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ASSESSING THE RECIPE TRADITIONS OF BRONZE AGE MOULD PRODUCTION IN CHINA

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Abstract: In the Bronze Age of China, bronze artefacts were mainly vessels, symbolizing social power by their quantity, volume, type and decoration. The exquisiteness of Chinese bronzes is often attributed to a smith's excellent casting technique and mastery of the alloy composition, while the importance of moulds for the production of bronzes has been overlooked. Therefore this article will focus on an experimental campaign assessing the mould composition, rather than looking at the alloy composition, to expand our understanding. The effects of different recipes of moulds on the process of mould making and bronze casting were evaluated by the method of experimental archaeology. It has been explored that the botanical ingredients in the mould recipe were favourable for casting high-quality bronzes. For example, plant ingredients could eliminate or reduce cracks on the inner surface of moulds having an effect on the finished surface of bronze after casting. Moreover, this article investigates the theory that high-quality moulds are the basis of producing exquisite bronzes. The mould recipe and alloy composition are the core technologies of bronze production in the Bronze Age of China.

Keywords: Recipe, Bronze Age, China, Mould Production

Introduction

Over the past thirty years, Chinese bronzes have attracted scholars from various countries due to new analytical techniques such as XRF and isotope analysis. Until now, far too little attention has been paid to mould production in the Bronze Age of China. The Bronze Age of China is from 2070 BC to 221 BC, including Erlitou Culture, Shang Dynasty, Western Zhou and Eastern Zhou (770 BC-221 BC) (Jiang, 2010). In the Bronze Age of China, most bronzes were made by moulds (Pei 1989).

The quality of the mould can be considered to be due to the properties of the mould. Moreover, many Chinese bronzes have delicate ornamentation on the surface, the clarity of which is affected by the quality of the mould. This article aims to establish the relationship between traditional mould recipes and bronze casting performance in the Bronze Age of China. This article follows an experimental design, with an in-depth analysis of the bronze casting and mould production, to provide practical insights into mould recipes and bronze casting. Also, the design of the experiment is based on undertaking a desk-based review of current studies of moulds in the Bronze Age of China. Then a comparative study of the experimental process and results to identify critical components and relationships in the casting process will be undertaken. Observing the ground after completion of the casting process is then compared with the archaeological discovery of the casting site to rethink the archaeological metallurgical material (moulds, hearths and charcoal). Also, analysis of the results of the experimental work, with comparison to the literature and evidence from excavation, will consider how regionally specific mould technologies emerged in China in the Bronze Age of China.

Background: The Tradition of Chinese Bronze Casting

Mould making is an essential part of the entire bronze casting process. According to " Xun Zi ", the quality of moulds has a significant influence on the success of bronze casting, according to "Xun Zi", an ancient Chinese classic written in the late Warring States Period (the late Bronze Age of China). (Xun c. 313 BC) " Xingfanzheng, jinximei, gongyeqiao, huoqide, pouxingermoxieyi " means that making high-quality moulds is the priority in the whole process of bronze casting. Only after having a mould with excellent performance and then control the distribution of copper and tin ratio, through skilled melting techniques of a smith at the right temperature of molten alloy, can the successful production of satisfactory bronzes. Also, the mould is a vital reference for estimating the shape and decoration of bronze after casting.

The moulds of the Bronze Age of China are made of clay in appearance, usually consisting of two layers of clay (Fig. 1). There is space

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between the inner mould and the outer mould, and this space is used to fill the molten alloy during the casting process to obtain the bronze. What is shown in the picture is the mould used to make a Ding (Fig. 2). No.7 and No.4 on the image are the inner moulds, and number 5 is the outer mould. The gap between these two moulds (No.6) is the shape of the final cast bronze. The thickness of the bronze is determined by the distance between the two layers of moulds. Also, the resistance to thermal shock, shrinkage coefficient, and other physical characteristics of the mould will significantly influence the formation of bronze during the casting process (Tan 1999). Moreover, elaborate ornamentation can often be seen on the surface of Chinese bronzes, and the successful production of these ornamentation requires high requirements for moulds. Therefore, the evaluation of the recipe of mould production is of great significance for understanding the casting method in the Bronze Age of China.

Figure 1 A two-layer ceramic mould unearthed at the Houma site (Shanxi Provincial Institute of Archaeology： 2012; Figure 25-3).

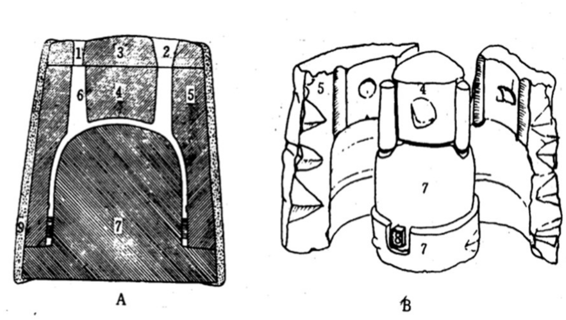

Figure 2 The method of casting a Ding by using moulds (Liu: 2008; Figure 5).

Previous Studies: Raw Materials, Production Technology and Related Sites for Making Moulds

This Examples of moulds excavated from Erlitou Site (Liu & Xu 2007), Panlongcheng Site (Zhang 2003), Miaopu Beidi Site (Feinman 2002), Wucheng Site (Childs-Johnson 2018), Houma Site (Lengyel 2000) and Xiaomintun Site (Stoltman et al. 2018) have been assessed and considered. The mould from the Xiaomintun site has been selected to be presented here. The site covers over 50,000 square meters and has unearthed more than 30,000 pieces of mould and a large amount of slag and charcoal. Most of these moulds are used to cast container type bronzes, and few were used to produce weapons and tools (Wang & He 2007; Bagley 2009). The colour of the mould is mainly light red and light grey (Fig. 3, 4) (Yue 2006). Also, it has black traces on the mould's inner surface where it touches the bronze molten liquid, similar to soot. The black traces are considered to be equivalent to the function of a mould release agent to facilitate the removal of bronzes from the mould after casting (Yue 2006).

Figure 3 A light grey mould found in Xiaomintun site (Yue: 2006; Figure 11-3).

Tan (1986) tested and analyzed a part of the moulds' unearthed from the Houma site and found that the particle size of the fine sand contained in these moulds is close. Most of them are between 100 mesh and 260 mesh, indicating that the fine sand used to make the mould is artificial selection. This conclusion corresponds to the fine sandpit found at the Houma site. Also, Tan (1986) tested the baking temperature of six moulds from the Xiaomintun site and found that the baking temperature of the mould in the pottery kiln was 550 °C-650 °C. However, Tan et al. (1999) studied the moulds of the Bronze Age of China through experimental archaeology. They believed that the baking temperature of the moulds was between 850 °C and 950 °C. They also suggested that the clay used to make the moulds needed to go through the two steps of pugging and decay before use, which was helpful to improve the physical properties of the moulds. Also, Tan (1999) analyzed the moulds of the Houma site and found that most of the moulds unearthed at Houma were added with temper (broken mould).

Moulds found at all the sites detailed above were studied to try and understand the production methods and inclusions added to the clay. This study informed the variations selected to be explored in the experimental campaign.

Figure 4 A light red mould found in Xiaomintun site (Yue: 2006; Figure 10-6.).

Many archaeological records of excavated moulds, such as the Xiaomintun site, Miaopubeidi site, Erlitou site and Houma site, shows that the moulds contain plant ingredients. Some scholars have studied and discussed the plant composition in moulds in the Bronze Age of China. Liu et al. (2008) studied the plant composition in the mould and believed that the plant composition in the mould was grassed like rice hull. Tan Derui (1986) suggested that the plant ingredients in the mould are plant ash or rice hull ash. Rice has been cultivated in China since the early Bronze Age of China (Li 2018). The word "秜" can be seen in many oracle bone inscriptions (the Shang Dynasty) unearthed in China. "秜" means rice, which indicates that rice in the Shang Dynasty is already an important crop (Li 2018). Also, the climate in the North China region of the Shang Dynasty is warmer and wetter than that of North China today, which was suitable for growing rice (Tang 2017). Tan Derui (1986) analyzed the mould unearthed at the Houma site and found that the mould contained tiny broken moulds (grog) and charcoal components. Also, some scholars speculated that the black traces on the inner surface of moulds unearthed at the Xiaomintun site might be related to charcoal (Wang 2007). Therefore, grog and charcoal are selected as the components of the recipe of moulds in this experiment. Moreover, a mould with 50% clay and 50% sand was used as the standard substance in this experiment compared with other moulds with other recipes to compare and study the influence of different recipes of moulds on mould making process and bronze casting process.

The plant ingredients in the raw materials of moulds, Ni Yizang (2013) believed that the practice of adding botanical ingredients to clay is influenced by Chinese pottery making technology. In the Neolithic Age of China, sand, limestone, straw, rice hull, and temper (pottery shards) are usually added to the clay used to make pottery. Mixing sand, botanical ingredients or temper (mould pieces) in the clay used to make moulds similarly to pottery to improve the fire resistance of moulds and reduce deformation and cracking during drying and baking.

Experimental Method

This experiment is divided into three parts: the preliminary experiment, experiment 1 and experiment 2. The purpose of the preliminary experiment is to explore the differences in the patterns formed on the surface of moulds with different recipes (ash (rice hull), chapped rice hull, rice hull). In Bronze Age China, the clarity of pattern on the surface of moulds determines the degree of the exquisite pattern on the surface of bronzes cast by the mould. Also, the preliminary experiment helps to explore the role of botanical ingredients in moulds during mould making and drying.

Experiment 1 explores the operation difficulty of four recipes of mould (sand + clay, chapped rice hull, rice hull, ash (rich hull)) in the process of making moulds and the quality difference of the moulds produced. Moreover, these moulds are used in bronze casting to explore the effects of different mould recipes on the casting results, such as the integrity of bronzes and the clarity of decoration. Also, the casting mould was observed and compared with archaeological excavation moulds.

Experiment 2 is based on Experiment 1 to explore furthermore mould recipes' influence on the mould-making and bronze casting processes. There are four kinds of mould recipes in Experiment 2: ash (rice hull), grog, wood ash, and charcoal. The grog is made from the ash (rice hull) mould fragments cast in Experiment 1.

Mould Production

This experimental campaign takes the recipe of moulds as a variable. It explores the influence of the recipe on the mould production process, such as the plasticity of moulds, by changing the raw materials for making moulds. Also, the impact of the recipe of moulds on bronze production is discussed by comparing the use of moulds with different recipes in the process of bronze casting, such as the clarity of decoration on the surface of bronzes.

The recipe of moulds in this experiment is based on archaeological records and previous scholars' analysis and research on the composition of moulds. Sand, clay, rice hull, chapped rice hull, ash (rice hull), wood ash, charcoal and grog constitute the recipe for the mould. Sand and clay are the essential components in the recipe of moulds. In many archaeological sites related to mould making in China (such as the Houma and Xiaomintun sites), pits specially used for storing fine sand and clay (Wang 2007; Yang 2015) have been found, indicating that fine sand and clay are essential components in making moulds. Moreover, some scholars have tested mould composition and found that the mould contains a high content of clay and fine sand (Tan 1986; Liang et al., 2011). Therefore, fine sand and clay are used as the basic raw materials for mould making and the invariants in the recipe of moulds in this experiment, in which the content of clay is 50%, fine sand is 25%. The remaining 25% is the content of temper to form different recipes of moulds.

Firing temperatures for the moulds were taken from Tan et al. (1999), who presents that the baking temperature of moulds was between 850°C and 950°C. To facilitate the operation, the baking temperature of moulds in this experiment was set at 900°C by using a kiln. In making moulds, the performance of moulds is observed and recorded in detail, such as plasticity, hardness and smoothness. Also, the change of moulds before and after baking was observed and recorded.

The traces left on the ground by the activities (mould making and bronze casting) were observed and recorded throughout the experiment. The gender and working status of people participating in the activities were observed and recorded. These records help to rethink the people involved in the mould making process and bronze casting process in the Bronze Age of China.

Preliminary Experiment

The clay used to make moulds needs to be screened according to the previous studies (Tan 1999; Tan 1986; Wang 2007). Therefore, the natural clay in the laboratory was screened before use (Fig. 5).

A stamp with an intricate design was used on all the clays to test the clarity of the different mixtures using the different inclusions (Fig. 6). The raw materials which were added to the clay were prepared in the necessary methods. The percentage of inclusions added to the clay for each variable is as follows: The recipe of the ash (rice hull) mould is 50% clay (100 ml), 25% sand (50 ml), and 25% ash (rich hull) (25 ml). The chapped rice hull mould recipe is 50% clay (100 ml) and 25% sand (50 ml), and 25% chapped rice hull. Also, the recipe of the rice hull mould is 50% clay (100 ml) and 25% sand (50 ml) and 25% Rice hull (50 ml) (Fig. 7).

Figure 5 The screened clay (Photo taken by Author: 2019).

Figure 6 The stamp used to make patterns on the surface of moulds (Photo taken by Author: 2019).

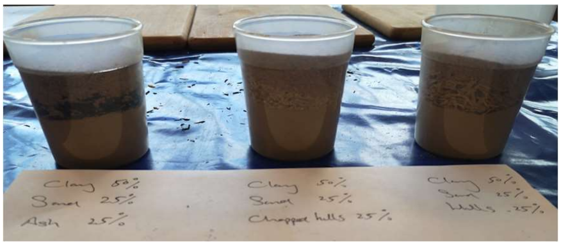

Figure 7 Three different recipes of mould in preliminary experiment (Photo taken by Author: 2019).

Water was used when mixing the ingredients and the amount used was recorded:_the ash (rice hull) mould uses 40 ml water, the chapped rice hull mould uses 60 ml water, and the rice hull mould uses 40 ml water. The stamp was placed flat on the surface of the mould made of three different recipes. For control, a 9.4kg weight was placed on the stamp to create the impression (Fig. 8).

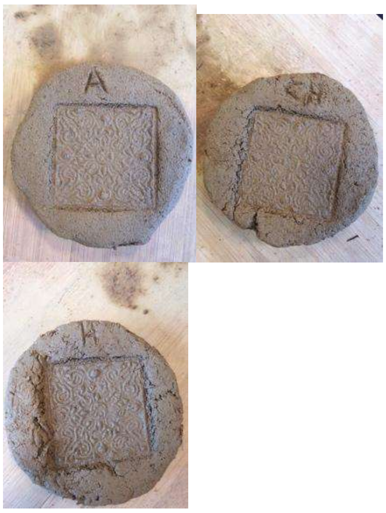

Figure 8 The moulds that have just been made were ash (rice hull) mould, chapped rice hull mould and rice hull mould from left to right (Photo taken by Author: June).

Experiment 1

Experiment 1 is a further experiment based on the material of the preliminary experiment, which is divided into three phases. The first stage is the making of moulds, the second stage is the baking of the made mould, and the third stage is the use of the baking mould for the bronze casting.

The moulds were made using the same method for the preliminary experiment. However, this time a two-piece mould was made using a plastic model to create the relief of the shape which would be cast (Fig. 9 and Fig. 10). The moulds were left to dry then fired at 9000C as per the method in the preliminary experiment (Fig. 11,12,13,14 and 15).

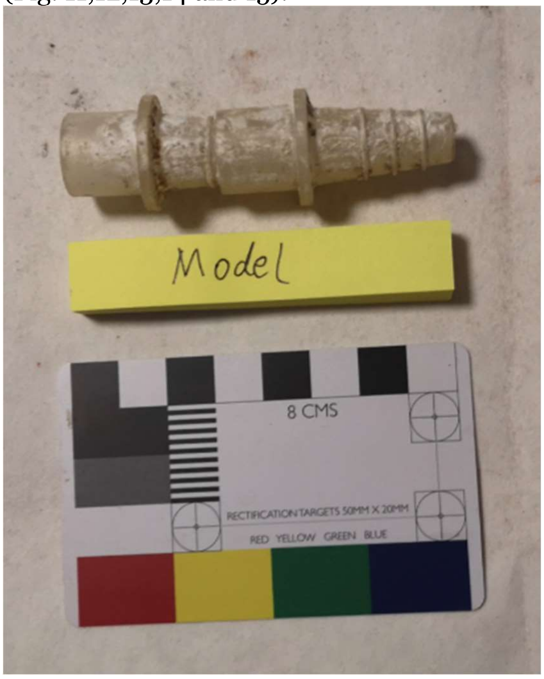

Figure 9 The model used in experiments (Photo taken by Author： 2019).

Figure 10 The model was placed on one of the rectangular moulds (Photo taken by Author: 2019).

Figure 11 The four moulds were placed in a ventilated place to dry (Photo taken by Author: 2019).

The moulds were carefully opened and recorded after they had dried, fired and after firing (Fig. 16,17,18 and 19).

Figure 12 The ash (rice hull) mould had been dried for one day (Photo taken by Author: 2019).

Figure 13 The chapped rice hull mould had been dried for one day (Photo taken by Author: 2019).

Figure 14 The rice hull mould had been dried for one day (Photo taken by Author: 2019).

Figure 15 The sand-clay mould had been dried for one day (Photo taken by Author: 2019).

Figure 16 The baking ash (rice hull) mould (Photo taken by Author: 2019).

Figure 17 The baking chapped rice hull mould (Photo taken by Author:2019).

Figure 18 The baking rice hull mould (Photo taken by Author: 2019).

Figure 19 The baking sand-clay mould (Photo taken by Author: 2019).

The site of the bronze casting has been prepared in advance with bellows, a crucible, charcoal and a hearth (Fig. 20). The first step of the casting experiment is to preheat the hearth with a wood fire. Then, bellows were used to steadily blow air into the interior of the hearth to promote charcoal combustion. The hearth is filled with charcoal which is renewed as it burns down.

Figure 20 The site of the bronze casting in experiment 1 (Photo taken by Author: 2019).

The mould is tied together with strings (Fig. 21). Then the mould is placed on the edge of the hearth for preheating to increase the temperature inside the mould and reduce the possibility of mould cracking and failing (Fig. 22). The copper and tin are weighed and placed in a crucible: 368 grams of copper (85%) and 65 grams of tin (15%).

Figure 21 The rice hull mould tied with a rope (Photo taken by Author: 2019).

Figure 22 The pouring gate of moulds is oriented away from the fire (Photo taken by Author: 2019).

When the hearth is up to temperature (assessed from charcoal and flame colour) crucible with alloy material is inserted into the hearth (Fig. 23) When the metal is melted, it is poured into the moulds. After the mould is cooled, the mould was opened to observe and record whether the bronze has been successfully cast and note the working state of the mould (Fig. 24,25 and 26). Finally, the moulds used and obtained bronzes in experiment 1 are taken to the laboratory for analysis.

Figure 23 A crucible was inserted into the bowl hearth (Photo taken by Author: 2019).

Figure 24 A pit with moulds (Photo taken by Author: 2019).

Figure 25 The molten bronze was poured into moulds (Photo taken by Author: 2019).

Figure 26 The sand-clay mould after casting. (Photo taken by Author: 2019).

Experiment 2

This experiment explores the impact of more types of mould recipes on the mould making process and the casting process based on experiment 1. There are four mould recipes in this experiment: ash (rice hull) mould, grog mould, wood ash mould and charcoal mould. As for the raw material for the mould, wood ash and charcoal are prepared by the laboratory in advance. The raw material of grog comes from the ash (rice hull) mould in experiment 1 that has been used in casting, grinding a small part of the ash (rice hull) mould into a powder to obtain the grog. Furthermore, the recipe of ash (rice hull) mould is the same as that of ash (rice hull) mould in experiment 1, which contains 100ml clay (50%), 50ml sand (25%) and 50ml ash (rice hull) (25%). Also, the recipe of the Grog mould is 100ml clay (50%), 50ml sand (25%), 25ml ash (12.5%) and 25ml Grog (12.5%). The recipe for wood ash mould is 100ml clay (50%), 50ml sand (25%) and 50ml wood ash (25%). Also, the method of using the four different recipes to make moulds is the same as that of experiment 1, and the drying and baking treatment of moulds are the same as that of experiment 1.

It is worth noting that when the prepared charcoal mould was dried, it was found that the charcoal mould was easily broken due to the drying process. To further confirm this phenomenon, a repeated experiment was carried out with 100 ml of clay (50%), 50 ml of sand (25%) and 50 ml of charcoal (25%) of the recipe for remaking mould and drying. However, after the charcoal mould had been naturally dried in a ventilated place for a week, the surface of the mould still broke and was not suitable for the subsequent casting process. Therefore, ash (rice hull) mould, grog mould and wood ash mould were used for subsequent bronze casting.

Also, in the bronze casting process, experiment 2 adopts the same method as experiment 1 (Fig. 27).

Figure 27 A mould were placed on the edge of the hearth (Photo taken by Author: 2019).

Results

Results of the Mould Making Process

It was evident there is a need for water throughout the mould making process because water is an essential additive when mixing the raw materials of the mould, such as clay and sand. Also, the amount of water used to make moulds varies with different recipes. For example, the preliminary experiment shows that the chapped rice hull mould needs more water to produce than the ash (rice hull) mould or rice hull mould. The possible reason is that the rice hull itself is water absorbent; ash (Rice hull) no longer has water absorption because it has burned. Furthermore, the quantity of chapped rice hull is higher than that of rice hull in the same unit volume. Therefore, more water is needed in the process of making the chapped rice hull mould. Also, the difficulty of making moulds with the different recipe is apparent. For example, the chapped rice hull mould is the most difficult to shape by hand.

For the moulds in the preliminary experiment, observations and records were performed after the mould production and drying for one day. The results are shown in Table 2 and Table 3. By comparing the results of Table 2 and Table 3, we can see the effects of drying and age on the improvement of mould performance in the process of mould production. In terms of colour, the ash (rice hull) mould, chapped rice hull mould and rice hull mould changed from grey to light grey after drying and aged for one day. The light grey mould is precisely the same colour as some of the moulds unearthed in China, such as some light grey moulds excavated in the Erlitou site (early Bronze Age of China). Also, according to the preliminary experiment results, drying and ageing can improve the coarseness of moulds and reduce the cracks on the surface of moulds.

Moreover, one of the most critical roles that moulds play in the production of bronzes is to generate patterns on the surface of bronzes. However, according to the preliminary experiment results, the clarity of the patterns on the surface of the mould will change when it is just produced and when it is dry. For example, the pattern on the chapped rice hull mould surface was evident when it was produced but not clear enough when it is dried for one day. The pattern on the surface of the rice hull mould was not clear when it was finished, but it became clear after one day of drying. Also, the pattern on the surface of the ash (rice hull) mould was stable and did not change significantly before and after drying. It shows that the recipe of moulds has a significant influence on the stability of the pattern clarity of moulds surface. Also, the clarity and stability of the pattern on the surface of moulds have a considerable impact on the whole bronze production process. By only keeping the pattern on the moulds unchanged, we can be sure that the pattern on the surface of bronzes obtained after casting is the pattern that people first imagined when making moulds. Furthermore, from the preliminary experiment results, the recipe of the ash (rice hull) mould is the most suitable for bronze casting. Also, although the surface ornamentation of rice hull mould and chapped rice hull mould has changed, the degree of change is acceptable, so the two recipes of moulds can also be used to cast bronze.

Characteristic / Name of mould	Colour	Coarseness	Clarity of ornamentation	Number of surface cracks
Ash (rice hull) mould	Gray	Fine	Clear	Less
Chapped rice hull mould	Gray	Medium	Clear	Medium
Rice hull mould	Gray	Coarse	Not clear enough	More

Table 2: When moulds are finished

Characteristic / Name of mould	Colour	Coarseness	Clarity of ornamentation	Number of surface cracks
Ash (rice hull) mould	Light grey	Fine	Clear	Less
Chapped rice hull mould	Light grey	Medium	Not Clear enough	Medium
Rice hull mould	Light grey	Medium	Clear	Medium

Table 3: The moulds were left to dry naturally in a ventilated place for one day.

Characteristic / Name of mould	Colour	Coarseness of the inner surface	The clarity of the internal surface decoration	Number of cracks on the inner surface	External surface
Ash (rice hull) mould	Khaki	Fine	Clear	Less	Ash can be seen
Chapped rice hull mould	Khaki	Medium	clear	More	Chapped rice hull can be seen
Rice hull mould	Khaki	Coarse	clear	Less	Rice hull can be seen
Sand-clay mould	Khaki	Medium	clear	Medium	Normal

Table 4: Moulds after one day of drying in experiment 1 (unbaked)

Characteristic / Name of mould	Colour	Coarseness of the inner surface	The clarity of the internal surface decoration	Number of cracks on the inner surface	External surface
Ash (rice hull) mould	Brick red	Fine	Clear	Less	Ash cannot be seen clearly; Similar to the sand clay mould
Chapped rice hull mould	Brick red	Medium	clear	More	The burnt chapped rice hull left small grooves can be seen
Rice hull mould	Brick red	Medium	clear	Less	The burnt rice hull left small grooves can be seen
Sand-clay mould	Brick red	Medium	clear	Medium	Normal

Table 5: Moulds after baking in experiment 1

Experiment 1 further explores the influence of baking on the mould making process based on the preliminary experiment. As can be seen from the results of experiment 1 (table 4 and table 5), the baking will further change the colour of the moulds. The drying process will change the mould from grey to light grey, and as the drying time goes on, the mould will vary from light grey to khaki. Baking the mould will change its colour from khaki to brick red. It is worth noting that the light grey, khaki, and red brick moulds have been found in many mould production sites and casting sites in China in the Bronze Age of China, such as the Erlitou, Houma and Xiaomintun Sites. Also, baking moulds will improve the hardness of moulds and improve the coarseness of moulds. However, baking moulds cannot improve the number of cracks inside moulds. In combination with the preliminary experiment, the number of cracks on the inner surface of moulds is affected by the treatment of the inner surface during the mould making process and is also affected by the drying process. It is worth noting that if the recipe of moulds contains botanical ingredients, these ingredients will disappear due to baking and leave small pits on the surface of moulds, such as chapped rice hull and rice hull. However, the small pit left by the ash (rice hull) on the surface of the mould after baking is not apparent, probably because ash (rice hull) has burned and is much smaller than the chapped rice hull.

Experiment 2 further explored the influence of more types of mould recipe (grog, wood ash, and charcoal) on the mould making process based on Experiment 1. In experiment 2, a part of the ash (rice hull) mould used in casting in experiment 1 was ground to make a grog (Fig. 28). It was found that the ash（rice hull） mould was easily ground into small powder, similar to fine sand. Moreover, from a plasticity point of view, the grog mould is more accessible to shape than the ash (rice hull) mould, wood ash mould and charcoal mould. Also, the wood ash mould and the ash (rice hull) mould have similar plasticity, while the charcoal mould is difficult to make a shape by hand.

Moreover, regardless of whether the mould has been baked or not, the different recipes of mould will have a significant influence on the colour of moulds. For example, in the drying stage, the charcoal mould was black, the grog mould was dark khaki, the ash (rice hull) mould was khaki, and the wood ash mould was light khaki. When these moulds were baked, the grog mould, the ash (rice hull) mould and the wood ash mould all turned brick red, but the colour of the grog mould was darker, and the colour of the wood ash mould was lighter than that of the ash (rice hull) mould. Furthermore, the charcoal mould is prone to crack due to uneven water loss during the drying process, which is unsuitable for the subsequent bronze casting process (Fig. 29). Also, the internal surfaces of the grog mould, ash (rice hull) mould and wood ash mould were all clear after baking, but the interior surface of the grog mould was the clearest.

Moreover, the inner surface of the grog mould has more holes than the ash (rice hull) mould and wood ash mould, probably due to the burning of grog and ash. However, in the smoothness of the mould surface, the wood ash mould was smoother than the grog mould and the ash (rice hull) mould. Therefore, from the results of experiment 2, the charcoal mould is not suitable for the bronze making process, while the grog mould, ash (rice hull) mould, and wood ash mould are all suitable for the subsequent casting process.

Figure 28 A part of the ash (rice hull) mould was grinded to grog (Photo taken by Author: 2019).

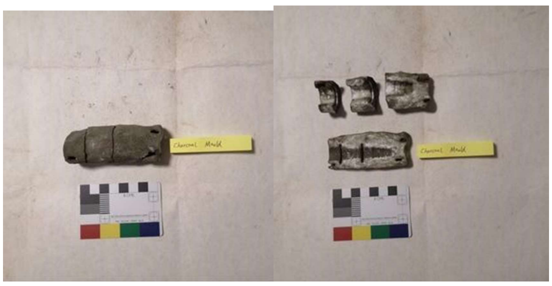

Figure 29 The charcoal mould broken during drying (Photo taken by Author: 2019).

Performance and Results of Different Recipe of Moulds in the Casting Process

Through the performance and casting results of the different recipe of moulds in the casting process (table 6 and table 7), it can be found that the most straightforward and basic recipe (50% clay and 50% sand) can successfully produce bronze. A comparative study of bronzes cast using ash (rice hull) mould, chapped rice hull mould, rice hull mould, and sand-clay mould reveals that the moulds' botanical ingredients help reduce the influence of cracks on the inner surface of moulds on the Bronze cast surface. Because from the surface of the bronze cast by sand-clay mould, it can be seen that more cracks are cast as the ornament on the bronze surface, but the surface of bronzes cast from rice hull mould or chapped rice hull mould that showed fewer cracks being cast as a pattern on the surface of the bronze. Moreover, the surface of bronzes cast by ash (rice hull) mould and grog mould showed no ornamentation of cracks of the mould's inner surface (Fig. 30 and Appendices 2). This finding indicates in the casting process that the smaller the size of the botanical composition in moulds, the less the influence of cracks on the inner surface of moulds on the bronze ornamentation.

Also, when the bronze melt was poured into the wood ash mould, the wood ash mould will immediately separate to cause the casting failure, which indicated that the wood ash mould was poor in thermal shock resistance. Therefore, wood ash mould cannot be used in the production of bronze. Moreover, although the pattern on the surface of the bronze cast by chapped rice hull mould is clear, the surface of the bronze is uneven, possibly because the chapped rice hull leaves many pits on the inner surface of the mould. The chapped rice hull mould is also not suitable for bronze production. Although the surface of the bronze cast by rice hull mould is clear and smooth, the metallic lustre of the bronze is very dark (Fig. 30 and Appendices 3). After polishing, the metal lustre of the bronze becomes brighter but compared with the bronze cast by other moulds, the metal lustre is still very dark. Also, when the bronze is taken out from the rice hull mould, the mould's inner surface is significantly damaged, so that rice hull mould cannot be reused. Therefore, to cast bronze with better metallic lustre and to minimize the difficulty of grinding the bronze in the later stage, it is considered the reusability of moulds. The rice hull mould is not suitable for the production of bronze.

Figure 30 The cast bronzes of experiment 1 and experiment 2 (Photo taken by Author, August 2019).

Moreover, sand-clay mould is not suitable for bronze making, although the pattern of the bronze cast by sand clay mould is clear. The metal lustre of bronze is good; when the bronze is taken out of the mould, it will cause considerable damage to the mould's inner surface and make the mould unable to be used again. Also, although the bronze cast by grog mould is clear and shiny, when the bronze is removed from the mould, the mould's inner surface will be largely destroyed, so the grog mould is not suitable for the bronze casting. Therefore, judging from the reusability of moulds and the effect of the bronze cast by moulds, the ash (rice hull) mould can be better used for bronze production.

Characteristic Name of mould	Can bronze be successfully cast by using the mould?	Does the mould open easily after casting?	Is the pattern on the inner surface of the mould damaged when the bronze is taken out?	Can the mold be used again?
Sand-clay mould	Yes	Yes	Yes（More）	No
Ash (rice hull) mould	Yes	Yes	Yes (Less)	Yes
Chapped rice hull mould	Yes	Yes	Yes (Less)	Yes
Rice hull mould	Yes	No	Yes (More)	No
Grog mould	Yes	Yes	Yes (More)	No
Wood ash mould	No	Unable to work	Unable to work	Unable to work

Table 6: Performance of the mould in the casting process

Characteristic Name of bronze	The metallic luster of the bronze surface	Are there mould fragments on the surface of the bronze?	Is it easy to clean the mould fragments on the surface of bronze?	Is the decoration on the surface of the bronze clear?
The bronze cast by sand clay mould	Light	Yes (More)	Yes	Yes (But there is some interference)
The bronze cast by ash (rice hull) mould	Light	Yes (Less)	Yes	Yes
The bronze cast by chapped rice hull mould	Light	Yes (Less)	Yes	No

The bronze cast by rice hull mould	Dark	Yes (More)	No	Yes
The bronze cast by grog mould	Light	Yes (More)	No	Yes
The bronze cast by wood ash mould	Unable to work	Unable to work	Unable to work	Unable to work

Table 7: Bronze cast from different recipe of moulds.

Discussion

The colour change of moulds in this study is beneficial to understanding moulds unearthed in China in the Bronze Age of China. Combined with the experimental results of the preliminary experiment, experiment 1 and experiment 2, the colour of the mould is grey when the mould is just finished, and the longer the mould is dried, the colour of the mould changes from grey to light grey, then to khaki. The colour of the mould will change to brick red after baking, and the colour of the mould after casting is not changed much. Therefore, it is possible to explore the state of moulds excavated by archaeology through the colour of moulds in experiments. For example, light grey moulds, khaki moulds, and brick red moulds were found in the Xiaomintun site, Miaopubeidi, and Erlitou sites. Scholars often used these moulds as already used moulds for analysis and research (Wang 2007), such as Tan Derui (1999) believes that the colour of moulds is different because of the various recipes of mould.

This study provides a new perspective that the baking of moulds without changing the recipe will lead to a difference in the colour of moulds. Therefore, the grey and khaki moulds unearthed in the archaeological excavation may be unbaked moulds. These moulds are preserved after being made by people and are baked in advance when needed for casting. Moreover, grey and khaki moulds unearthed in archaeology mostly appeared in sites related to mould making, while brick red moulds mostly appeared in sites related to bronze casting. Also, it can be seen from the results of experiment 1 and experiment 2 that baking moulds or moulds used in casting are more easily broken than unburned moulds, which may be the reason why people do not continue to fire after the mould is made and dried.

Also, this study, through experimental archaeological methods, found that the plant composition in the mould recipe can improve the influence of cracks on the inner surface of moulds on the formation of bronze during the casting process. Moreover, combined with the moulds unearthed in China, the exterior surface and cross-section of ash (rice hull) moulds are most similar to those discovered in archaeology (Fig.31, 32). The plant components in moulds used for casting bronze in the Bronze Age of China were ash (rice hull) or other burned plants similar to rice hull. Furthermore, Tan Derui (1986) believes that many moulds unearthed at the Houma site contain grog. Combining the conclusions of experiment 1 and experiment 2, it is reasonable to add grog into moulds. Although the grog mould was destroyed when bronze was taken out of the mould, the bronze cast from the grog mould was better in terms of both metallic lustre and clarity of pattern, even better than bronze cast from the ash (rice hull) mould. The cross-sections of the grog mould, the ash (rice hull) mould, the sand-clay mould, the chapped rice hull mould and the rice hull mould after casting are compared, and the grog mould and the ash (rice hull) mould have many tiny holes on cross-sections (Fig. 33). Also, there are a larger number of tiny holes on the cross-section of grog mould than ash (rice hull) mould, and there are few tiny holes on the cross-section of sand-clay mould.

Figure 31 A mould found in the Xiaomintun site (Yue: 2006; 8.7).

Fig. 32. A mould found in the Houma site (Yang: 2015;10).

Figure 33 The cross-section of moulds (Photo taken by Author: 2019).

Moreover, the under-burned chapped rice hull or rice hull can be seen in the cross-section of the chapped rice hull mould and the rice hull mould. From the casting results, the tiny holes in the cross-section of moulds can improve the quality of the cast bronze. According to Tan Derui's research (1999), many moulds in the Bronze Age of China had many tiny holes inside.

Notably, it was easy to make a broken ash (rice hull) mould into grog, and the grog in the mould recipe helped cast bronze with more elaborate ornamentation. Therefore, the use of grog moulds can be mastered after people are familiar with the use of ash (rice hull) moulds. Also, the Houma site is later than the Xiaomintun site and the Miaopubeidi site, so there may be progress in the technology of making moulds, and the moulds unearthed at the Houma site were more exquisite than the moulds found at the Xiaomintun site. One possibility is that in the middle and late Bronze Age of China, people used ash (rice hull) moulds to produce some bronzes of the same shape because of the high requirement for moulds' reusability. Grog moulds were used for some individual exquisite bronzes produced for the royal family or social elites. Although the grog moulds were easily damaged after casting, the cast bronzes were of high quality.

This study also raises some different opinions on the past research results of the recipe of moulds in the Bronze Age of China. Wang et al. (2007) observed that some black material on the surface of some moulds was considered to contain charcoal in the recipe of moulds. However, it can be seen from the results of experiment 2 that the charcoal mould cannot be used for the production of bronzes because the charcoal mould is broken due to uneven water loss during the drying stage.

Moreover, according to the observation of mould surface after casting in experiment 1 and experiment 2, it can be found that black substances also appeared on the surface of some moulds, such as sand-clay moulds and ash (rice hull) moulds. These black substances were charcoal ashes accumulated in the bottom of small pits that fixed moulds during casting. In the Bronze Age of China, the pits used to fix moulds during the casting process were more extensive than those used in the experiments. Therefore, the amount of accumulated charcoal ash would cause the surface of the casting mould to look like it was deliberately smeared with charcoal ash or the mould itself contained charcoal.

Also, when the wood ash mould in Experiment 2 was split twice by the poured bronze melt, half of the wood ash mould was placed on the ground, and the bronze melt was poured onto it (Fig. 34). The bronze was taken out after wood ash mould cooling, and it was found that the shape of the bronze cast by such a method was curved, and the surface decoration was unclear (Fig. 35). Therefore, the technique of casting bronzes with two erect pieces of moulds is more

suitable for the production of a large number of bronze containers with exquisite decoration in the Bronze Age of China.
This study shows the critical role of mould recipe in the mould making process and casting process. Only the right recipe of moulds can produce suitable quality moulds and cast high-quality bronzes.

Figure 34 The molten bronze is poured on a half of wood ash mould (Photo taken by Author: 2019).

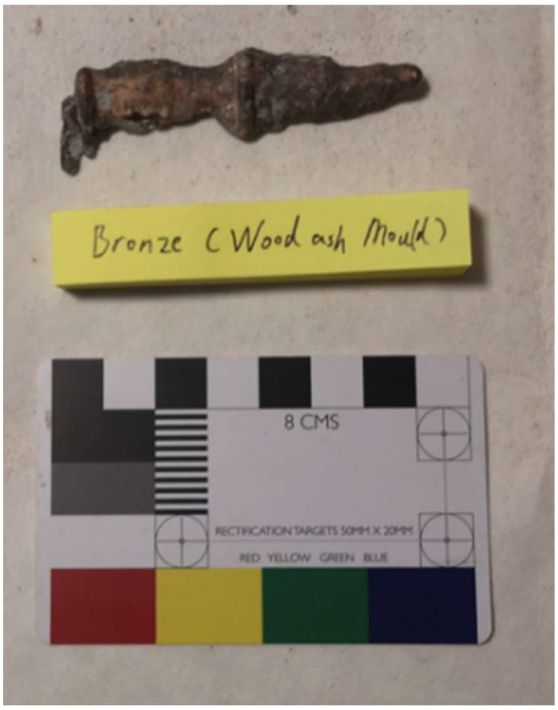

Figure 35 The bronze cast by wood ash mould (Photo taken by Author: 2019).

Conclusion

This article has evaluated how the composition of a mould can affect the success of casting bronze artefacts and how the ingredients added to the clay used to make the mould can have an effect on the surface and clarity of a cast object. The experimental campaigns presented in this article have demonstrated that the mould itself and the ingredients added to the clay of the mould can have a significant effect on the object cast within. This conclusion highlights how it is not just the metal alloy or the casters' skill that affects the quality of the cast object, but also the skill of the craftsperson who made the mould, their knowledge of materials, and the ingredients used to make the mould.

List of Figures:

Fig. 13. The chapped rice hull mould had been dried for one day (Photo taken by Author, July 2019.).

Fig. 14. The rice hull mould had been dried for one day (Photo taken by Author, July 2019.).

Fig. 15. The sand-clay mould had been dried for one day (Photo taken by Author, July 2019.).

Fig. 16. The baking ash (rice hull) mould (Photo taken by Author, July 2019.).

Fig. 17. The baking chapped rice hull mould (Photo taken by Author, July 2019.).

Fig. 18. The baking rice hull mould (Photo taken by Author, July 2019.).

Fig. 19. The baking sand-clay mould (Photo taken by Author, July 2019.).

Fig. 20. The site of the bronze casting in experiment 1 (Photo taken by Author, July 2019.).

Fig. 21. The rice hull mould tied with a rope (Photo taken by Author, July 2019.).

Fig. 22. The pouring gate of moulds is oriented away from the fire (Photo taken by Author, July 2019.).

Fig. 23. A crucible was inserted into the bowl hearth (Photo taken by Author, July 2019.).

Fig. 24. A pit with moulds (Photo taken by Author, July 2019.).

Fig. 25. The molten bronze was poured into moulds (Photo taken by Author, July 2019.).

Fig. 26. The sand-clay mould after casting. (Photo taken by Author, July 2019.).

Fig. 27. A mould were placed on the edge of the hearth (Photo taken by Author, August 2019.).

Fig. 28. A part of the ash (rice hull) mould was grinded to grog (Photo taken by Author, August 2019.).

Fig. 29. The charcoal mould broken during drying (Photo taken by Author, August 2019.).

Fig. 30. The cast bronzes of experiment 1 and experiment 2 (Photo taken by Author, August 2019.).

Fig. 31. A mould found in the Xiaomintun site (Yue, 2006, 8.7).

Fig. 32. A mould found in the Houma site (Yang 2015).

Fig. 33. The cross-section of moulds (Photo taken by Author, August 2019.).

Fig. 34. The molten bronze is poured on a half of wood ash mould. (Photo taken by Author, August 2019.).

Fig. 35. The bronze cast by wood ash mould (Photo taken by Author, August 2019.).

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