The ancient Chinese casting techniques

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Abstract: In the course of Chinese civilization, which lasted more than 5,000 years, casting production has made a huge contribution. In this paper, some representative metal castings were presented. According to their forming techniques, they can be grouped into stone mould casting, clay mould casting, ablation casting, lost wax casting, stack casting, permanent mould casting, sand casting, etc. According to their materials, they can be categorized into tin bronze, bimetallic bronze, malleable cast iron, ductile cast iron, brass, cupronickel alloy (Packtong), etc. According to their surface decorative techniques they can be devised into gem inlay, gilding, gold and silver inlay, copper inlay, engraved decoration, surface tin-enrichment, mother-of-pearl inlay, burnished works with gold or silver inlay, surface coloring and cloisonné enamel, etc.

Key words: ancient Chinese; casting techniques; alloying; surface protecting and decoration

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The more than 5,000 years of Chinese civilization is a civilization that created by bronze and iron. During the long process of history, the foundry industry has made a huge contribution. Many casting techniques, non-ferrous metal & ferrous metal, and the surface decorating techniques were successively invented and developed.

1 An overview of the ancient Chinese casting technologies

1.1 Stone mould casting

The earliest stone mould found in China is from Xia County, Shanxi province which was used to cast an adze ben (a farm tool).

It was dated to Xia Dynasty (2070 BC−1600 BC, See Fig. 1).

A stone mould casting is only used to cast a simple object, but it could be reused for many times. So it was usually used to cast tools. Up to the present, it is still used at some remote mountainous areas.

Fig. 1: A stone mould, Xia Dynasty (2070 BC−1600 BC), length: 6.5−6.9 cm, thickness: 3.4−3.9 cm

1.2 Clay mould casting

The clay mould material is made by firstly mixing the clay with precalcined clay and plant ash, and then mixing with water. The production period is very long, but clay moulds have a good filling and copy ability, suitable green and dry strength. It can be used to cast not only the thin-wall objects with fine decoration, but also the large-scale heavy section ones.

The clay mould casting had been one of the most important techniques all the time in ancient China, especially in the Chinese Bronze Age. The abundant excellent bronze ritual wares with elegant decoration and complex shape had appeared, please see Figs. 2−7.

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Fig. 2: Clay pattern (a) and mould (b) with line decoration excavated from Houma City, Shanxi Province, the Spring and Autumn Period (770 BC–476 BC). Size: 20 cm × 18.5 cm

Fig. 3: You (Tiger cannibalism wine container), late Shang Dynasty. Height: 35.7 cm, weight: 5.09 kg. The movable handle was cast-on to the body which cast in one-piece mould.

Fig. 4: Four Rams Shaped Zun (a wine vessel), late Shang Dynasty. Height: 58.3 cm, weight: 34.5 kg. The ram’s curled horns were first cast separately and then cast-on to the ram’s heads.

Fig. 5: The Chime Bells of Marquis Yi of Zeng State, Early Warring States Period (5th–4th century BC). The bell cot (frame) has a length of 748 cm, a width of 335 cm and a height of 273 cm. The whole set of 65 chime bells weighs 4.4 t. All bells cast in one piece and their thicknesses were controlled while designing and casting. Each bell can play two tones and the chime bells could play eight musical scales.

Fig. 6: Iron Oxen, cast in 724 AD, Tang Dynasty. Length: about 3.32 m, weight of each: about 70 t. Four oxen have stood at the side of Yellow River to be pillars of the bridge for more than one thousand years. They were cast in one piece.
1.3 Ablation casting

The ablation casting uses some kinds of fiber materials such as rope to be the pattern to make the clay mould. After baking, the pattern is ablated and the ash can be removed from the clay mould. The earliest bronze rope-shaped handles were cast by this kind of technique in early Shang Dynasty in China. This technique has been used for about 800 years in ancient China (see Figs. 8–9).

1.4 Lost wax process

The earliest lost wax castings appeared in late Spring and Autumn Periods (770 BC–476 BC). It has been used for about 2,600 years in China until now. In the lost wax process, patterns were made of wax, which melts or burned away when the mould was heated. This make it easier to cast complicated objects such as three-dimensional openwork and deeply undercut or twisting parts, as shown in Figs. 10–12.
Fig. 11: Zun and Basin of Marquis Yi of Zeng State. Early Warring States Period (5th century BC–4th century BC). Height of Zun: 30.1 cm, height of Basin: 23.5 cm. The sketches show three-dimensional complicated openworks. They were the masterpieces of the lost wax casting.

Fig. 12: Gilt bronze Yamantaka Mandala. In the reign of Emperor Yongle, Ming Dynasty (1403 AD–1424 AD). Height: 82 cm

1.5 Metal mould Casting

The use of iron mould to cast a batch of iron castings has been introduced in the Warring States Period, about 2,000 years ago. Some iron cores were also used in the iron mould casting. The metal mould casting was mainly used for the production of agriculture tools, hand tools and chariot fittings. It increased the productivity and contributed greatly to the social progress.

Before an iron object was cast by the iron mould casting, an accurate iron mould need to be cast first used the clay mould. The working procedure was complicated and highly qualified, as shown in Fig. 13.

Using bronze mould to cast bronze objects like bronze coins in batch was started in Warring States Period, as shown in Fig. 14.

Fig. 13: Casting process of iron tool ploughshare, Han Dynasty
1.6 Stack mould casting

Stack-mould casting was used to cast bronze coins in Warring States Period, and in Han Dynasty it was widely applied in producing coins, horse harnesses and chariot fittings, weighing apparatus and so on. Popularity of stack-mould casting technology greatly enhanced the social productivity at that time.

Bronze master mould for making clay moulds must be carefully designed and cast. They have high precision and well symmetry and any pair of moulds could be closed well to make a complete mould. It indicated that the casting techniques had achieved a very high level 2,000 years ago.

1.7 Sand mould casting

The sand mould casting was used to cast coins in Southern Dynasty (about 420 AD–479 AD), and was popular later. The two major moulding materials were fine sand and charcoal powders in Ming Dynasty. The record about the casting process of coins can be found in the ancient book "Tian Gong Kai Wu", Ming Dynasty.

2.2 Bimetallic casting

There were two kinds of bimetallic castings in Chinese Bronze Age, i.e. the bronze and iron bimetallic casting, and bronze casting that has different tin content in different position of the casting.

As early as late Shang Dynasty, ancient Chinese metalworkers had produced weapons by combining aerosiderite and bronze (see Fig.16). With the discovery of iron smelting technology in the Spring and Autumn Period, man-make iron and bronze bimetallic castings were invented (see Fig.17).

2 An overview of the alloys of ancient China

2.1 Tin-bronze formulas

The ancient book "Kaogongji", written in the 5th century BC and reedited in Han Dynasty, is the earliest literature known in the world to discuss copper and tin formulas. It recorded six formulas of copper and tin to cast vessels with suitable functions, bells with good sound, weapons or tools with high mechanical properties, mirrors with bright surface. The formulas of copper and tin recorded in the book were a little higher than the actual ones, but the trend was the same. The bronze bells had a higher tin content than bronze vessels; the bronze weapons or tools had a higher tin content than bells; the mirrors had the highest tin content than any other kind of bronze objects. It showed that the ancient metalworkers already understood how to cast different objects by control of the tin amount.
Another kind of bimetallic casting was to combine high-tin bronze with low-tin bronze in order to make the casting is not only strong but also soft (see Fig. 18).

Fig. 18: A bimetallic sword, the Spring and Autumn Period. Its blade was made of high-tin bronze and its spine was made of low-tin bronze.

2.3 Paktong

There were two kinds of paktongs: nickel paktong and arsenic paktong.

(1) Nickel paktong

Nickel paktong was used to cast commodities like stationeries and water pipes, in Eastern Jin Dynasty (317 AD–420 AD), see Fig. 19. It was introduced to Europe after 18th century and called “Chinese Silver”. In 1823, England and Germany copied it successfully and then changed the name into “German Silver”.

(2) Arsenic paktong

Arsenic paktong was found through ancient alchemy practice in Jin Dynasty (265 AD–420 AD).

Fig. 19: Some nickel paktong mini inkstone box, Qing Dynasty (1644 AD–1911 AD)

2.4 Brass

The metallurgical technology of brass was introduced from Persia. The earliest record about it in China was in Song Dynasty (960 AD–1279 AD). Then brass gradually replaced bronze in China, see Fig. 20.

Fig. 20: The Wudang Golden Temple (a) and the Taoism Statue (b) at Wudang Mountain, in the reign of Emperor Yongle (1403 AD–1424 AD), Ming Dynasty. Height of the temple: 5.4 m, depth: 4.2 m

2.5 Malleable cast iron

Ancient Chinese craftsmen invented iron casting techniques in the Spring and Autumn Period (770 BC–473 BC). 2,000 years ago, during Warring States Period (476 BC–221 BC), craftsmen had already found out the way to make iron more strong and tough.

Cast iron tools were widely used in China in the over one thousand years of the beginning of the Warring States Period (476 BC–221 BC). It made a great contribution to the social development of China (Fig. 21).

Malleable cast iron was made from the high carbon and low silicon cast iron through two kinds of the annealing atmosphere: oxidizing atmosphere and neutral or weak oxidizing atmosphere. Five kinds of malleable cast irons can be produced: the incompletely decarburized whiteheart malleable iron, the whiteheart malleable iron, the cast-iron decarburized steel, the blackheart malleable cast iron and the ductile cast iron.
(1) Under oxidizing atmosphere, the incompletely decarburized whiteheart malleable iron, the whiteheart malleable iron or the cast-iron decarburized steel could be obtained. Their properties become better from brittle to bendable along with the constantly advanced fabrication techniques.

(2) Under the neutral or weak oxidizing atmosphere, two kinds of cast irons could be obtained: the blackheart malleable cast iron, which graphite shows flocculated or cauliflower-shaped structure; and the ductile cast iron, which graphite was nodular, by spheroidization annealing treatment (see Figs. 22–23). Ancient Chinese craftsmen used charcoal to smelt iron ore and got low-silicon cast iron. The ductile cast iron could be made from low-silicon cast iron just by annealing treatment for a long time and did not need any nodulizer. Iron tools which were made of these two kinds of materials had high qualities.

3 Surface decoration and protection techniques

In the 5,000-year history of metallic techniques, a lot of surface treatment and surface protection techniques were created. Some representative ones are introduced as follows.

3.1 Gem inlay

As early as the Erlitou Culture Period (about 3,800–3,500 years ago), turquoise inlay technique appeared. Some bronze wares inlaid with turquoise were unearthed at the Erlitou Culture sites. Since then, gem inlay technique was used to decorate Chinese ancient bronzes.
3.2 Gold and silver gilding

Till now, the earliest gilding bronze ware being found was cast in late Spring and Autumn Period or early Warring States Period. Gilding technique reached the peak in Han Dynasty (206 BC–220 AD), as shown in Fig. 26 and it is still in use up to the present.

In addition, the overlaying technique with gold leaf/foil was also used for decoration.

Fig. 26: Gilding bronze incense burner, Han Dynasty (206 BC–220 AD)

3.3 Gold or silver inlay

The earliest bronze ware with gold inlay was bronze Wei (a part of chariot) with dragon design which was unearthed from Yin ruin. So this technique was already invented in late Shang Dynasty (14th–11th century BC). It became popular in Eastern Zhou Dynasty (770 BC–256 BC) and is still in use up to now (see Fig. 27).

3.4 Copper inlay

Copper inlay had appeared in Shang Dynasty (16th century BC–1046 BC) and began to prevail in the Spring and Autumn Period (770 BC–476 BC). Ancient Chinese craftsmen not only inlaid copper into groovy, but also cast copper on bronze body (see Fig. 28).

3.5 Engraved decoration

Since the iron tools appeared, a new surface decoration technique has been invented. The emergence of the engraved line decoration occurred in the late Spring and Autumn Period or even earlier. It is using iron tools to engrave line decoration on the surface of thin-wall bronze wares. Most of them were vivid scenes of hunting and battles and were very different from cast patterns, as shown in Fig. 29.

3.6 Surface tin-enrichment

Ancient Chinese craftsmen invented several kinds of surface tin-enrichment techniques to decorate and protect bronzes. There were mainly three methods: rubbing tin-enrichment, paste diffusion tin-enrichment and hot tinning.

The rubbing tin-enrichment technique was that: (1) making a mirror-polishing powder of tin amalgam; (2) rubbing on the mirror surface with the powder at room temperature. Tin will diffuse into mirror’s surface to form a tin-rich layer
which the tin content was up to 60%. The tin-rich layer will be oxidized later and a thin SnO₂ layer will be formed. This layer has a high corrosion-resistant ability and can prevent the mirror from corroding for a very long time (see Fig. 30).

3.7 Mother-of-pearl inlay

Mother-of-pearl inlay can form a very colorful decoration on a metal surface. The process was that: (1) polishing the mother-of-pearl pieces; (2) sticking them onto a metal surface; (3) burnishing the surface; (4) carving patterns on the mother-of-pearl pieces. This kind of decoration technique became a trend in the reign of Emperor Xuanzong (685 AD–762 AD), Tang Dynasty.

3.8 Mirrors with gold or silver leaves adhering

Mirrors with gold or silver leaves adhering were famous luxury goods in Tang Dynasty (618 AD–907 AD). They were very exquisite and refined. Emperor Xuanzong often rewarded them to minions and envoys. The manufacture process was that: (1) lacquer on the back of a mirror; (2) adhering the gold and silver leaves on the lacquer; (3) polishing the surface; (4) engraving patterns on the gold and silver leaves.
3.9 Variegated copperware
Variegated copperware was cast by special brass and showed a variegated surface after annealing (see Fig. 34). It was invented 300 years ago.

3.10 Surface coloring
The best famous "Xuande Incense Burners" were produced by the lost-wax process in the reign of Emperor Xuande (1428 AD), Ming Dynasty. More than sixty colors were found on their surfaces (see Fig. 35).

3.11 Cloisonné enamel
Enamel ware has beautiful coloring patterns. Most of them were for emperors and their families, see Fig.36.

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