This process seems to be the same as that of Yang Kuan described above.

But there is insufficient evidence to support their hypothesis. The “Men Gang”, which Yang Kuan regarded as a variation of Mysore Wootz, is just a case-hardening process. Wrought iron was sealed in a ceramic box together with

charcoal, and with powdered animal bones or niter added as activators. The box was heated at about 900°C for periods varying from several hours to days. The product was an inhomogeneous steely iron with a high carbon content in the outer layer and low carbon wrought iron in the core. It is not really a steel-making process at all. There is also no documentary or archaeological evidence which could confirm that an in situ carburizing crucible process had been used in ancient China.

3.2. Co-fusion Steel-making Process

Co-fusion steel-making process was commonly used in ancient China from very early times, since China never lacked cast iron through the whole history of iron making.

Famous swords named “Ganjiang 干将” were made about 500 BC in the area of Zhejiang Province and Jiangsu Province in Eastern China. “Ganjiang” originally meant smiths from the “Gan” tribe, later it gradually became the name of swordsmiths, and at last the swords they made were also called “Ganjiang”. “The Ganjiang collected ‘*Tie Jing* 铁精’ of Wushan and ‘*Jin Ying* 金英’ from Liuhe to make swords for the King of Chu 楚. He chose a proper season and a proper site to smelt them as many times he had done successfully before, but this time he failed. He did not know what had gone wrong this time. His wife, Moye 莫邪, cut off her hair and finger nails, and threw them into the ‘Lu 炉’, and their 300 apprentices worked together to add charcoal into the furnace and using big ‘*Tuo Yue* 橐龠’ to blow air into the furnace. The two metals finally ‘*Ru 濡*’ (fused) together. Ganjiang made two swords from it. One he called ‘Ganjiang’, and the other after the name of his wife, ‘Moye’. The Ganjiang sword had a turtle shell patterning with it and Moye sword had watered patterning.”⁹ In this text, “*Tie Jing*” means “iron’s semen”, and refers to liquid cast iron, “*Jin Ying*” means “flowers of iron”, and refers to forged billets of wrought iron, especially sponge iron, “*Tuo Yue*” was a type of bellows made from the whole hide of a buffalo or horse. “*Ru 濡*” means “moistening”, referring to the melting of metals. There are some divergences of meaning of “*Lu 炉*”, commonly it refers to a furnace, but here it probably means a crucible. The hair and nails of human beings contain phosphorus, which can add fluidity to liquid cast iron or steel. Ganjiang must have used a crucible co-fusion process to make the watered steel blades! Other ancient books also mentioned the Ganjiang swords, saying that they were hard and sharp,

and could cut a crocodile in a river or a tiger in the mountain into two halves with one blow. Some think that “*Tie Jing*” should refer to tin here, and that “*Jin Ying*” refers to copper, that is that the Ganjiang sword was of bronze rather than steel. This standpoint can be easily disproved. The melting point of bronze is not higher than 1000°C, and could be melted easily, and certainly does not need hair and nails as catalyzers, and or to be blown by powerful bellows. In 1964 and 1972, two graves of the East Zhou Dynasty (770-256 BC) were excavated respectively in Liuhe, Jiangsu provinces, and in them pellets of cast iron and billets of sponge iron were found. It proved that the Ganjiang had the raw materials to produce co-fusion steel at that time. Joseph Needham thought that Ganjiang probably had produced a hyper-eutectoid steel like Indian Wootz.¹⁰ When writing about the Ganjiang sword, F. R. Tengengren, in his book “The Iron Ores and Iron Industry of China”, also said, that in ancient times, the temperature of furnaces were not high enough to melt iron easily, and that the ancient Chinese people must have discovered the effect of phosphorus to lower the melting point of iron.

After Ganjiang and Moye, a co-fusion process for steel-making named “*Guan Gang* 灌钢” became widespread in China. The principles of “*Guan Gang*” are the same with Ganjiang’s method, wrought iron and cast iron were melted together to make a high carbon steel, though the manipulations changed. A Daoist of the South-North Dynasty (420~589 AD), Tao Hongjing 陶弘景 once summed up his experiences of steelmaking thus: “The steel blade of swords and sickles are made by heating cast iron and wrought iron together.” Song Yingxing 宋应星 wrote: “There are two irons: one is cast iron, the other is wrought iron. The iron which flows out from the furnace without being puddled is cast iron, after puddling it turns into wrought iron. Smelting the two irons together, steels would be attained.”¹¹

The main use of Guan Gang, was making blades. Another Daoist in South-North Dynasty, Qiwu Huaiwen 綦毋怀文 was famous for his “*Su Tie* 宿铁” sabers. His method was as follows:

“Preparing cast iron liquids and pouring them onto preheated wrought iron. Repeating this operation several times produced a fine steel. Forge it into a blade with soft steel as the back, quench it in the animal’s urine first and then immerse it into the animal’s grease to cool down to room temperature completely. The saber made in such a manner is very sharp, and could cut through thirty layers of leather armors.”¹²

In the Middle Ages, three variants of *Guan Gang* were developed by the Chinese.

The first is the “*Tuan Gang* 团钢” process recorded by Sheng Gua 沈括.

“Coil together pieces of wrought iron and cast iron plates, seal this mass with clay, then heat and forge, until they are welded and turn into a whole steel billet. It is called ‘Tuan Gang’, also called ‘Guan Gang’.”¹³

The second is the process recorded by Song Yingxing.

“Making steel: wrought iron is forged into pieces about one finger wide and 5cm long. They are tied into a bundle by wrought iron strips with cast iron being placed on top. The whole is put into a forging furnace, covered with straw shoes which had been dipped into a clay slurry before use and powerful blowing is applied. When sufficient temperature is achieved, the cast iron melts and infiltrates into the hot wrought iron under it, and a steel billet forms. Take out the billet to be forged, and again heat it with cast iron on top, and again forged, for several times, it becomes a fine steel in the end.”¹¹

The third process is “*Su Gang* 苏钢”, which was invented in the later Qing Dynasty (1644-1911 AD), and continued in use until the 1950s. A forged puddled wrought iron or steel was put inside the outlet of a high-temperature furnace on the furnace bars, and a piece of selected cast iron was held by a worker’s right hand on top of the outlet. The furnace was blown by powerful bellows. As the temperature rose, the cast iron melted and dripped down onto the wrought iron. A hook was held by the worker’s left hand to turn over the wrought iron or steel continuously, in order to ensure it dripped evenly over the iron (Fig. 5). When the wrought iron ceased to absorb any more cast iron drops, it was taken out and forged². Because the hot iron was exposed to an oxidising atmosphere, this process did not add carbon to the wrought iron or steel, but only burnt off the impurities such as P, S, and Si. The ingredients of the wrought iron or steel before and after being treated are given in Table 1. The *Su Gang* was such a good steel for weapon-making that its production was forbidden by the government of Qing Dynasty.

Bintie was also deemed to be a co-fusion crucible steel by Hui Lin 慧琳. He was a Buddhist monk of the Tang Dynasty, born in Shule 疏勒.

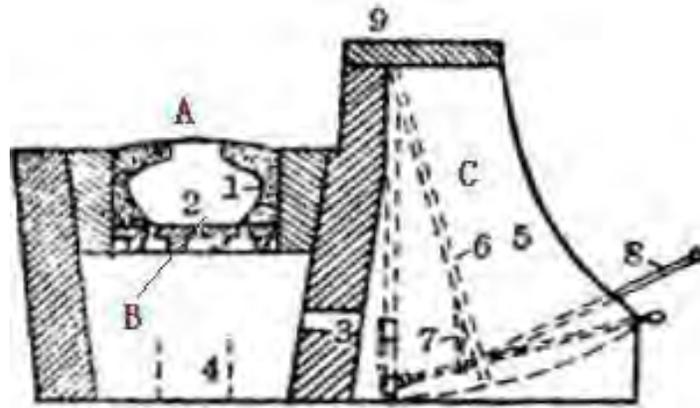


Fig. 5. A *Su Gang* furnace in Beibei, Chongqing in 1938¹⁴. A: Where cast iron was placed; B: Where wrought iron was placed; C: Bellows.

Table 1: Ingredients of *Su Gang* and its Raw Materials [14]

	C	Si	Mn	P	S
Cast iron	3.05	0.28	0.18	0.22	0.05
Wrought iron/steel	0.92	0.19	0.10	0.08	0.02
<i>Su Gang</i> -outer layer	0.92	0.036	0.024	0.037	0.008
<i>Su Gang</i> -core	0.92	0.036	0.029	0.046	0.011

Xinjiang, a site adjacent to Ji Bin, where *Bintie* was produced through the ages. He explained the word “*Bintie*” in his book on Buddhism:

“It is a high grade iron, made by ‘*He He* 和合’ several types of iron, very clean and sharp.”¹⁵

The direct meaning of “*He He*” here is “mixing and combining”. Some people guess that it was a pattern-welding process, but the pattern-welded steel would not be as sharp as true crucible steel. The poet Liu Yin of the Yuan Dynasty also knew *Bintie* very well, and in one of his poems, “General Zhang’s Precious Saber”, he mentioned, that the Uigur blacksmith made *Bintie* from the powder of cast iron. The blades they made looked bluish. It must have been a crucible process. Another poet of the Yuan Dynasty was also a person who knew about *Bintie*. In his poems, he stated that a West Barbarian saber with a black blade was made by melting “Yang 阳” iron (cast iron) and “Yin 阴” iron (wrought iron) together. In the ruins of iron workshops in historic *Bintie* production areas such as Xinjiang, Liaoning and Inner Mongolia, used crucibles are often found (Fig. 6).



Fig. 6. Debris of crucibles and of tuyeres found in Kuche 库车, Xinjiang, in ruins of an ancient iron workshop. The base of a furnace also was found in these ruins. Photograph from CCTV.

Qian Wei, a young expert of archaeometallurgy in University of Science and Technology, Beijing, after studying the writings of Al-Kindi, B. Bronson, etc., together with the research results of G. Pearson, P. P. Anosov, Ann Feuerbach, etc., and a great deal of documents of ancient China, concluded that ancient China was probably one of the birthplaces of co-fusion steelmaking. Furthermore, as one of the earliest countries of cast iron production in the world, China probably had exported cast iron, the necessary raw material of co-fusion steel, to Central Asian countries along the Silk Road. Together with cast iron, the methods of co-fusion steel-making may have spread at the same time.¹⁶ According to Han Shu, of the West Han Dynasty (202 BC. ~ 8 AD.), there were some soldiers who were disgusted with service in army and fled to the Ferghana Valley where they lived and taught the locals cast iron and steel-making techniques and among these the co-fusion process may have been included. There is also an interesting phenomenon that all of the historic sites of co-fusion steel production in China, Central Asia and Indo-Persia, such as Kuche, Shule, Merv, Ferghana and Kashmir etc. are connected by the route of Silk Road, probably hinting at a relation between co-fusion steel making and cast iron trading (Fig. 7).

But why did the co-fusion crucible process of steel-making disappear in China? As mentioned above, the Ganjiang process was obviously a co-fusion

soldiers were beheaded or cut into two halves by these sabers. The survivors were so scared that they dared not fight without an iron neck-guard. This was because the Japanese believed that the dead whose body had been cut into two could not go to heaven. These sabers of the 29th Army were made of “*Bintie*” which was produced in the southeast of Shanxi 山西 province. The “*Bintie*” here referred to a type of iron produced by a crucible process.

This process had been the main iron-making method in the northern part of ancient China, from Henan Province to Inner Mongolia and from Liaoning Province to Xinjiang, since the Han Dynasty (206 BC ~ 220 AD), and had continued to use until the late 20th century (Fig. 8). In North China there was not enough wood charcoal to supply the blast furnaces but the region was rich in coal as well as the refractory clays necessary for the crucible process. The product was believed to be cast iron, but actually they were hypereutectoid steels, not the ordinary blast furnace cast irons.



Fig. 8. A iron smelting crucible of the Han Dynasty was excavated in Nanyang 南阳, Henan 河南 province. It was in the shape of a cylinder, but looked like an ellipsoid, as a layer of clay mixed with grass was adhering to its outside surface.⁶

The crucible iron-smelting process in China has been known to the western world through the accounts of travelers such as Kocher, Dickman and Needham.

Wagner has a description of this process¹⁷:

“Iron smelting in Shanxi used the ‘crucible smelting’ technique. A mixture of crushed ore and coal was packed in crucibles, and the crucibles heated in a stall furnace fuelled with more coal (Fig. 9). Details varied greatly from place to place, but typically the crucibles might be 15–20 cm in diameter and 50–100 cm high. The charge in each was 10–15 kg ore and 2–4 kg of coal. The number of crucibles in the furnaces varied from under 100 to over 300; the heating time was from 1–3 days; and the yield of iron from ore 20–40%. Natural draught was sometimes used, but more often a man-powered blast. The iron produced in this way was normally in the form of a very slaggy bloom, with a carbon content in the range 1–3%. This was either decarburized by a fining process to make wrought iron or carburized in a cupola or crucible furnace to make cast iron.”



Fig. 9. Stall furnace for the crucible smelting of iron, partly loaded with crucibles packed in coal. Photograph by Dr. Knapp, 1936, in Hunan 湖南 province, China.¹⁷

A sketch of a stall furnace's structure is shown in Fig. 10, together with a photo of the furnace from Shockley (Fig. 11).

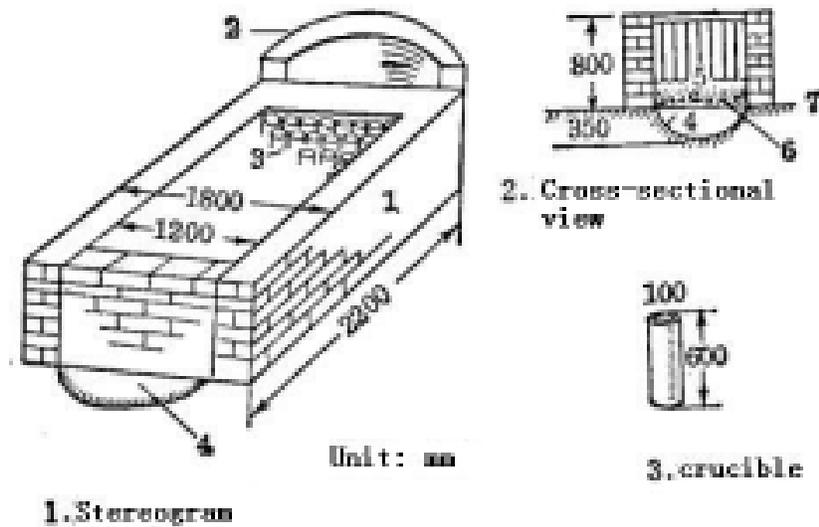


Fig. 10. The structure of a stall furnace used in Weifang 潍坊, Shandong 山东 province.¹⁸



Fig. 11. Crucible smelting of iron in progress in Gaoping 高平 County, Shanxi, photograph reproduced from Shockley (1904, AIME fig. 1, facing p. 854).¹⁹

The crucible iron-smelting in Jincheng 晋城, Shanxi, was investigated by Fan Baisheng in 1980s. The ingredients of crucible irons were analyzed (Table 2).

Table 2: Ingredients of Crucible Cast Irons²⁰

	Fe	Si	Mn	S	P	C
Dayang iron workshop	94.34	1.85	0.34	0.16	0.85	2.46
Jincheng iron workshop	97.15	0.17	trace	0.13	0.73	1.30

The products were not ordinary cast iron, but natural ultrahigh carbon steels (UHCSs) or low carbon eutectic cast irons. Being treated properly, they could achieve good malleability. They were usually sorted into three classes according to their qualities in latter-day Shanxi. “The output of a single smelt is about 225kg: 50kg is of first class iron, which is sent to forging furnaces to be forged into slim billets for the making of nails, iron wires, etc. 125kg is of second class iron, to be sent to puddling furnaces to produce wrought iron; 50kg is third class iron, to be remelted to cast into *woks*.”²¹ The first class iron which was directly forged must be a good quality blade steel.

Ferdinand von Richthofen wrote a description of the annealing process of the crucible iron in Dayang 大阳 Shanxi, in 1870, as follows¹⁹:

“When everything is burning and the heat is great, the blowing is stopped, since the natural draught is sufficient to maintain the heat.

If the intention is to make cast iron [*Roheisen*], the crucibles are taken out after a certain period of time and the contents cast as flat plates; the result appears to be a clean white steelmaking pig iron. If wrought iron is desired, the heap is allowed to burn out and cool off over a period of four days. The crucibles are then taken out and broken. In this case the iron is in the form of a hemisphere.”

Richthofen also noted that: “The best product is the wrought iron, which is far superior to that of Europe and possesses great malleability.”

As Fan Baisheng had mentioned in above paragraphs, the products of crucible smelting were low in silicon and when they were annealed for a long time and cooled down in very low rate, the graphitizing process would not have been extensive, but instead a divorced eutectoid transformation (DET) would have occurred mainly. The iron as such was not wrought iron but rather a superplastic UHCS with globular cementite in a matrix of ferrite, which was similar to the

typical true Damascus steel. Although the P and S content in the iron was high, it did not prevent the swords or sabers made from this iron being as sharp, hard and fearful weapons as the Japanese soldiers had ever seen. As governments in ancient China did not like weapons being made privately, most of the production of the iron and steel was used in agricultural tools and household utensils. Then the utility of crucible iron for weapon-making became neglected.

CONCLUSION

It was probable that both Wootz steel ingots made by the in situ carburizing process in southern India and ingots made by co-fusion crucible process in Central Asia or Northern India were imported into ancient China. They were all called “*Bintie*”. However there are insufficient historical records or concrete archaeological evidences to support the idea that the in situ carburizing process had been used to produce *Bintie* in ancient China. Conversely, the co-fusion crucible process was used to produce *Bintie*. The latter seemed to have a centuries-old Eastern origin, and had influenced the development of similar processes in Central Asia and Northern India, together with the trading of cast iron and the spread of cast iron producing technology.

The crucible iron-smelting process was widely adopted by people in Northern China, which produced good quality high carbon natural steels similar to *Bintie*. It is significant process and should be seriously investigated as a possible process of *Bintie*-making.

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