CHINESE MONUMENTAL IRON CASTINGS

BY

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Abstract

This article reviews the technical aspects of the production of very large iron castings in pre-modern China. Among the matters taken up are: the piece-moulding technique and the amelioration of the flash-lines which are unavoidable when this technique is used with white cast iron; the use of sulphur in producing better detail in the castings, and the effect of sulphur on the sound-quality of cast-iron bells; the use of wrought-iron reinforcement and stage-casting in the enormous Cangzhou Lion; the special problems involved in casting iron artillery; and the riddle of the lack of corrosion on many of the pre-modern monumental iron castings. The corrosion-resistance of the ancient iron castings may be related to their very low silicon content.

Monumental iron castings[1]—statues, bells, pagodas—weighing many tons have been produced in China at least since the eighth century, as evidenced for example by the magnificent "iron oxen" and "iron men" shown in Figures 1-2,[2] which were cast in AD 724. Before these were excavated, in 1989, the earliest known well-dated monumental iron castings were Korean, for example a seated Vairocana Buddha, 2.51 m high, dated AD 858, at the Porim-sa 寶林寺 Temple in Chŏlla-namdo 全羅南道 (Best 1990: 14-15).

These castings have attracted the attention of many Western metallurgists and travelers,[3] but very little has yet been written in Western

[1] A German translation of an earlier version of this article was published in *China, eine Wiege der Weltkultur* (Mainz 1994), without most of the illustrations and with the addition of some irrelevant illustrations. The photographs in Figures 9–11, 22–23, and 33 were taken by the author in 1984, Figures 4–8, 12–16, 18–20, and 29–30 in 1987.

[2] For color versions of most of the figures in this article, please see them online at URL <http://www.EastAsianArchaeology.org/archaeologists/dbwagner/monfig.html>.

[3] See, for example, Boerschmann 1924; 1931: 336–365; Dickmann 1937; Foster 1919; 1926; Johannsen 1942; Paludan 1994; Read 1936; Till & Swart 1993; Vogel 1930.

British troops occupying Zhenjiang 鎮江, on the Yangzi River in Jiangsu, in 1842 took note of an iron pagoda whose present whereabouts is unknown (Ouchterlony 1844: 490–491):

> On the heights east of the town is a venerable old joss-house, built in a style differing a good deal from that which is observed in their more modern temples. . . . [There]

Figures 1–2. Two photographs of the recently excavated "iron oxen" and "iron men" which served as anchor-weights for the Pujin Bridge 蒲津橋, completed in AD 724. The bridge crossed the Yellow River outside the ancient city of Puzhou 蒲州 in modern Yongji 永濟 County, Shanxi (Needham 1962: 40–41; 1971: 160–161; Paludan 1994; excavation report in Fan and Li 1991). One of the oxen is 3.3 m long and 1.5 m high, and the rest are similar. Photographs by Tang Huancheng 唐寰澂 in the archives of the Needham Research Institute, Cambridge; used with permission.

languages on the technical problems imposed by the task of casting such large iron objects and how these problems were solved. In the following I shall consider the technical aspects of several important monumental iron castings which I have inspected myself or for which adequate information has been published.[4]

Piece-mould casting

We may start with the famous four iron warriors of the Zhongyue Temple 中嶽廟, shown here in Figures 3-5. The rectilinear network of "flash" (impressions of mould-seams) which can be seen in Figure 4 makes it clear that the traditional "piece-mould" method was used in the casting of these pieces.[5] This method, used for large and small bronze objects as early as the Shang 商 period and still in use in the twentieth century, is well known (e.g. Karlbeck 1935; Fairbank 1962/72) and needs only a brief description here. First an exact full-scale model is made of the intended casting. This is of clay, suitably reinforced with wooden or metal supports. When the model is dry it is plastered to a considerable thickness with wet clay; when this clay has dried to a leather-hard consistency it is cut into blocks which are carefully removed, retaining the impression of the model. These separate blocks are dried and perhaps fired for greater durability. In order to form the mould-core the model is then carefully scraped down, removing a thickness of clay corresponding to the intended thickness of the casting. The previously formed blocks are reassembled around this core to form the "cope" (the outer mould). This is reinforced with a wooden framework and buttressed with earth. One or more casting inlets are made, and the molten metal is poured into the mould thus formed. When the mould is removed the casting shows obvious seams at the joins between the individual blocks of the outer mould. In bronze cast-

was a pagoda of nine stories, formed of cast iron, . . . having a height of about twenty-five feet, and a girth of sixteen to eighteen feet [7.6 m, 4.9–5.5 m] at the base. It had been cast in segments, like the column in the Place Vendôme, each forming a story of the building, the figure being octagonal, with well-turned gothic-looking arches on each face. The woodwork was entirely destroyed, and the metal much defaced by time. This tower may be accounted one of the many proofs seen, during the progress of the expedition, of the very early knowledge which the Chinese possessed of the art of casting iron. There had been an intention of sending this iron pagoda to England as a trophy, and a scaffolding of strong spars had actually been commenced for its removal, but the peace put a stop to the proceeding . . .

[4] Li Xiuhui (1989) has given a very useful survey of monumental metal castings in China, with references to published studies.

[5] It is curious that there are still some art historians who cling to the idea that flash-lines like these indicate that the statues were cast in many separate pieces and somehow assembled afterward. (See e.g. Shi Yan 1988: 19, 35; Best 1990: 16.)

Figure 3. The four cast-iron warriors guarding the "Depository of Ancient Spirits" (*Gu shen ku* 古神庫) of the Zhongyue Temple in Dengfeng, Henan, photographed by Édouard Chavannes (reproduced from Chavannes 1909–15). Heights range from 254 to 260 cm. An inscription cast into one indicates that they were cast in AD 1064 (Shi Yan 1988: 35); Chavannes appears to be mistaken when he gives the date 1213.

Figure 4. One of the warriors shown in Figure 3 (photographed by author in 1987).

Figure 5. Detail of the casting shown in Figure 4 (photo by author).

Figure 6. The "Iron Rhinoceros" in the village of Tieniu 鐵牛, 2 km northeast of Kaifeng, Henan, dated AD 1446 (Wang Xinmin 1982: 61–63; photo by author).

Figure 7. Detail of the back of the "Iron Rhinoceros" shown in Figure 6 (photo by author).

ings these are usually removed by grinding and polishing, but in iron castings this is usually not practicable.

An interesting aspect of the piece-mould method can be seen in the "Iron Rhinoceros" near Kaifeng 開封, dated 1446, shown in Figures 6-7. Clearly it too was cast by the piece-mould method. Figure 7 shows what at first appears to be a later repair; close inspection shows, however, that the metal is continuous through it. What we see here are traces of a repair to the *mould* rather than the casting. It would seem that while the cope was being built up around the core some accident occurred which resulted in the break clearly outlined here. At this point the model had already been destroyed to make the core, and it was not possible to start again. Therefore the broken piece was replaced in position as well as it could be; the three excrescences are traces of some arrangement used to hold it in place.

Most of the Chinese monumental iron castings have the lines of flash seen here, and we must wonder whether this did not detract from their aesthetic qualities. Osvald Sirén (1927: 14) takes note of an iron Arhat in a German collection, dated 1499, with "traces of paper and paint," and it is easy to imagine that many of the statues discussed here were originally covered with gesso or some kind of *papier-maché* to hide the flash-lines.[6] The Korean Vairocana Buddha cast in 858, mentioned above, is described as having "paint and clay embellishments," and though these appear to be modern they may well be faithful restorations of earlier embellishments (Best 1990: 15). In photographs some flash-lines are visible on this statue, but they are presumably less obvious than they would be without the clay covering.

White cast iron

We have no metallographic or chemical analyses of the iron of these statues, but the fact that the flash was not removed indicates with considerable certainty that they are the form of iron known as white cast iron. This contains a large proportion of iron carbide (Fe_3C), which is extremely hard, harder than quartz, and extremely difficult to work with; an ordinary saw or file cannot cut it at all. When iron is cast it solidifies in the white form if (1) its silicon content is low or (2) its sulphur content is high or (3) it cools very quickly in the mould.[7] Large castings like these cool very slowly in the mould, but available analyses suggest that virtually all pre-modern Chinese cast iron has very low silicon content, and that much of it has high sulphur content.[8]

A modern ironfounder, given the task of casting a large iron statue like these, would prefer to use the form of iron known as grey cast iron, and therefore would use iron with a silicon content of one to two per cent and a fairly low sulphur content. In grey cast iron the carbon content is in the form of microscopic flakes of graphite rather than in combination with iron as iron carbide. It is normally considered much easier to cast than white cast iron, and it is also softer, so that imperfections such as casting seams can easily be filed away.

The very low silicon content of pre-modern Chinese cast iron (which is due to specific aspects of Chinese iron-smelting techniques) means

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[6] At the Kaifeng Museum (Kaifeng Bowuguan 開封博物館) in 1987 Mr. Li Kexiu 李克修 kindly showed me in a storehouse several iron Arhats (*luohan* 羅漢) which may have been treated in this way, but our only light was a flashlight and I was unable to inspect them properly.

[7] For a fuller introduction to the metallurgy of cast iron see Wagner 1993, chapter 7.

[8] Analyses of cast iron artefacts: Pinel et al. 1938; Wagner 1993, chapter 7, table 7.1; Rostoker et al. 1984: 760; note also the analysis of the iron of the Cangzhou Lion, below. The high sulphur content of many ancient Chinese castings is often taken to be a sign that the iron was smelted or remelted using mineral coal. It is known from both written sources (Hartwell 1967; Hua Jueming 1989) and radiocarbon methods (Qiu and Cai 1986) that coal was used in iron metallurgy in China as early as the Song period, probably earlier, but the high sulphur content of many monumental castings can also be the result of intentional alloying, as will be noted further below.

Figure 8. The "Eastern Iron Pagoda" of the Guangxiao Temple 光孝寺 in Guangzhou 廣州, Guangdong, cast in AD 967. It is protected by a building recently built around it, and could only be photographed through a window. Compare Figure 9 (photo by author).

Figure 9. Remains of the "Western Iron Pagoda" of the Guangxiao Temple. Compare Figure 8 (photo by author).

that iron rarely has been grey-cast, and most monumental iron castings show casting seams like those noticed above. Sometimes these are not apparent, as in the two iron pagodas shown in Figures 8-11, dated AD 963 and 967 respectively. They were assembled of separately-cast sections. It is extremely unlikely that these are not of white cast iron, but there is virtually no sign of casting flash—except perhaps a slight trace of flash on the corner in Figure 10.

Presumably in this case the flash was ground down with some tool like a whetstone. This would have been inordinately laborious;[9] to minimize the labor involved, special preparations would have been made. The moulds would have been designed in such a way that the seams occurred in parts of the casting where they were easily reached by the grinding tool. Great care would have been taken in the construction of

[9] Rostoker et al. (1984: 765) state categorically that this would be virtually impossible, presumably meaning that it would require an unreasonable expenditure of labour. Clearly what expenditure of labour would have been considered "reasonable" in a religious context in a pre-modern culture is a difficult question to deal with.

Figure 10. Detail of the "Western Iron Pagoda" of Figure 9 (photo by author).

the moulds to effect a perfect join of the sections, thus minimizing the flash. Another approach to the problem of casting seams is to design the casting so that the seams become a part of the décor, as on the bell shown in Figure 12.

For some purposes there are advantages to high-sulphur cast iron and to white cast iron in general. Réaumur, who in the eighteenth century did the first systematic studies of cast iron, found that one of his experiments had been ruined by a foundryman who added sulphur to the iron in order to make it easier to cast (Sisco and Smith 1956: 287). Experiments reported briefly by Rostoker and Bronson (1990: 22) indicate the reason for this: it seems that a high sulphur content reduces the surface tension of liquid cast iron, so that it can better fill in the fine details of the mould.

In addition, white cast iron has a very low vibration-damping capacity and is therefore an excellent material for bells, as has been discussed in detail by Rostoker et al. (1984).[10] Cast iron bells are very common in China, and rare or non-existent in other parts of the world. Some magnificent examples can be seen at the museum of the Great Bell Temple (Da Zhong Si 大鐘寺, formerly Juesheng Temple 覺生寺) in

[10] Grey cast iron, on the other hand, is prized for its *high* vibration-damping capacity and is the preferred material in such modern applications as machine bases.

Figure 11. Detail of the "Western Iron Pagoda" of Figures 9–10, showing an image of the Buddha Bhaiṣajyaguru (Yaoshi Fo 藥師佛) (photo by author).

Figure 12. Iron bell in the Great Bell Temple in Beijing, cast in the Yongle 永樂 reign period (1403–1424) (photo by author).

Beijing,[11] for example the one shown in Figure 12. The only metallographic examinations available are those of Rostoker et al. (1984: 760) for three Chinese cast iron bells in the Field Museum of Natural History in Chicago, dated to the Ming 明 and Qing 清 periods: these are of white cast iron and contain respectively 0.29, 0.40, and 0.57 per cent sulphur. Such high sulphur contents could be obtained either by specifically choosing high-sulphur iron from blast furnaces fuelled with mineral coal, or by the addition of sulphur-bearing minerals such as iron pyrites (FeS_2) to the molten iron before casting.

A specific problem caused by the low silicon content of pre-modern Chinese cast iron is that bubbles tend to form in castings. Bubbles can be seen just below the surface in Figure 14, which shows the fracture of a large broken bell, cast in AD 1204, at the Shaolin Monastery 少林寺 in Dengfeng 登封, Henan. These can be extremely deleterious to the quality of a bell, for they increase the vibration-damping capacity of a metal (Schad and Warlimont 1972: 14-15; note also Schad and Warlimont 1973). Bubbles just below the surface may also be the cause of another defect: the surface spalling seen in several places on the bell shown in Figures 15-16.

[11] On the Bell Museum see e.g. Cao Bailong 1987.

Figure 13. A broken bell at the Shaolin Monastery in Dengfeng, Henan, cast in AD 1204 (photo by author).

Figure 14. Detail of the fracture of the bell shown in Figure 13 (photo by author).

Figure 15. Iron bell at the Great Bell Temple in Beijing, cast AD 1626 (photo by author).

Figure 16. Detail of the bell shown in Figure 15 (photo by author).

The cast iron lion of Cangzhou

Figures 17-20 show what is often said to be the largest iron casting in the world, the famous Cangzhou Lion in the city of Cangzhou 滄州, Hebei, cast in AD 953. It is 5.4 m high, 5.3 m long, and 3 m broad; its weight is estimated at 50 tons. Art historians believe that the lion was originally inside a Buddhist temple, now long gone, and that a bronze statue of the bodhisattva Ma juśrī rode in the lotus flower on the lion's back. The bodhisattva was at some time removed for the value of its bronze; this could have happened as early as the reign of Shizong 世宗 (r. 954-958), emperor of the minor dynasty of Later Zhou 後周, in his campaign against Buddhism.

By 1603 the tail was missing. The lion toppled over in a storm in 1803, with the result that the snout and belly were damaged. In 1886 the Department Magistrate Gong Yu 宫昱 sent masons to prop it up with bricks and stones.[12] When the American mining engineer Thomas T. Read saw it in 1910 the casting was broken into four parts: the body, the lotus seat, the head, and the lower jaw, which lay on the ground. The lower jaw has not been seen since. In 1984 the lion was professionally restored and placed on a reinforced-concrete pedestal two meters high.

The chemical analysis and metallographic examination of a sample taken by Read was summarily reported by Pinel et al. (1938), and recently a team of Chinese archaeologists and metallurgists has published a more thorough study of the way in which the lion was cast (Wu Kunyi et al. 1984). The following description is based almost entirely on the published accounts.

The rectangular grid of casting seams on the surface of the lion indicates that it was cast by the piece-mould method. When the cope was built up, numerous round-headed wrought-iron spikes were driven into the sides of the core to establish the correct spacing. On the lion's back, cast-iron blocks (called "chaplets" by foundrymen) were used for the same purpose. When the iron was poured into the mould the spikes and chaplets were incorporated into the casting; their traces can be found by close examination of the outer and inner surfaces.

Examination also shows that a reinforcing framework of wrought iron was cast into the neck and back of the lion (see Figure 19), presumably because cast iron alone would not have been strong enough to carry the five-ton lotus plus the bronze bodhisattva.

[12] On the history of the casting see Anon. (1603) 1: 9b–10a, 12b, 8: 12a, 19a–b, 21b, 22b, 43a–45a; Zhang and Xu (1933) frontispiece, 13: 1b–2a, text appendix 1: 26b–27a, 2: 1a–2a, 17a; Read 1936; 1937; Luo Zhewen 1963; Wang Minzhi 1985.

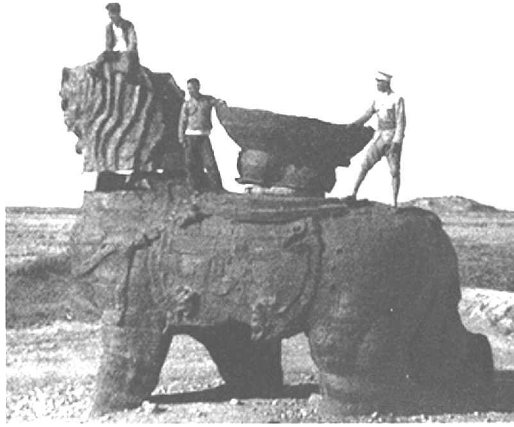


Figure 17. The Cangzhou Lion, photographed by Thomas T. Read at some time between 1907 and 1910. His caption reads, in part (Read 1937: 383): "It . . . was cast in 953 AD in sections, like a concrete building. It was broken, in falling over, into four separate pieces, one of which, the lower jaw, is lying on the ground, not visible in the picture, while the head and the 'lotus seat' have been awkwardly propped in place with slabs of stone, so something of the original appearance has been lost."

Figure 18. The Cangzhou Lion photographed in 1987. Note the modern repair and the missing lower jaw (photo by author).

Figure 19. Inside the head of the Cangzhou Lion, showing more of the modern repairs. Part of the cast-in wrought iron reinforcement can also be seen extending from the center of the photograph to the lower right corner (photo by author).

Figure 20. The rump of the Cangzhou Lion (photo by author).

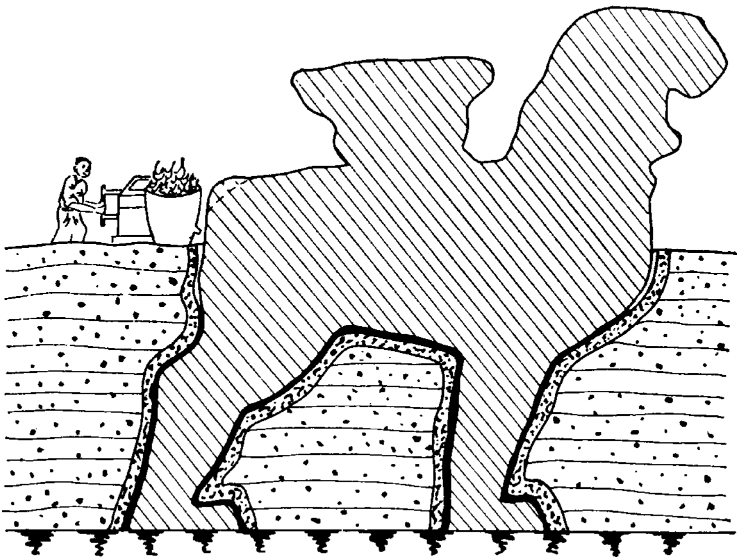


Figure 21. Sketch showing how the Cangzhou Lion was cast (reproduced from Wu Kunyi et al. 1984: 83).

Horizontal lines of what foundrymen call "cold shuts" are found at regular intervals from about middle height upward. A cold shut is a fault in a casting caused by premature cooling in the mould before the mould is filled. These indicate that the lion was cast in several stages. First the outer mould was built up to about half of the total height and iron was cast into this (Figure 21). Hereafter the building of the rest of the mould and the casting into it proceeded upward in alternating stages. Cold shuts severely weaken a casting. The founders were aware of this problem, and dealt with it by inserting pieces of wrought iron into the solidifying iron surface, after each partial pour, to act as pegs holding the separately cast levels of the casting together. The operation was not entirely successful, and some of the pegs were displaced by the hot running metal from their intended positions. Some have since fallen out of the casting, leaving behind characteristic cavities or even holes.

Two chemical analyses are available for samples from the iron lion, the first by Read (Pinel et al. 1938) and the second by the Chinese team (Wu Kunyi et al. 1984). In the chart below, these show (Read above, the Chinese below) the following values (neither report indicates from what part of the casting the sample for chemical analysis was taken):

	Carbon	Silicon	Phosphorus	Manganese	Sulphur
%	3.96	0.09	0.231	0	0.022
%	4.3	0.04	0.087	0.02	0.022

Figure 22. A Qing-period cast-iron gun, photographed at the Great Bell Temple in Beijing in 1984. In 1987 it was no longer there, and I do not know its present whereabouts (photo by author).

The difference between the two analyses, especially with respect to phosphorus, is another clear indication that the casting was not the result of a single uninterrupted pour. The very low silicon content is typical of pre-modern Chinese cast iron: modern ironfounders would prefer an alloy with about 2 per cent silicon for such a casting. Metallographic examination of Read's sample indicates that it is white cast iron, with a streak of mottling (Pinel et al. 1938). The Chinese team took three metallographic samples of the cast iron fabric of the casting, one from the right side of the lion's back and two from the lotus; two of these were pearlitic grey cast iron and one, from the upper rim of the lotus, was white cast iron with a small amount of mottling.

Cast iron artillery

After the Chinese invention of the large gun, apparently in the fourteenth century,[13] the early experience with monumental iron castings served well. The preferred material for guns was for many centuries bronze, but cast iron had such an enormous economic advantage over bronze

[13] On artillery in China see especially Needham 1986; Hu Jianzhong 1986; Liu Xu 1989.

that it was nevertheless widely used for this purpose in China. In Europe the earliest iron artillery was of *wrought* iron (see e.g. Ritter 1938), and the need for a less laborious technique is, in the opinion of many historians, what led to the development of iron casting here.

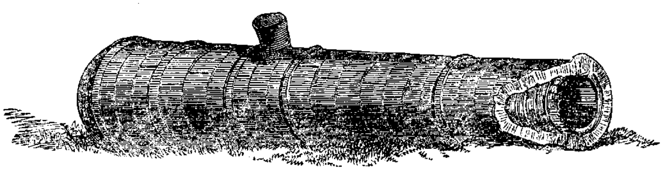
Figure 22 shows an early Qing period cast-iron gun, and it is clear from the lines of casting flash that it was made using the piece-mould method. On the other hand, the gun shown in Figure 23, cast in 1841, does not have these lines, and probably was made using a different moulding technique—perhaps that shown in the drawings and watercolors of Figures 25-28. The cope seems to have been made without a model. It looks as if the core is of wood, but this hardly seems possible, considering the high temperature of the molten iron; however, there seems to be an answer to this problem as well.

There have as yet been no modern metallurgical examinations of Chinese guns, but Figure 24 gives sketches (made by a surgeon in English service in the Arrow War of 1856) of two which were damaged in such a way that something of their internal structure was revealed. In each case a barrel of wrought iron provides strength and toughness while the cast iron which is cast around it provides weight and additional strength. The great difference between early Western bronze and cast iron artillery lay in what happened when a gun failed: a bronze gun merely split, but a cast iron gun shattered and threw fragments in all directions, most often killing the crew as well as any nearby spectators (Rostoker 1986). Combining wrought iron and cast iron in the way seen in Figure 24 provided an economical gun which nevertheless would not fail in this disastrous way. If the gun of Figure 23 has such a wrought-iron barrel (I found it impossible to determine this from inspection alone), it would explain how this could have been an acceptable weapon when it is clearly a "rotten" casting, with large "blowholes" visible in the broken part (these are technical terms used by foundrymen). With a wrought-iron barrel encased in the cast iron, the cast iron would not be required to provide much strength at the muzzle end of the gun.

It seems likely, then, that the wooden shaft inserted into the mould in Figures 27-28 is not a casting core, but is being used to hold a wrought-iron barrel in position while iron is cast around it. The tilt of the mould was necessary to prevent damage to its bottom by the molten iron falling a distance of two or three meters; at some point in the pouring process it would have been raised to an upright position. The use of an open mould like this, with no "casting head," would almost surely result in blowholes at the upper end of the casting.

Another composite gun, shown in Figures 29-30, is in the Capital Museum in Beijing, dated 1643. It has an iron barrel (wrought or cast?),

Figure 23. A cast-iron gun, cast in 1841, photographed in front of the Guangzhou Museum in Guangzhou, Guangdong, in 1984 (photo by author).



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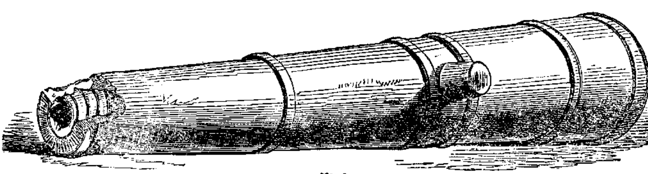
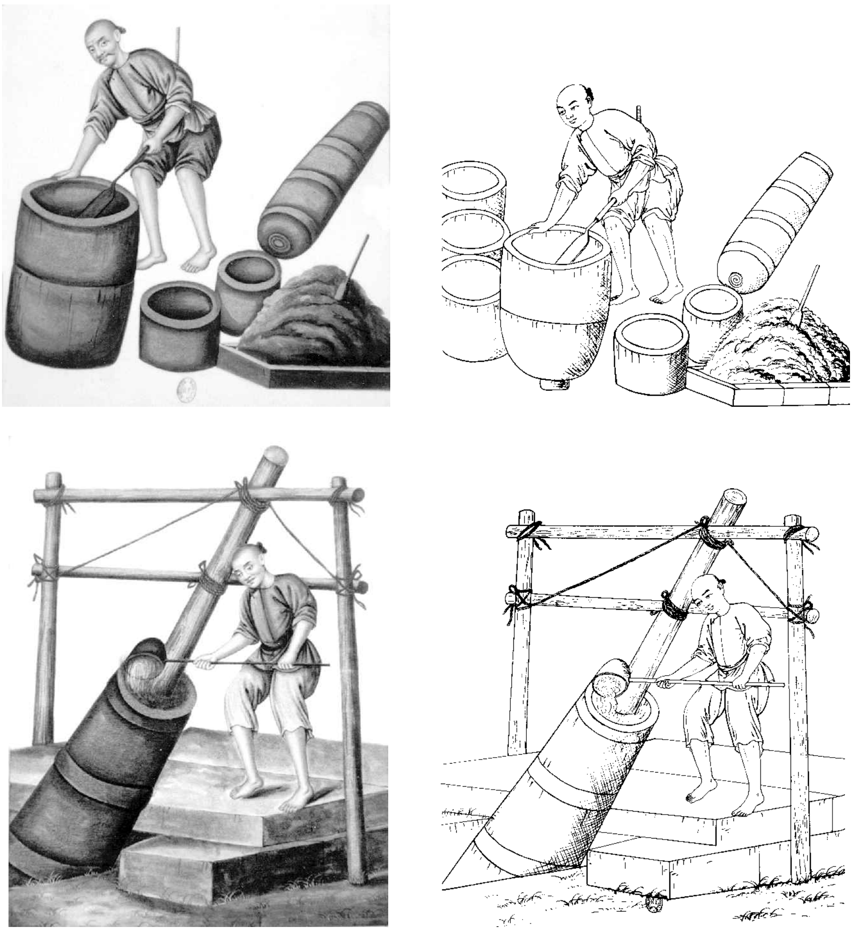


No. 2.

Figure 24. Two Chinese guns sketched in 1860 by George Banks at the Dagu 大 Forts, in modern Tianjin Municipality. Banks believed that these were "evidently very old," from the seventeenth century or before, and while this dating is quite plausible it is not clear what evidence he could have had for it. He does not mention any inscriptions (Banks 1861): "No. 1 had a piece broken from the muzzle, which enabled me to see how it was made. The inner part or bore was made of longitudinal bars, one inch wide and half an inch thick [2.5 cm, 1.3 cm], welded together, and forming a lip where they terminated at the muzzle. Round these, and binding them together, were rings, one inch thick and three inches wide [2.5 cm, 7.6 cm], also welded. Outside these, again, is a layer of cast iron, two inches and three-quarters [7 cm] thick at the muzzle, and of course much thicker at the breech, giving shape to the gun. The faint lines on the surface are caused by the crevices between the bricks of which the mould was built in which the casting took place. This piece is 9 feet 6½ inches long, 23¾ inches diameter at the breech, and 15½ inches diameter at the mouth [291 cm, 60 cm, 39 cm]. No. 2 is a similar gun, but with only rings welded together and encased in cast iron. It is very singular that both these guns should be broken in the same way. It is 9 feet 7 inches long, 2 feet 1 inch diameter at the breech, and 16 inches at the mouth [292 cm, 64 cm, 41 cm]."



Figures 25–28. The moulding and casting of a gun: line drawings and watercolors by unknown Chinese artists. Purchased by members of the Mission Lagrenée in Guangzhou, ca. 1842, and now in the Bibliothèque Nationale, Paris ("Métallurgie du fer," OE 114 4°, nos. 3–4; "Métallurgie du fer," OE 118, nos. 3–4. Cf. Huard & Wong 1966: 199, 217–219) (reproduced with permission of the Bibliothèque Nationale, Paris).

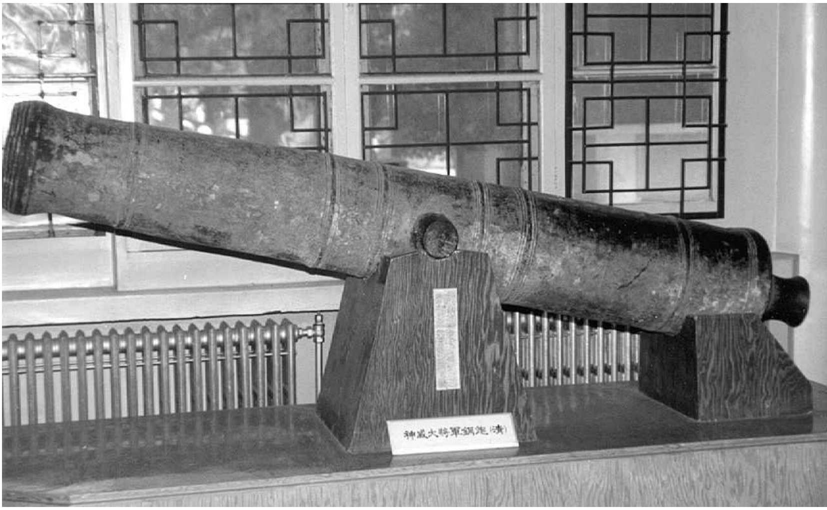


Figure 29. A large gun in the Capital Museum (Shoudu Bowuguan 博物館 Beijing, cast in 1643. Cf. Figure 30 (photo by author).

Figure 30. The muzzle of the gun in Figure 29. Note that it is iron on the inside and bronze on the outside (photo by author).

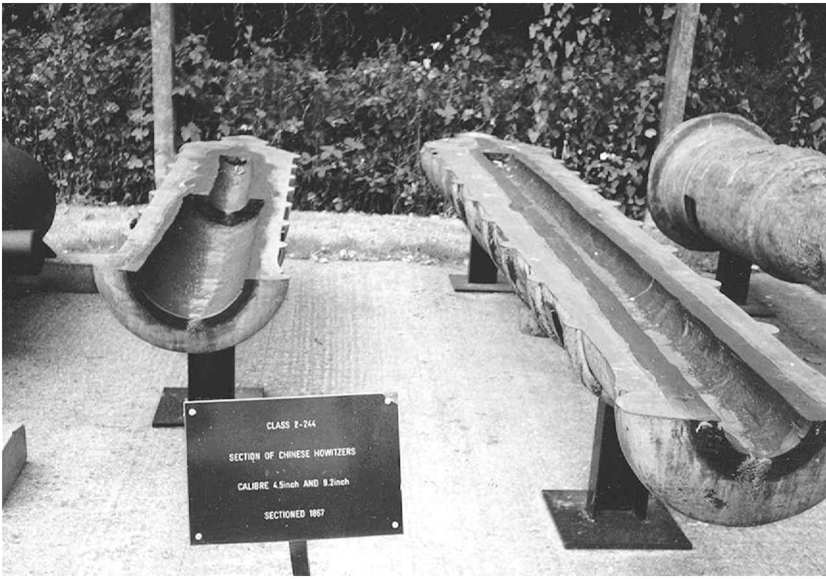


Figure 31. Longitudinal sections of two Chinese bronze–iron guns, captured by British forces in the Opium Wars and subjected to a technical investigation in 1867. Rotunda Museum, Woolwich, no. 2-244, photographed 1996. The iron parts have been painted black to prevent rust, and it is important to note that the boundary between bronze and iron parts cannot be accurately distinguished in this photograph or Figure 32. On the gun on the left part of a long inscription remains, but as far as I could see the remaining part does not include a date (photo by author).

around which bronze has been cast.[14] Two other Chinese bronze-iron guns, captured by British forces in the Opium Wars, were the object of a technical investigation by the Royal Armoury in 1867. The guns were sectioned, revealing their structure very clearly (see Figures 31-32). In Figure 32 can be seen a clear boundary between an inner and an outer layer of the iron; apparently the outer layer of iron is cast iron, cast around the inner layer, which may have been wrought or cast.[15]

[14] Still another interesting use of a composite of materials is a small gun in the Tower of London, which was captured by English forces in the Opium Wars. It has an iron barrel wrapped about with layers of silk cloth; I do not know whether the barrel is cast or wrought. Silk is about as strong as wrought iron, but much lighter and also much more elastic, and no doubt this made an excellent portable weapon. A photograph of the artefact can be seen in Anon. (1988).

[15] A metallographic examination of these guns will soon be published by Brian Gilmour of the Material Science-Based Archaeology Group, Department of Materials, University of Oxford.

Figure 32. Detail of the gun on the left in Figure 31. The arrows indicate the boundary between two layers of iron (photo by author).

Corrosion

Many of the castings discussed in this article have stood exposed to the weather for centuries, but they are surprisingly free of rust. How is this possible? One important factor is that they are so massive that, after being warmed by the sun during the day, they retain enough heat through the night that the morning dew does not settle on them. It appears, however, that this is not the only reason: early Chinese cast iron does seem to be more resistant to rust than modern cast iron. An example can be seen in Figure 33: inscriptions indicate that the lower section of this incense burner (the bottom half of the vessel and legs) is original, cast in the Ming period, while the upper section (the shoulders and rim) is a replacement, cast in 1934. The upper section is badly rusted, while the lower is quite free of rust. In conversations with metallurgists I have often heard the opinion that a low sulphur content in the older cast iron may be responsible; but many of the ancient bells probably have high sulphur. Another possible factor is the low silicon content of the older cast iron. A series of laboratory experiments which I performed some years ago required the deep-etching of some cast-iron samples with concentrated hydrochloric acid to reveal the microstructure of their graphite. In doing this I noticed that there was at

Figure 33. An incense burner photographed in Hangzhou 州 in 1984. The lower half of the vessel (bottom bowl and legs) is original, cast in the Ming period; the upper section (shoulders and rim) is a replacement for a lost piece, cast in 1934. The join occurs at the widest body diameter (photo by author).

least a ten-fold difference in the speed of etching, apparently depending only on the silicon content of the iron, which varied between 0.2 and 2 per cent.

Conclusion

In the artifacts discussed here we see some of the ways in which Chinese foundrymen took ancient methods and developed them in response to new technical challenges. White cast iron is much more difficult to cast than bronze, requiring higher temperatures and sophisticated mould design, and the large size of these castings meant larger melting furnaces as well as arrangements for quick transfer of large quantities of molten metal to the mould. The Cangzhou Lion was too large for a single pour with any melting arrangements which its founders could provide, and instead an interrupted pour was used, giving further technical problems to be solved. The hardness of white cast iron meant that "flash" had either to be minimized in the mould design, or incorporated into the décor, or hidden with a covering of some sort. The poor strength and toughness of this material was dealt with by the incorporation of wrought-iron reinforcements in the Cangzhou Lion and in some later guns; this seems to have led to the development of a new casting technique for guns. Continuity and change are both obvious here; both must be taken into account in an understanding of traditional Chinese technology.

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