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Lost-Wax Casting in Ancient China: New Discussion on Old Debates

WEIRONG ZHOU[1,2] and WEI HUANG[1]

1.—China Numismatic Museum, 17# Xijiaominxiang, Beijing 100031, China. 2.—e-mail: 5378432@qq.com

The possible use of lost-wax casting in China has long been a matter of controversy. Based on the study of pertinent ancient texts concerning the technical origins of lost-wax casting in China, direct examination of questioned ancient Chinese bronzes as well as definite lost-wax castings from both overseas and China, and modern production of objects using piece-mold casting, the authors point out their own conceptual ideas about ancient lost-wax casting as follows. First, the lost-wax casting technique does not have its earliest origins in ancient China but rather from the Sumerians in Mesopotamia, where it was predominantly used to cast small human and animal figures (statuettes). Next, some essential characteristics of the lost-wax casting technique can be identified from the point of view of a distortable soft starting model. The locally deformed shape of lost-wax castings is found to be variable. Finally, it is improper to consider the ease of extraction from the mold as the criterion for distinguishing lost-wax casting from piece-mold casting. It is therefore incorrect to conclude that the three-dimensional openwork decorations present on Chinese bronzes from the Spring and Autumn Period, and the Warring States Period, are fabricated using lost-wax castings.

INTRODUCTION

In the early 1900s, Western scholars suggested that lost-wax casting had been used to produce the Shang and Zhou dynasty bronzes.[1–3] This opinion has been gradually rejected and replaced by the belief that piece-mold casting was the production route, because of new excavations and research after the 1950s in China. However, since 1979, when the *zun* (Fig. 1) and *pan* vessels from the tomb of the Marquis of Yi were unearthed in Sui county, Hubei province, and a bronze *jin* was unearthed from the Chu State tomb at Xiasi, Henan province, these and other openwork bronzes have evoked debates on the possible presence of lost-wax casting in ancient China. The use of lost-wax technology to produce bronze objects in the pre-Qin dynasty was therefore again proposed at a meeting about traditional precision casting held by the Casting Institute of the China Mechanical Engineering Society. However, since 2006, the current authors have pointed out that lost-wax technology could not have been used in the previously well-developed piece-mold casting system already in place in Bronze Age China;[4–6] this view is drawn from combined research of historical documents and casting experiments over the past 10 years.

LOST-WAX CASTING IN ANCIENT CHINA

The history of the origin, spread, and technological development of lost-wax casting (cire perdue, or investment casting) in the Western world is well established and documented.[7–11] This is also supported by the many artifacts that have been found to verify this technology.[12–15] In ancient China, the first records found to relate to a wax model are in an institutional history of the Tang dynasty entitled *Tang Huiyao* (an official book of the Tang Dynasty) which stated that "according to the book *Huicui* written by Zheng Qian, the original wax coin model presented by Ouyang Xun for coinage was always touched by Queen Wende's fingernail during censoring, such that her mark was impressed on the reverse side". However, this does not mean that the

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Fig. 1. Zun vessel of the Marquis of Yi.

lost-wax method was applied to cast coins during the Tang dynasty (618-907 CE), because all Tang dynasty coins were made by sand-casting,[16] but this historical document does tell us that wax had been applied to make a model in the Tang dynasty. Further written evidence with a description of details concerning the lost-wax technique is found in the Song dynasty's book—*Dong Tian Qinglu* (a book finished between 1225 and 1264 CE by Zhao Xigu of the southern Song dynasty). It documents the entire process of lost-wax casting at that time as follows: "In ancient times, a wax model must be prepared before casting of utensils or vessels. The wax model was finished … with patterns and inscriptions, then it was put it into a slightly larger container with a little bit of a seam at the bottom, pouring the dilute clay and water which were mixed well, repeating the procedure after drying each day until the wax model was totally protected by clay. Getting rid of bucket and covering with a mixture of fine-grained loess, salt and paper scraps on the outer clay layer, then adding loess on it. … Of course, a hole should remain through the inner core, which provides the channel for pouring the liquid alloy. However, the casting process was not usually successful for every one. So, such cast objects were valuable."

Tiangong kaiwu (*The Exploitation of the Works of Nature,* a Ming Dynasty encyclopedia) described the lost-wax cast process as follows: "The casting method for the great bell is the same as its tripod. Dig a deep pit, keep drying and then tamp it, [in a shape that] looks like a house. Mud mixed with lime, fine sand, and clay were used for inner model skeleton without any break. After drying, butter and beeswax were applied on the surface of some *cun* (a linear measure) in thickness. The proportion of butter and beeswax were 80% and 20%, respectively. Build a high shed for a bell model in order to protect against the sunlight and rain (in summer, this process does not work because the butter will not freeze and cannot be manipulated). The wax layer is trimmed with a knife, and the various characters and decorations can be engraved on the surface perfectly according to the requirements. Fine mud is made by [mixing] clay and carbon powder and after careful fine processing and filtering, is mixed with water, applied on the surface of butter and wax with some *cun* in thickness. After complete natural drying throughout the layers, heat slowly which makes the butter and wax melt and escape entirely from the hole in the model. So the cavity between inside and outside model would be substituted for the liquid metal to shape the bell and tripod."

Three traditional Chinese lost-wax methods are of interest for the current discussion: *Bo lafa*, *Tie lafa*, and *Shuan kefa*. *Bo lafa* is the most common, using a directly made wax model. *Tie lafa* uses a clay inner core with wax pieces finger-pasted over the core, and *Shuan kefa* is an indirect lost-wax model method that uses an assemblage of cavity blocks, duplicated from original models, into which the wax is poured in order to produce the final wax model.

Yin dian [a book for seals (stamps) in the Qing Dynasty] described the lost-wax process as follows: "Using *Bo lafa,* the stamp model was made using beeswax and rosin, then engraving decorations, and making the button. Apply baked clay, dry and add more raw clay. Then heat to drive the wax out completely, and bake the clay well. Melt and pour the alloy. Finally, the characters on the stamp and button were clearly formed."

There were two kinds of wax used for the *Bo lafa* technique. One was used for casting objects without decorations, melting the rosin completely, then adding vegetable oil in defined amounts, and mixing it uniformly. The amount of oil used in the spring season was the same as in the autumn, but half the amount was used in summer, and double in winter. The other type of wax was used for objects with a decorated surface, and by mixing the beeswax and vegetable oil, which makes it soft, the method was similar to that using rosin. For casting a metal seal, first make the model skeleton with rosin in advance, then by covering the outer layer with beeswax, the button model and its engraved characters would be perfect.

Pure and fine clay powder mixed with straw scraps was used for seal molds: baking it completely, cooling, grinding it to a powder, mixing with raw mud (liquid) uniformly, covering the surface of the wax, then drying in sunlight or open-air, but do not heat. If the mold was made with raw clay, the liquid metal could not be poured in, and some hollow voids would be formed during casting. Refined clay usually contained chaff, feathers, broken rice and so forth; therefore, the liquid metal would not fill the space occupied by these materials. Generally, baked mud was covered over the wax, then raw clay was

added on the outer layer of the baked mud. After casting, raw clay could be reused as baked clay.

The technical characteristics of lost-wax casting in ancient Chinese documents can be summarized as follows. First, wax material was directly shaped and engraved starting from the Song to early Qing dynasty, using *Bo lafa* and simple direct lost-wax casting. *Tie lafa* and *Shuan kefa* had not yet appeared during this period. Second, lost-wax technology became developed during the Song to Qing dynasties. The material for models used in the Song dynasty was made only of beeswax. Beeswax and butter were used in the Ming dynasty, and rosin was introduced in the early Qing dynasty. Therefore, the raw material for the model used in ancient Chinese lost-wax casting had undergone ongoing development and change of procedures, not always generally using beeswax, rosin and fat, as some scholars have suggested.[17] Third, lost-wax technology described in the ancient Chinese books *dong tian qing lu*, *tian gong kai wu* and *yin dian*, cannot be used to cast the very complicated or reticulated interlaced openwork bronze objects because the casting mold is unable to support the weight of the thick wet clay material. Therefore, scholars and their academic circles considered that the *zun* and *pan* of Marquis Yi of Zeng, and the openwork bronze of Marquis Ning of Xu, were made by lost-wax technology in ancient times because of the successful modern duplication using lost-wax casting.[18,19] This paper proposes an alternative view.

Ancient, Traditional and Modern Lost-Wax Casting in China

Confusion has often existed concerning ancient, traditional and modern lost-wax casting. We believe that there was no unique or special development of Chinese traditional lost-wax casting, but rather it has been based on the early fundamental techniques of ancient lost-wax casting, only adding contemporary materials and technical environments. The traditional lost-wax casting described today is based on technology derived from the late Qing dynasty, and its continued development is aimed at duplicating bronze objects, such as cast animal figures and statue-like figures. These so-called traditional technologies could be simply interpreted as the direct and indirect lost-wax casting processes.

Direct lost-wax casting involves a wax model shaped by hand and with some ancillary implements. It is the most basic technique for lost-wax, also the oldest way for casting god-like, human and animal statuaries, just as lost-wax castings were made in ancient Mesopotamia.[20] This method has always been utilized from ancient times until the present for casting Buddhist images and similar objects. No two identical objects are made by this technique because a unique model is used and destroyed during this process. A direct lost-wax casting could also be fabricated by another approach. Wax subsections made by using a die and other implements are pasted on a shaped inner core model, followed by rolling the wax piece to the desired thickness of the final casting, then amending the thickness of the wax piece. For decorative parts, a template is engraved using a hardwood tool, the wax is then impressed into it and the wax acquires the decoration shape and is then attached to the corresponding main part. This technique originated from the bronze duplicating workshop at Suzhou in the Republic of China, and is also the given name 'Suzhou piece method',[21,22] It is also utilized to duplicate ancient bronzes using cavity blocks that are first made from an original object, and wax pieces are then attached onto the inner layer of the block. The inner core (or core mold) is finished after assembling all the cavity blocks, and the wax pieces are therefore pasted onto the core after removing the clay cavity blocks.

Indirect lost-wax casting is a technique developed in modern industrial production for duplicating ancient bronzes or casting other metal art products. A concave mold is first made from the original object, the mold sections are then bound together, molten liquid wax is poured into the mold, solidifying to the desired thickness, and the excess wax and mold are removed producing an integral finished wax model. This technique is beneficial for rapid and massive production, but decorations are often vague due to insufficient pressure used during shaping of the wax model, and the thickness of the final object is uneven owing to the variable thickness of the wax model.

Although the methods used for traditional lost-wax casting are not identical to ancient lost-wax casting methods developed over the history of Chinese lost-wax technology, there are many similarities.

PIECE-MOLD CASTING IN BRONZE AGE CHINA

The Development of the System of Piece-Mold Casting

Any technology is usually synchronous with the context of social development. It does not overstep or lag contemporary requirements, and this is exemplified by the development of piece-mold casting technology in Bronze Age China. The systematic development of piece-mold casting experienced during pre-Shang, Shang, western and eastern Zhou periods corresponded with other crafts in every period.

From the Xia to early Shang period, bronze piece-mold casting existed in a preliminary phase. Parting designs and stamping of figures onto the piece-mold were adopted in order to obtain a complete mold. Preparation and design for an object to be cast consisted of a model and mold that were needed for casting each time, and decorative patterns were

made by hand by individual craftsmen on the surface of the mold.

After the middle Shang period, the increasing demand for bronzes promoted further development in piece-mold casting technology, and brought about the use of a pattern model technique such that the basic pattern was finished on a model and this was then directly impressed onto the mold surface, improving production efficiency. During this same period, pasting of mud strips onto the assembly was also invented. These new techniques made it possible for large-scale pattern manufacturing after the western Zhou period, and some pattern groups are often found on the bronzes dating to that period.

Ritual bronzes began to be integrated into the lives of the common people after the Spring and Autumn period, together with the production and use of many other metal farm implements, instruments and weapons. The casting sections were sometimes divided into many units; for example, the main part and appendages were commonly cast individually and then assembled, which facilitated large-scale production. If an object was complicated, it could be cast by piece-mold casting during the Spring and Autumn and Warring States period. Piece-mold casting at this time not only enhanced the production efficiency but also considerably fulfilled the social requirements for bronzes.

Piece-mold casting technology was able to completely satisfy the need for casting various bronze objects in Bronze Age China based on a full understanding of the development of its technological history. A great number of piece molds have been excavated from bronze casting sites at Houma Shanxi province,[23] and the perfection of the patterns that were produced can be seen from the surfaces of the molds and models shown in Fig. 2a–d; furthermore, these patterns demonstrate many of the features of typical three-dimensional openwork structures.

Piece-mold casting technology evolved into an extremely well-developed system during the Bronze Age of China, and it paralleled the social development of that time. It thus appears likely that, on the one hand, any object that would be produced during that time would depend on the currently existing technological system that was already in place, and that, on the other hand, this existing technology could support the design needs required to cast any form of the objects produced.

We are of the view that the lost-wax casting technique stems from the modeling art developed in the early ancient western world and evolved within its own system and social requirements. In Bronze Age China, however, there is not the technological basis nor an objective social requirement for lost-wax casting. Therefore, such a technology without local technological evolutionary development and without the necessary social environmental requirement could not develop and come into being.

The Technical Aspects of Piece-Mold Casting

As can be seen from the Houma molds and models in the figures, the piece molds and patterns are quite distinct and tidy, but these individual parts could be assembled together to produce an integrated entity used to produce a very complex casting. A residual feature of this type of assembly is that the casting lines between mold sections remain on the surface after casting, due to the mold seams; these casting seam lines are the principal characteristic for the identification of piece-mold casting. Moreover, different parts of the model design have recognizable parting faces which enable separation of the mold from the model. Smooth, clean parting faces are also a typical feature of piece-mold casting. Mold seam lines and parting faces are the essential characteristics that distinguish piece-mold casting from lost-wax casting.

TECHNICAL CHARACTERISTICS AND IDENTIFICATION OF LOST-WAX CASTING

The identification of the processing route of an ancient Chinese bronze object to have been fabricated by lost-wax casting is unclear. During the past 30 years, the presence of very complicated shapes, especially curvature which makes it difficult to extract a cast object from its mold, has always been the principal proof for deciding if an object was

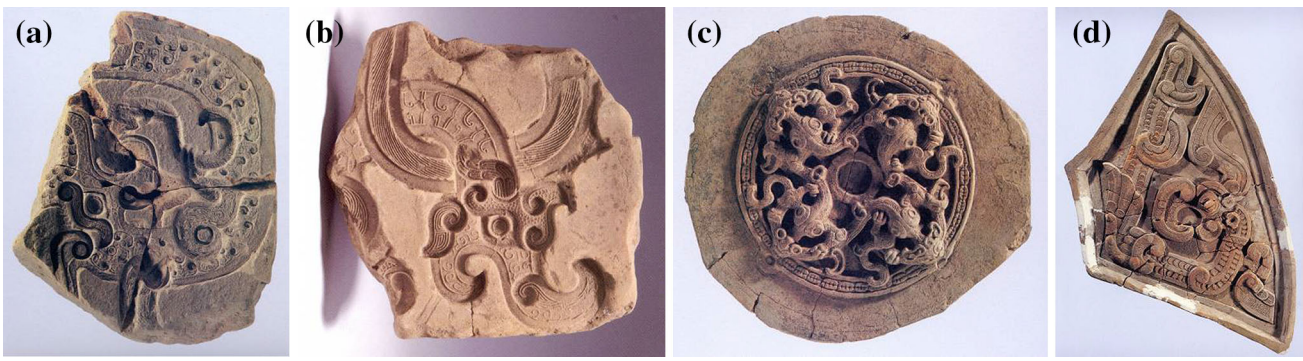

Fig. 2. Piece molds and models unearthed from the Houma site. (a) Kuilong decoration mold. (b) Another Kuilong decoration mold. (c) Danglu model. (d) Part of a bell model.

Fig. 3. Tang dynasty Buddha statuary in the Capital Museum Beijing (a, b).

Fig. 4. Lost-wax Buddha statuary Tang dynasty.

made using lost-wax technology. In our opinion, this is not a proper criterion for deciding the process route, and so far no convincing logical criteria for technical interpretation has been presented.

The use of a deformable, flexible, or distortable soft mold or model is the key characteristic for identifying lost-wax casting, whereas a hard mold or model is indicative of piece-mold casting, and these are the essential distinctions between lost-wax and piece-mold casting. The present authors have used the following criteria for the past 10 years:

(1) Distorted appearance. Lost-wax castings show a free extension in all dimensions due to the use of a soft wax model which can be easily shaped (Fig. 3a, Tang dynasty Buddha statuary presently in the Capital Museum, Beijing).
(2) Softness of form. A soft wax model can be easily used to produce elegant, streamline castings. Figure 3b is another Tang dynasty Buddhist image, also currently in the Capital Museum, Beijing It was definitely cast by lost-wax technology according to the detailed observation and research by the authors as well as by other investigators. This lost-wax casting shows completely tender, stretched characteristics.
(3) Unclear parting surfaces. Soft wax models would not indicate forceful, sharp, clear profiles and decorations of castings. The base plane of the undecorated areas often illustrates unevenness and undulating features. Ridges and spines are also intermittent, variably convex and concave, as can be seen from Fig. 4, another lost-wax Tang dynasty Buddha statuary in the Capital Museum, Beijing.

THE CASTING METHOD FOR THE OPENWORK BRONZE

The openwork bronze castings (questionably said to be lost-wax castings) of the *zun* and *pan* of the Marquis Yi of Zeng show casting lines left by the parting faces, which are impossible to have been left using lost-wax casting. Furthermore, this observation entirely negates the conclusion of casting by the lost-wax method, as suggested previously. In fact, we propose and demonstrate that the casting method for these openwork bronzes developed directly from ceramic piece-mold casting. We believe that the incorrect attribution of lost-wax casting to openwork bronzes is the result of a lack of a full understanding of the technological and social context of piece-mold casting in Bronze Age China, which prevented the relationship between model, mold and core being analyzed correctly.

Wang Jinchao, a bronze casting expert at the Nanjing Museum, has successfully established the logical relation of model, molds and core by simulation experiments. The resolution to successful understanding of openwork bronze casting via a piece-mold approach is to design the outer pattern of openwork appendages as an outside mold, linked to an inner mole via a middle mold section having a set of linking holes which allow liquid metal to flow through its many holes and which connect the outer and inside mold together. The replica of the openwork bronze *zun* and *pan* of the Marquis Yi of Zeng[24] was cast using only piece-mold casting, and the clay mold and core design can be seen from Figs. 5–8. This is the logical understanding of the capability of piece-mold casting technology used especially in the Chu States during the Spring and Autumn and Warring States periods.

For example, Wang Jinchao's design approach for the *zun* can be explained by:

(1) Fabricating a basic model with decorations and then dividing the entire outer circular rim edge piece into ¼ edge sections, and then using a set of five outside mold pieces, as shown in the

Fig. 5. Core mold and five outside molds for casting zun and pan.

Fig. 6. Pouring cross-channels formed by piercing holes for casting the zun.

Fig. 7. Second set of pouring channels on the inner core mold for casting the zun.

middle and right of Fig. 4, which are duplicated from the original model; the depressed decorations are impressed into the mold surfaces.

(2) The core mold, shown in the left of Fig. 5, is then made from the outside molds described in the former step. The appropriate decorations are also counter-duplicated.

(3) The pouring channels are made by piercing holes through the core and outside molds, and along the inner surfaces of the outside molds (Figs. 6, 7). The locations of the channels and pouring gates are correspondingly designed among model, core molds and out-molds.

(4) All of the mold segments are assembled together, the liquid metal is poured into the assembled mold, and the 1/4 cast sections (Fig. 8) are then joined together.

Fig. 8. Cast quarter-section of the edge rim of the zun.

Fig. 9. Yu Vessle of Chu State King.

A detailed description of the steps for making the molds and cores for casting such openwork bronze objects can be found Wang Jinchao's new research in 2014.[25]

Using this approach, it is easy to understand the casting technology used for openwork cast bronzes. For example, the Yu vessel of the Chu State King (Fig. 9), now in the Metropolitan Museum of Art in New York, was identified as the earliest lost-wax casting in China by Hua Jueming,[26] who wrote that

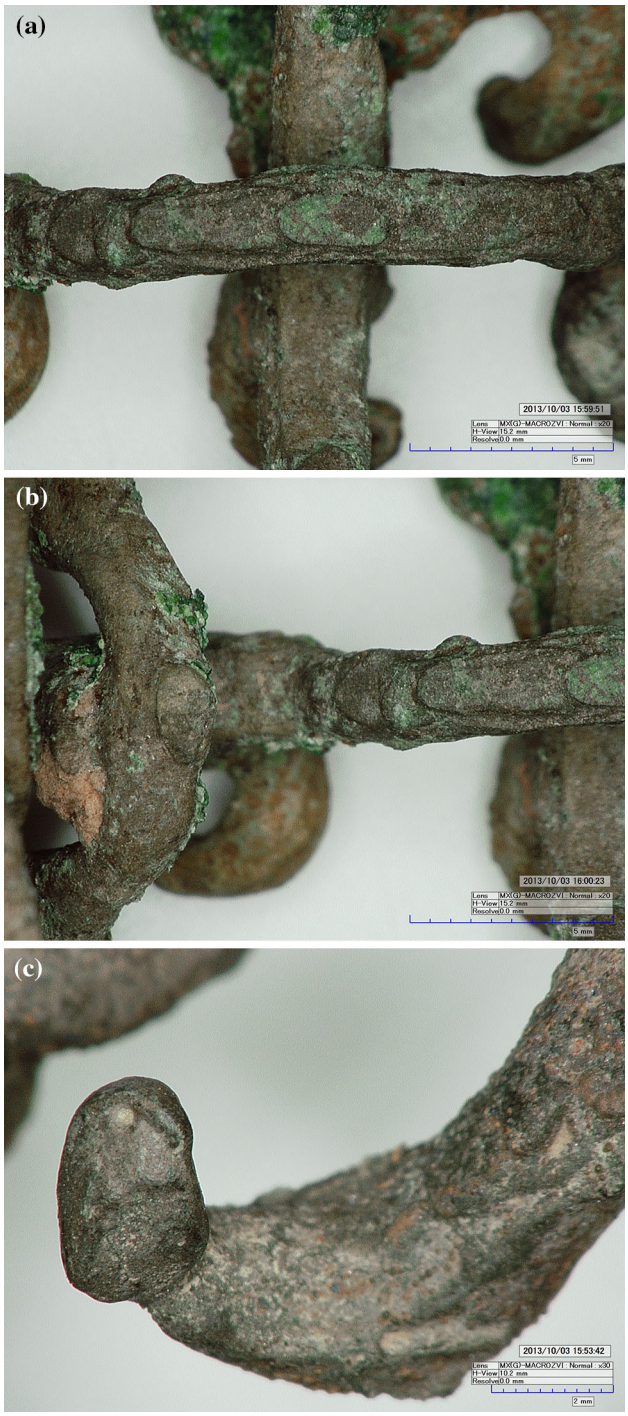

Fig. 10. The wrinkled surface of the appendix of the pan bronze of Zeng State unearthed from Wenfengta, Sui county Hubei province.

"the legs of the vessel have an openwork structure, the pattern on the sides show a hook-shaped three-dimensional interlinked space, which is certainly improbable for extraction by a mold from a model. However, an obvious mold seam line exists on the surface center of the leg. It is after all very difficult and complicated although ceramic piece-mold casting combined with some kind unknown craft may be used". Therefore, Hua still suggested that the leg of the Yu vessel was produced by lost-wax casting. It is now obvious that this type of vessel could be cast by Wang Jinchao's piece-mold method.

In recent years, the openwork appendages of a bronze pan, found by archaeologists in the Sui county of Hubei province, dating to the Spring and Autumn period (770-476 BCE), was identified as evidence of lost-wax casting based on the presence of a wrinkled surface on some of the metal cross-links, which were considered to be flow marks from the liquid wax (Fig. 10).[27] This can now be seen to be incorrect, and the wrinkled appearance should be attributed to piece-mold casting because the liquid metal cannot always maintain a continuous profuse flow over the long and bent cavity of the inner clay core, which finally results in the wrinkled structure after cooling.[28]

It is therefore concluded that the casting technology used for openwork bronzes in the Bronze Age China is developed from the outstanding piece-mold casting that already pre-existed. The interlaced three-dimensional structure can be made by the use of various layered core models and molds combined with channels inserted throughout the multilayer mold structure.

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