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Inscriptions, filing, grinding and polishing marks on the bronze weapons from the Qin Terracotta Army in China

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A R T I C L E I N F O

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A B S T R A C T

This paper is concerned with the inscriptions and finishing marks present on the surfaces of the thousands of bronze weapons recovered together with the Terracotta Army at the mausoleum complex of Qin Shihuang, the First Emperor of China (259–210BC). After utilising the textual information from the inscriptions to reconstruct aspects of labour organisation and political control during the production of the weapons, the work concentrates on documenting and explaining the techniques employed to produce the inscriptions, to file casting imperfections, and to obtain the smooth, shiny and sharp finish still noticeable on many of the weapons. Silicone rubber impressions of surface features of swords, lances, crossbow triggers and arrows were examined under the scanning electron microscope (SEM), and these observations were supplemented with examination of the artefacts under the stereomicroscope and the SEM. The evidence indicates the use of a variety of chisels for making the inscriptions, and of files for removing excess metal from surfaces. In addition, the grinding and polishing marks demonstrate the large-scale, systematic use of rotary wheels to achieve an ideal final polish. These findings are contextualised in the broader history of Chinese metallurgy, with special attention to the emergence of iron tools and of rotary mechanical devices.

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1. Introduction

Qin Shihuang (259–210BC) is one of the most famous and controversial figures in Chinese history. Widely known as 'the First Emperor', he forcibly unified China under his power, prosecuted intellectuals and opponents, abolished feudalism, and standardised philosophy, script and law. The Herculean mausoleum complex he commissioned for himself, an analogue of his life, has remained as the material representation of his world, providing an almost inexhaustible source of information about the powerful political and symbolic system orchestrated around his personality (Rawson, 2007). Among numerous other installations and constructions within the mausoleum complex, the Terracotta Army has acquired an almost iconic status in modern popular culture, as a manifestation of the exorbitant power, lavish wealth and artistic achievement of the Qin Empire. Stationed in three pits to the east of his tomb, the terracotta warriors are supposed to have been placed there to host and protect the Emperor in his afterlife. So far, approximately 2000 individually crafted warriors have been recovered during archaeological excavations, although it is estimated that their number may reach up to 8000 (Institute and Museum, 1988; Yuan, 1990; Portal, 2007; Guo and Lindesay, 1998).

While previous research has investigated the technology and artistic achievement behind the production of the warriors themselves (Yuan, 1990; Ledderose, 2000), comparatively little work has addressed the bronze weapons recovered in the army pit. The excavated assemblage includes over 40,000 arrowheads as well as hundreds of crossbow triggers, swords, lances, spears, halberds, hooks, honur weapons (*Su*) and the ferrules that were fixed at the end of wooden hafts. As a part of a collaborative agreement between the Emperor Qin Shihuang's Terracotta Army Museum and the UCL Institute of Archaeology, the research focus has now shifted to these bronze weapons. A major aim of this project is to investigate patterns of standardisation and labour organisation within this single, very large and intentional assemblage as well as to consider the nature of bronze production during the Qin period (475–206BC, i.e. including the Qin Kingdom during the Warring States era – 475–221BC – and the Qin Dynasty after the unification – 221–206BC). The work is involving an exhaustive typological analysis combined with extensive measurements and archaeometric studies, integrated with a spatial analysis of the data.

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This paper concentrates on a relatively inconspicuous yet important dimension of the weapons' study: inscriptions, filing, grinding and polishing marks identified on many of their surfaces. Scratches and marks visible on some of the artefacts suggested that grinding or polishing took place after casting. Furthermore, some of the weapons display incised inscriptions, which vary from small symbols to relatively long sentences referring to the workshop or workers involved in their production (Fig. 1). One specific objective of this study was to investigate the techniques employed to engrave and polish bronze during the Qin period, including the shapes and materials of the tools, and their modes of utilisation. Particular attention was paid to the potential identification of mechanical devices, including rotary tools. Furthermore, combining these technical features with the information recorded in the inscriptions, we sought to reconstruct aspects of workshops' organisation and the distribution of labour during the construction of the mausoleum.

2. Materials and methods

The bulk of this study has concentrated on Pit 1, where the majority of the weapons have been recovered. Most of these weapons were excavated during 1970s, although their recovery has continued during subsequent excavations. Except for a few items displayed on exhibitions, the majority of these are now housed at the Conservation Department of the Museum of Emperor Qin Shihuang's Terracotta Army. An initial typological analysis, including detailed measurements and spatial analyses of the distribution of the weapons in the pit, was carried out. Swords, lances, arrows and triggers were taken out of their storage, and macroscopic features of their inscriptions, grinding and polishing marks were noted.

A good number of these weapons were examined and photographed under a stereomicroscope in order to identify areas of interest. Subsequently, a subset of these, so far including pieces of twenty triggers, two swords, two lances and six arrowheads, were selected for more detailed analysis under the scanning electron microscope (SEM) at the Wolfson Archaeological Science Laboratories of the UCL Institute of Archaeology.

In order to view the characteristics of the inscribed features, grinding or polishing marks on the surface of the weapons under the SEM, over fifty detailed impressions of appropriate areas were made with silicone moulds. The selected area was cleaned with ethanol solution using a small piece of cloth. The moulding material was automatically dispensed from a gun fitted with a mixing tip together with a finely-pointed tip (Sax et al., 2004). Because the silicone dries quickly, a line of samples was arranged so that the moulding materials were applied as quickly as possible to the surface of the impressions. Delay would cause the silicone to dry and adhere to the gun fitting. The advantages of this method have been demonstrated by Sax et al. (1995, 1998, 2000, 2004) in their research on jade and other materials: firstly, it avoids the need either to apply a conductive gold coating to the artefacts (not necessary now if using variable pressure SEM) or to subject them to the high vacuum of the SEM; secondly, it allows the examination of deeply carved parts of an object that may be difficult to view directly, as moulds of carved lines are seen as positive features that show details very clearly. Furthermore, moulds can be made of areas of large objects that cannot fit into an SEM. A major advantage of this method is that it allowed the study of a relatively large number of samples at the laboratory in London without having to remove the actual artefacts from China.

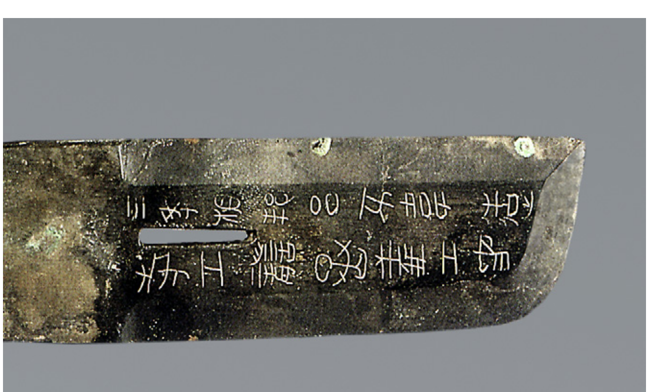

Fig. 1. The inscriptions on a halberd.

The silicone impressions were mounted on 51 mm diameter aluminium stubs, prior to being coated with gold for SEM observation. This was carried out in Hitachi S-3400N SEM, at high vacuum, using a large area 5 segments solid state backscattered electron detector for imaging. This imaging mode gave the best contrast and visual display of the depth of engraved features compared with conventional secondary electron imaging. The moulds were oriented and tilted in the SEM to give the best angles of observation, using detector segments A, B, C, D and E to create shadows and allow the photomicrographic records to represent accurately the geometric shapes and topographic features. It is important to note that the moulds record the carved features in reverse: features which appear as protrusions in the SEM images of the moulds represent depressions in the actual artefacts. This facilitates the observation of the depth and detail of engraved features.

Only a small number of actual artefact fragments, namely a sword and an arrowhead tang, were analysed directly under the SEM. The instrument employed in this case was a Philips XL30.

3. Terminology

In order to facilitate the characterisation of the marks identified in the weapons and the tools involved in their manufacture, it is appropriate to clarify the terminology to be employed. Here we use the terms as defined by Untracht (1969) and employed in modern metal crafts.

3.1. Filing, grinding and polishing

Filing, grinding and polishing are different techniques used in metal production and design, but sometimes they have overlapping definitions and functions. All of these methods are used to remove a certain amount of the metal surface to enhance its appearance and function, but the tools used for these different procedures are all slightly different. Filing is the act of using a file to shape or smooth an object. A file is a long, narrow tool with sharp ridges or points on its surfaces, typically used in an abrading motion. Designs can be made on thick metal objects by first removing large amounts of the surface using heavy files, and then refining the shape using small files, such as a needle file. The file needs to be harder than the material being processed.

Nowadays, most grinding is done on grinding wheels mounted on a frame attached to a grinding or buffing motor. These remove a relatively small amount of metal from the surface (although sometimes a coarse grinding wheel can remove a lot quickly form the surface). Three natural abrasives are used in wheels: corundum (aluminium oxide), emery (aluminium oxide plus abrasive iron oxide) and diamond, the hardest known substance. Hand grinding is still used in modern times as well, moving an abrasive paper back and forth over the metal surface. This is known to be a long and tedious process, but in certain cases it may allow better control of the operation (Untracht, 1969).

Polishing involves very little removal of metal, and its main purpose is to bring the condition of the metal to its final surface appearance. The abrasive polishing material can be applied by hand with a cloth or linen, or by the use of various types of buffing wheels mounted on a buffing motor. The technique chosen and the materials used depend on many factors, among which is the original condition of the surface of the piece in relation to the desired surface, and whether or not the object is plain or decorated. The selection of the method of polishing, whether by hand or by machine, typically depends on these factors. If a machine is used, then the speed of the motor, the size and the material of the buffing wheel, altogether are variable and affect the final outcome (Untracht, 1969).

3.2. Carving, engraving, and chiselling

Carving is a process where specific parts from hard materials are removed to create a desired pattern or shape. Engraving is a process of incising lines employing a thin, 'V' shaped pointed tool called a graver or burin. This can be done completely by hand, partly with the aid of mechanical devices, or entirely by machine (Untracht, 1969). Chiselling uses sharp, wedge-like tools to cut into and chip away the metal. Each method produces a different result, and will be selected by the craftsperson depending on the patterns they want to make and the hardness of the metal they are working on.

4. Inscriptions on the weapons

4.1. Chronology and production organisation

Not all the weapons of the terracotta warriors display inscriptions. Lances and halberds bear long sentence inscriptions, while the swords, triggers, hooks, and ferrules were only partially marked with numbers, a note of the *Gong* or *Sigong* (the name of the workshop) and/or other symbols. To date, no inscriptions have been found on the surface of the arrows.

During the partial excavation in Pit 1, 16 lances and 4 halberds were unearthed, and one more lance has been discovered in the continuing excavation of the pit in recent years. The long inscriptions on these weapons indicate the regnal year when they were produced, the name of the person in charge of production, the official or workshop, and the name of the specific worker, thus providing basic information on both the chronology and the organisation of production during their manufacture (Institute and Museum, 1988; Yuan, 1990). Based on this information, it is possible to establish that the inscriptions on the lances and halberds date from 244 to 228BC, that is, before the unification of the Qin Empire, which took place in 221BC (in the twenty-sixth year of the reign of Yingzheng, King of Qin). Interestingly, the times for their production do not overlap, as the diagram demonstrates (Fig. 2).

The remaining information on the inscriptions denotes a form of accountability and hence of quality control. The inscriptions on the halberds confirm that there was a supervisor called Lu Buwei (吕不韦), officials (*Sigong*,寺工), craftsmen (*Cheng*, 丞) and workers (*Gong*,工) involved in bronze production (Institute and Museum, 1988) (Fig. 3). The supervisor, Lu Buwei, was the Prime Minister of the Qin kingdom before the unification. According to the written documents of the Qin period, official *Sigong* were in charge of the production of bronze weapons and ritual bronze vessels in the governmental workshop. The craftspeople involved were very skillful workers, responsible for obtaining raw materials, training the workers in the manufacturing process and technology, monitoring the quality of the bronze weapons, and reporting to the officials. The workers were the actual producers of the weapons, and were usually slaves, convicts or soldiers (Yuan, 1984). Unfortunately, there is no clue on the inscriptions as to the location of the workshops.

The inscriptions on the lances and halberds also offer some hints of the political influence in this mass production of the bronze weapons. One of the obvious differences between the making of the halberds and the lances is the supervisor. The Prime Minister, Lu Buwei, appears as the supervisor of the halberds production (Fig. 3), but not of the lances (Fig. 4), as he presided over the Qin State when the First Emperor was young, but was condemned for his connection with a rebellion and dismissed in 237BC. All the halberds were produced before that date, and the lances were produced after it. The fact that the Prime Minister was inscribed as supervisor on the halberds indicates the strong degree of political control over the production of weapons. However, the new Prime Minister, Li Si, does not appear as supervisor in the later lances, suggesting changes in the production organisation connected with the political changes during the Qin era (Yuan, 1984).

Compared to the long inscriptions on the lances and halberds, the triggers' inscriptions are relatively simple. Approximately 150 out of the 229 triggers examined have inscriptions, including numbers, symbols and *Gong*. The function of these inscriptions has been interpreted as relating to quality control (Yuan, 1984; Ledderose, 2000). However, the high diversity of symbols noted (with almost no repetitions between triggers), together with the fact that some triggers bear the same number or symbol in two or all three mechanical parts, indicates that they may be related to their assembly. Among these inscribed triggers, the *Gong* character (工) has been found on 20 pieces.

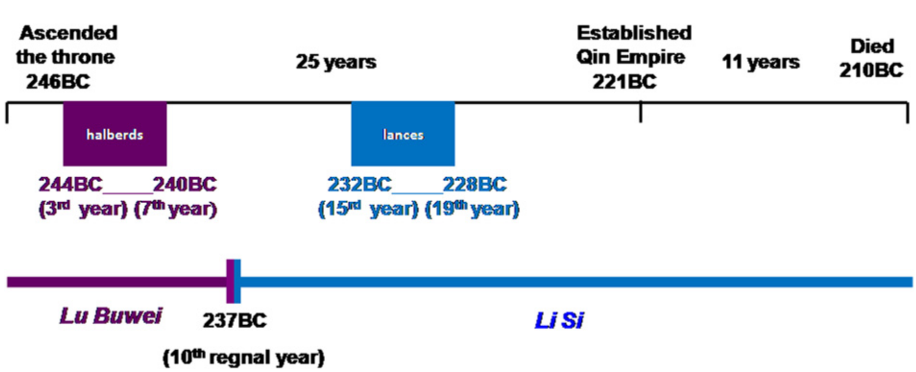

Fig. 2. Chronology of the bronze weapon production, based on the regnal years noted in the weapons' inscriptions and their relationship with major events during the Qin period. The Prime Ministers are noted at the bottom.

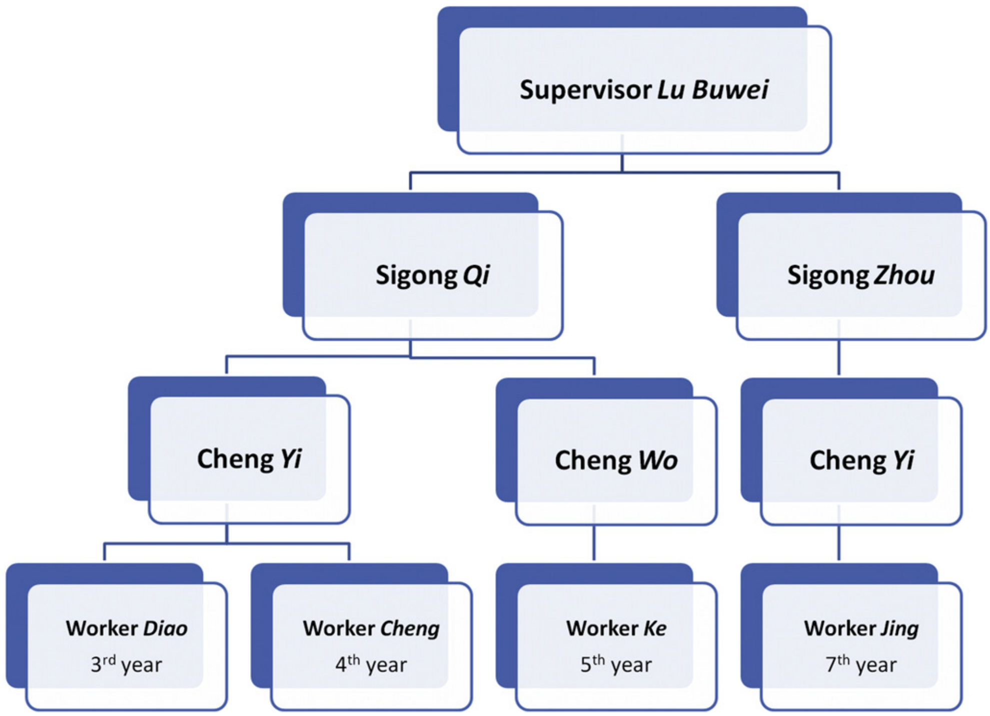

Fig. 3. The organisation structure during production of the bronze halberds, based on information from the inscriptions. The numbers at the bottom denote regnal years (3rd year being 244BC).

Ongoing work combining the inscriptions with typological, compositional and spatial analysis will show more insight about these bronze weapons, which will be discussed in a separate paper. The following sections will focus on the technical examination.

4.2. Tool marks – manufacturing traits

Fig. 5, obtained under the stereomicroscope, shows clear tool marks on the inscription of a lance. The three vertical strokes show the overlapping marks forming them, each of them with the overall shape of an elongated triangle. It can be interpreted that the line was chiselled step by step, with a finely-pointed tool ending on a wedge shaped like the letter 'V'. The way in which the marks overlap indicates that the chisels were hammered into the bronze sliding at an angle, starting from the bottom of the cone shape. In other words, the base of the triangle was the starting point of the cut, and the sharp end of the mark was the finishing point. These observations are supported by our limited experimental work in the laboratory. The horizontal strokes are relatively smooth and thinner, and chisel marks are not so obvious. However, both lines are still rough along the edges, slightly curved in overall design, and sharp at one end and round at the other end – all features typical of a hand chiselling technique but using, perhaps, a slightly different chisel.

Turning to the triggers, Fig. 6 shows three SEM micrographs of inscriptions on triggers. As already noted, the SEM micrographs,

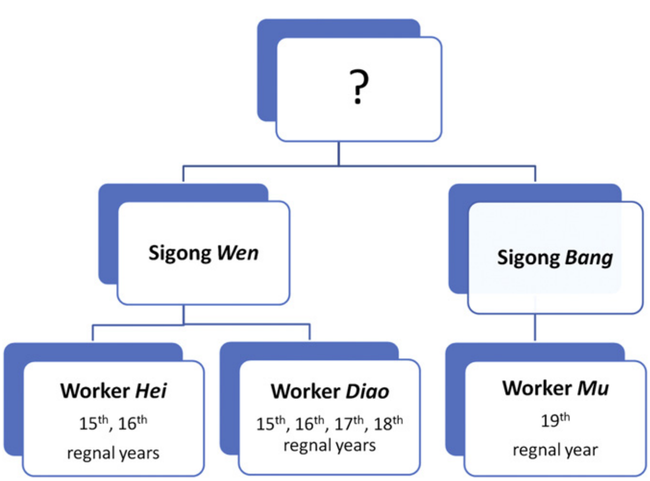

Fig. 4. The organisation structure during production of the bronze lances, based on information from the inscriptions. The numbers at the bottom denote regnal years (15th year being 232BC). Note the absence of both Cheng and supervisor.

Fig. 5. Inscription on the No. 860 lance under stereomicroscope, showing the chiselling technique. This area shown is a part of character "Sigong" (寺工).

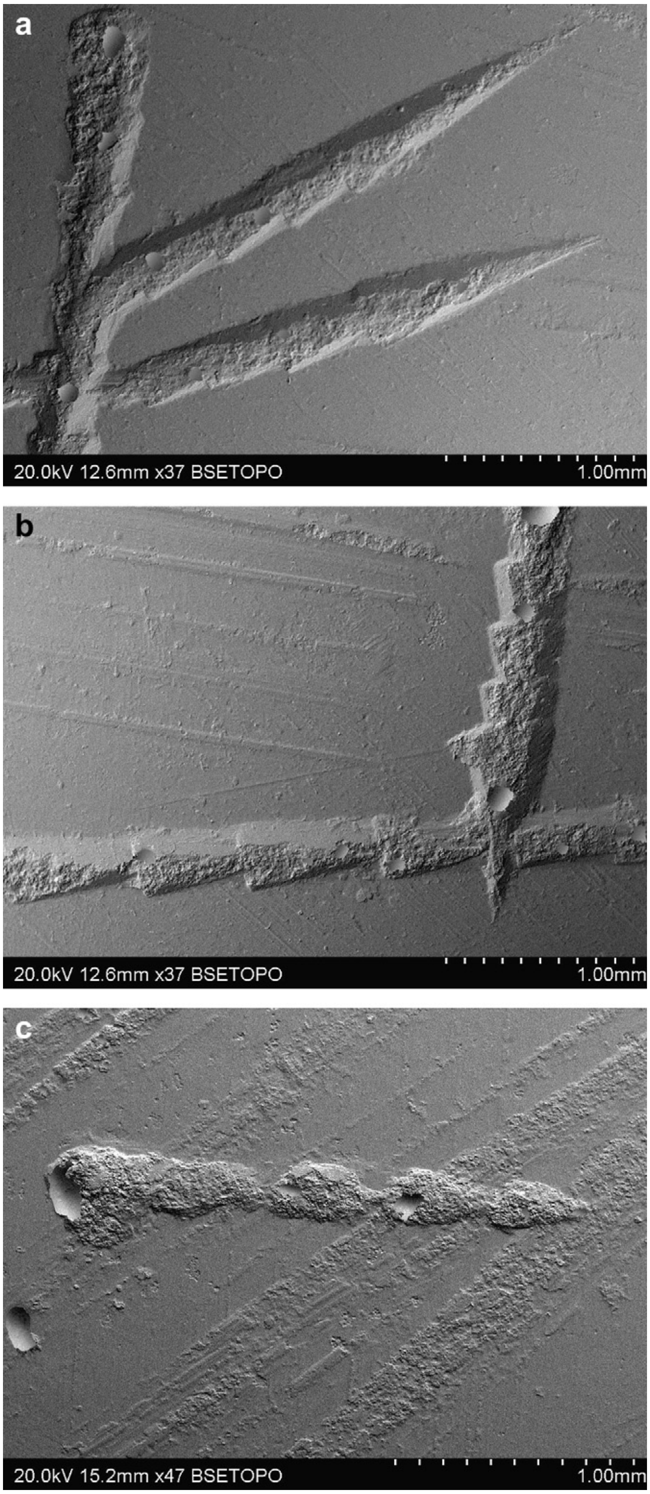

Fig. 6. Micrographs of inscriptions on 976B (a, b) and 974A (c) showing the chiselling techniques. Grinding marks are also noticeable on the surfaces (silicone impressions).

taken from silicone impressions, show the inscription in reverse, so that the positive features in the micrographs represent the negative grooved features on the weapons. These images show relatively clear tool marks, which are also interpreted as chiselling. The long lines are formed by individual overlapping marks, resulting in ragged edges. Like the chisels employed on the halberd, the tool here would have been pointed, ending in a 'V' shape.

However, the bottom part of each mark appears more rounded and, particularly, the back side of each impression (the shorter edge of the triangular shape) is different too – appearing straight or rounded on the trigger, while it forms an angle in the halberd. These small differences suggest the use of slightly different tools and, most probably, the involvement of more than one person in this chiselling activity for the variety of weapons.

Some of the inscriptions and the surface finishing marks (discussed in the next section) overlap, and from this a sequence of the processes can be interpreted. Some grinding marks were found beneath the inscriptions and, in other cases, inscriptions break through the grinding traces. This suggests that the filing, grinding and polishing were applied to the weapons at the first stage after casting, and the inscriptions were added thereafter.

4.3. Discussion

Based on the above observations, it is possible to establish the nature of the inscribing technique on the weapons, namely chiselling. Although carving and engraving are terms loosely used to describe techniques for inscribing bronze, and indeed they are used frequently when describing these weapons, the correct term should be chiselling.

The chisels would have to be made of a material both harder and tougher than the bronze weapons, to provide the sharp marks without becoming blunt after a few strokes. While stones can be harder than bronze, they are relatively brittle and thus not suitable for chiselling. It seems more likely that either high tin bronze, cast iron or quenched steel were used. During the Warring States period (475-221BC), iron tools and implements were already employed, and indeed some iron weapons, such as one iron spear and three iron arrows, have been unearthed from the pits of the Qin terracotta warriors (Institute and Museum, 1988: 249), as well as some iron implements discovered from the Emperor Qin Shihuang's mausoleum complex itself (Yuan, 2002). Although the chisels and other ferrous tools found in the mausoleum complex are too big to have been used on these weapons, their presence illustrate that the technology and tools were familiar to them. Unfortunately, due to lacking analytical data it is not possible to determine whether they are bloomery or wrought iron, or their carbon content. Evidence of quenched steel and cast iron has been discovered in many contemporary archaeological sites in central China (Wagner, 2008: 98–128; Han and Ke, 2007), and some even show the earlier iron production activities, which can be traced back to the 8th century BC, for example, the iron farming implements and weapons discovered from the Jin state (one of the seven states during the Warring State era, which is located in today's Shanxi province) (Han and Duan, 2009: 99). A cast iron or a quenched steel chisel would have been hard and tough enough to engrave the bronze, and the evidence available within the Qin mausoleum complex suggests this should have been available to Qin craftspeople.

The presence of symbols or texts on the surface of Chinese bronzes is widely documented in Shang (1600–1100BC) and Zhou (1100–221BC) bronzes. However, the predominant methods of application in the earlier periods concerned the design of the moulds, either by adding thin coils or strips of clay that would appear as depressions in the artefacts cast, or by carving the inscriptions directly on the clay mould – hence achieving inscriptions in relief (Ma, 1986; Li, 1980). Technically different from the cast inscriptions, the use of chisels directly onto the surface of the bronzes, as documented in the First Emperor's weapons, becomes common only during the Warring States period (Dong, 2006). Such a technical change may be related to both sociological and technological developments. In particular, it is tempting to think that the chiselling technique is associated to the availability of cast iron and steel tools. Further archaeometallurgical and experimental research should focus on the relationship between the casting and chiselling of inscriptions, and the development and use of cast iron and steel tools.

5. Filing, grinding and polishing marks

Filing, grinding and polishing marks were discovered on a large number of the weapons unearthed from the tomb complex. In some cases, these appear rather coarse and easily discernable with the naked eye. In other cases, the marks are much finer, and only perceptible thanks to the generally exceptional state of preservation of most of these artefacts. Crossbow triggers, lances, swords, and arrows were examined for signs of these.

5.1. Filing marks

Filing and grinding marks are discovered on the composite bronze crossbow triggers, and mainly found on the overlapping areas between them. Each trigger comprises three mechanical parts joined by two bolts, and each part has its own shape and function (Fig. 7a). The five parts were all cast separately, assembled together and fixed into the crossbow. The introduction of the trigger mechanisms during the Warring States period revolutionised military warfare, as it ensured the crossbow required less skill and strength to use than a composite bow and was said to be able to fire heavier arrows over a longer distance (Yuan, 1990; Yang, 1980). The majority of the grinding lines generally surround the holes of the three mechanical parts, i.e. they are most prominent in the overlapping areas between the three parts, where they would have to move by sliding over each other. These traces are probably the results of filing off excess metal from the surfaces to make them fit together properly during assembly, to ensure an effective functioning of the crossbow. However, similar traces have also been found on some of the bolt heads, where they would serve no obvious technical purpose (Fig. 7b).

Visually, the orientation of the marks on the triggers may appear parallel. However, under the SEM, it is possible to see that these marks are typically multi-directional, and that they cross each other (Fig. 8). These features are diagnostic of filing by hand, which involves back and forth movements of the file on the surface of the object. Based on measurements of the individual grooves, the diameter of the ridges or points on the file would have been approximately 100–200 μm.

Although we lack direct evidence for filing tools employed during the Qin period, the relative depth and the sub-parallel arrangement of the filing marks suggest that hand-held files made of a hard material, such as stone, steel or cast iron could have been employed. Experimenting with a hand-held polishing stone in a back-and-forth motion on a brass surface, we produced sub-parallel filing marks that, albeit thinner, resembled the arrangement of the archaeological ones (Fig. 9). However, considering the better definition of the marks in the archaeological examples, we are inclined to think that the filing would have been carried out with metallic tools. Only future experimentation may be able to clarify this point conclusively.

Similar marks from filing or a relatively coarse grinding are also noticeable on the tangs of arrowheads. They typically appear broadly parallel to each other and oriented diagonally. Although they appear predominantly on the casting seams, seemingly trying to remove imperfections, in some cases the marks embrace the entire circumference of the tangs. Under the SEM, the marks appear quite similar to those identified on triggers, hence suggesting a similar filing tool (Fig. 10). However, the fact that the filing marks sometimes turn around the curvature of the tangs suggests that either the files were curved or, alternatively, the tangs were mounted on a lathe to facilitate the filing.

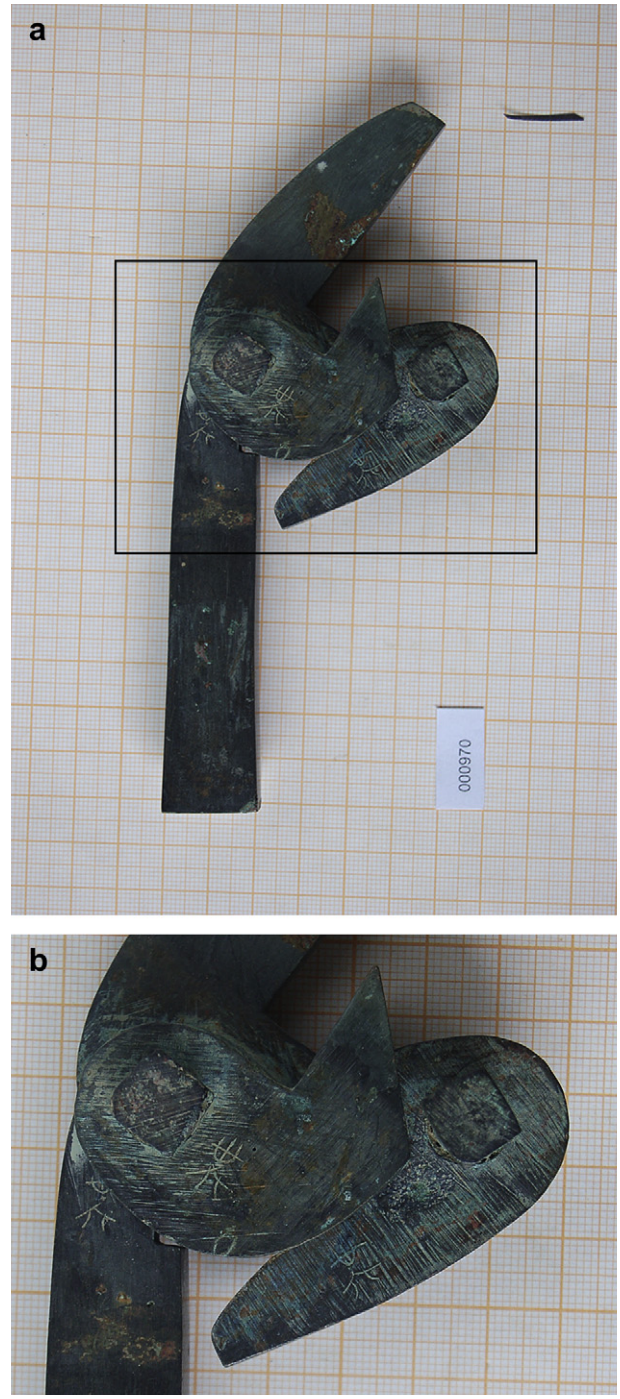

Fig. 7. Trigger mechanism (a) and detail of grinding marks and inscriptions (b).

A final explanation for the massive effort invested in filing the surfaces of several tens of thousands of arrow tangs has not been reached. It is important to note that the arrows would not have moving mechanical parts, hence the need of such filed or ground surfaces would seem less necessary. Furthermore, based on better preserved examples, it is known that these tangs were fitted inside a longer bamboo stick and would therefore not be visible – thus, it is unlikely that the filing responded to aesthetic concerns. The most

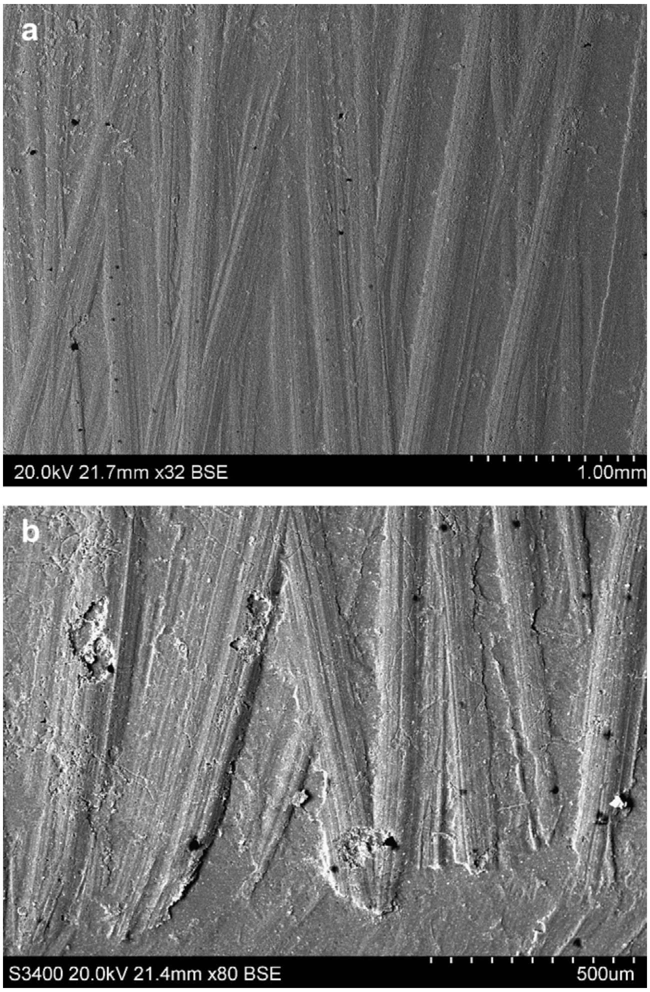

Fig. 8. (a) and (b): Micrographs of grinding marks on trigger 912C (silicone impression).

plausible explanation for the filing on the tangs may be that their makers wanted to achieve perfectly symmetrical arrows whose trajectory in the air would not be unbalanced by such small imperfections.

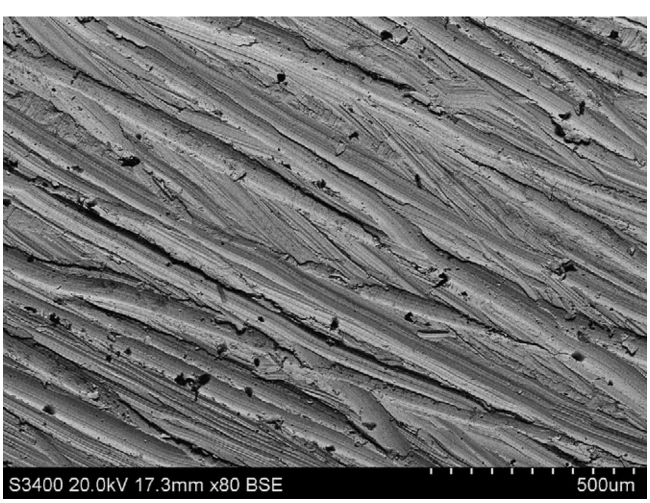

Fig. 9. Micrograph of filing marks experimentally produced on a brass surface using a hand-held stone. Compare to Fig. 8, but note the different scales.

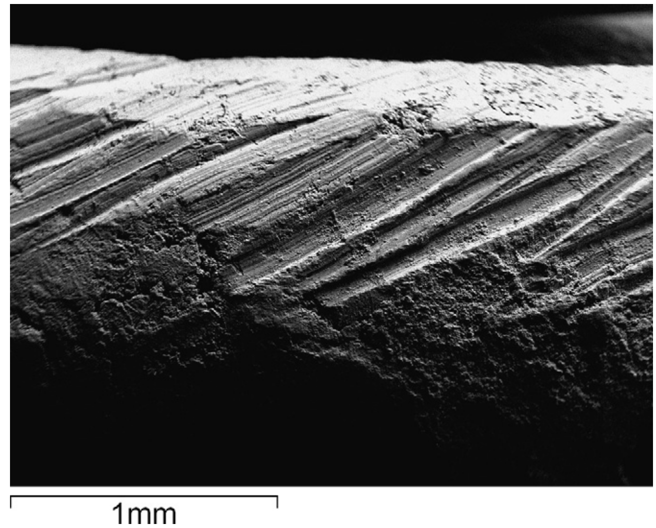

Fig. 10. Micrograph of filing marks on the tang of an arrowhead.

5.2. Grinding and polishing marks

Much finer grinding or polishing marks are found all over the surfaces of swords and lances, as well as on the arrowheads proper. In these cases, it is assumed that the aim of the polish was to obtain a smooth and shiny surface, as well as a sharp blade. On the swords and lances, the marks are generally longitudinal on the spine section, and transversal on the blade section (Fig. 11). On the arrow surfaces, these marks are transversal on all sides, and they often continue from one plane to another (Fig. 12). In some cases, it is possible to discern two stages of fine grinding/polishing on the arrowhead surfaces, one finer than the other, carried out in orientations perpendicular to each other. Sometimes these finer marks extend onto the surface of the arrow tangs, removing the evidence of the coarser filing described in the previous section.

When examined under the SEM, the grinding marks on all three types of artefacts are remarkable in two aspects: on the one hand, their extreme fineness and high density; on the other hand, their perfectly parallel disposition (Fig. 13). Such characteristics leave little doubt that they originate from a mechanical grinding device, most likely a rotary tool. The comparative shallow archaeological marks suggest that only a very small amount of material was

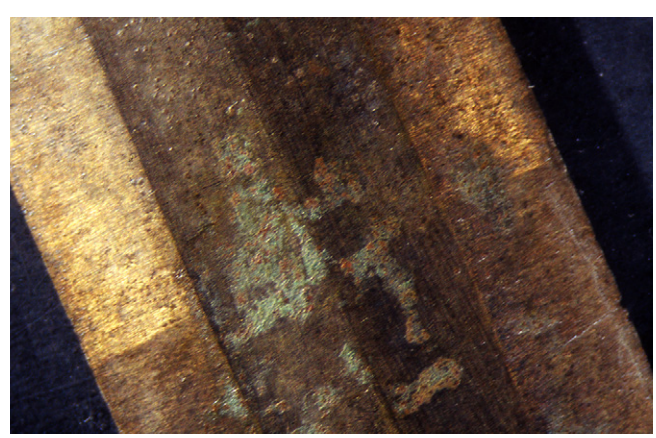

Fig. 11. Grinding marks on a sword, as seen under the stereomicroscope. Note the different orientation of the fine grinding and polishing marks on the various planes of the blade.

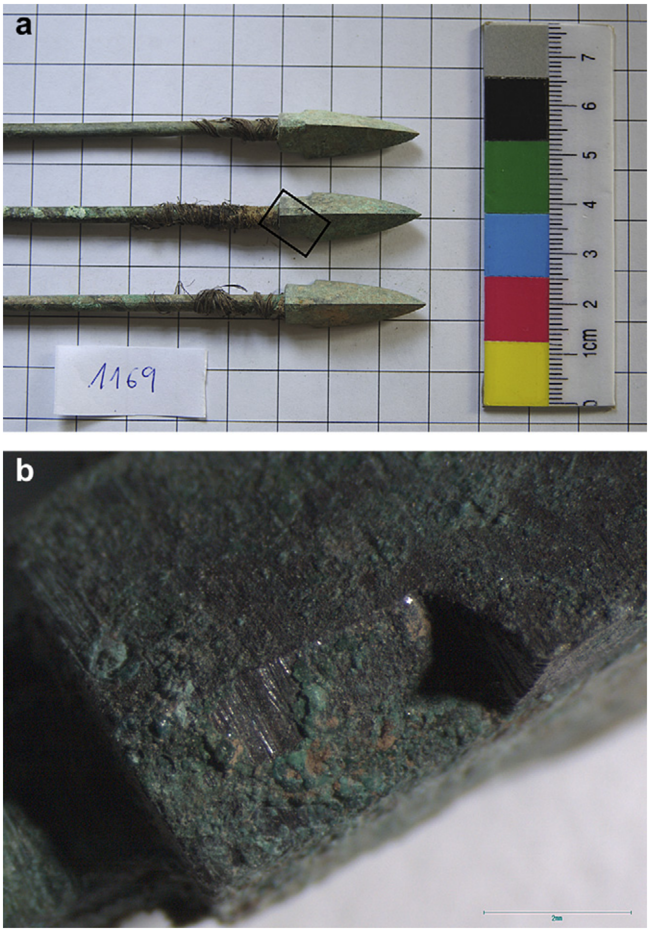

Fig. 12. Detail of the grinding marks on an arrowhead, as seen under the stereomicroscope. Note the presence of grinding lines that overlap two different planes.

removed from the weapons' surfaces during this finishing stage. These technical interpretations are supported by our experimental replications created by grinding a brass surface using a small hard stone rotary wheel (Fig. 14).

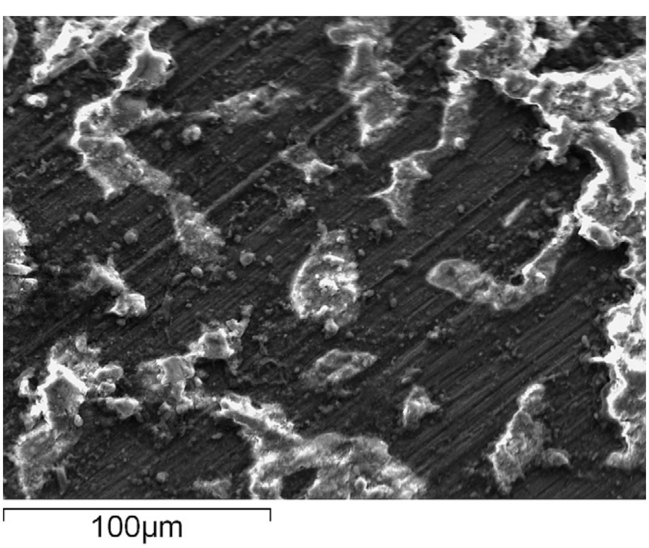

Fig. 13. SEM photomicrograph of the surface of a sword, showing dense, shallow and perfectly parallel grinding marks. The bright crusts and grains covering some of the marks are corrosion products.

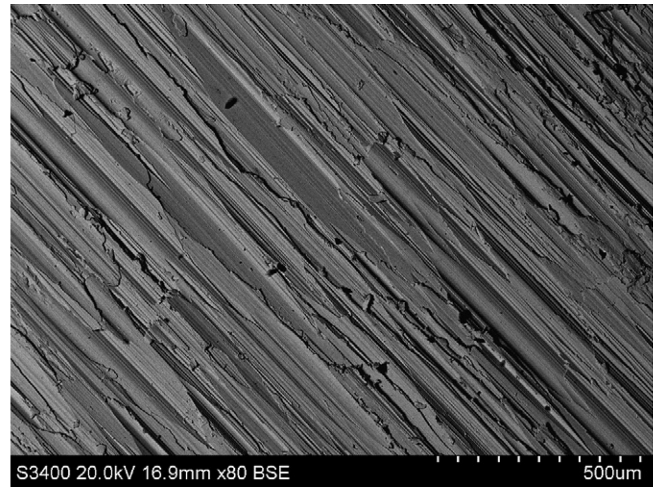

Fig. 14. SEM photomicrograph of a brass surface experimentally ground using a rotary wheel made of stone.

The fine grinding and polishing marks on the surface of the lances, swords and arrows seem not to have been made by loose abrasive materials. A relatively hard stone was most probably the material used for this finishing process, since natural abrasive materials were easy to acquire and hard enough for grinding the bronze weapons. It is also possible that relatively soft organic materials, such as linen, could have been employed for the last and finest stage, which would furnish the weapons with their characteristic sheen. The tools employed for this purpose could be comparable to the bristle brushes or buffing wheels used in modern crafts. The softness and flexibility of these materials would better explain the continuity of polishing marks overlapping different planes of the same weapons, and their very presence in small, hardly accessible, intricate parts of the arrowheads. When we used a bristle brush on a brass surface, however, we obtained a pattern of marks that does not resemble exactly those in the weapons (Fig. 15). Further research will have to concentrate on the potential differences between grinding and polishing marks, and the possible materials and tools used during these processes.

Another interesting finding of this work is the noteworthy similarity among the grinding marks detected on the different

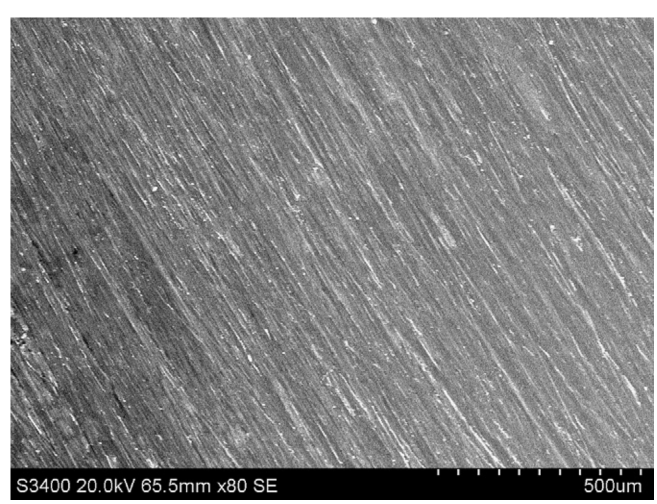

Fig. 15. SEM photomicrograph of a brass surface experimentally polished using a rotary bristle brush.

artefacts. This similarity applies to the thickness, density and relative shallowness of the marks (Fig. 16). Although the exact dates for the manufacture of the swords and arrowheads are unknown, the inscriptions on the lances indicated a narrow chronological range of 232–228BC (see above). The technical similarity of the grinding marks on all three artefact categories may be taken as an indication that all the weapons could have been ground in the same period and possibly at the same workshop, or at least employing very similar techniques. Future comparative examination of grinding marks on the halberds, dated to a different moment of Qin Shihuang's reign, may confirm whether or not the same grinding technique was employed over several years, or whether indeed arrowheads, lances and swords may be deemed as contemporary.

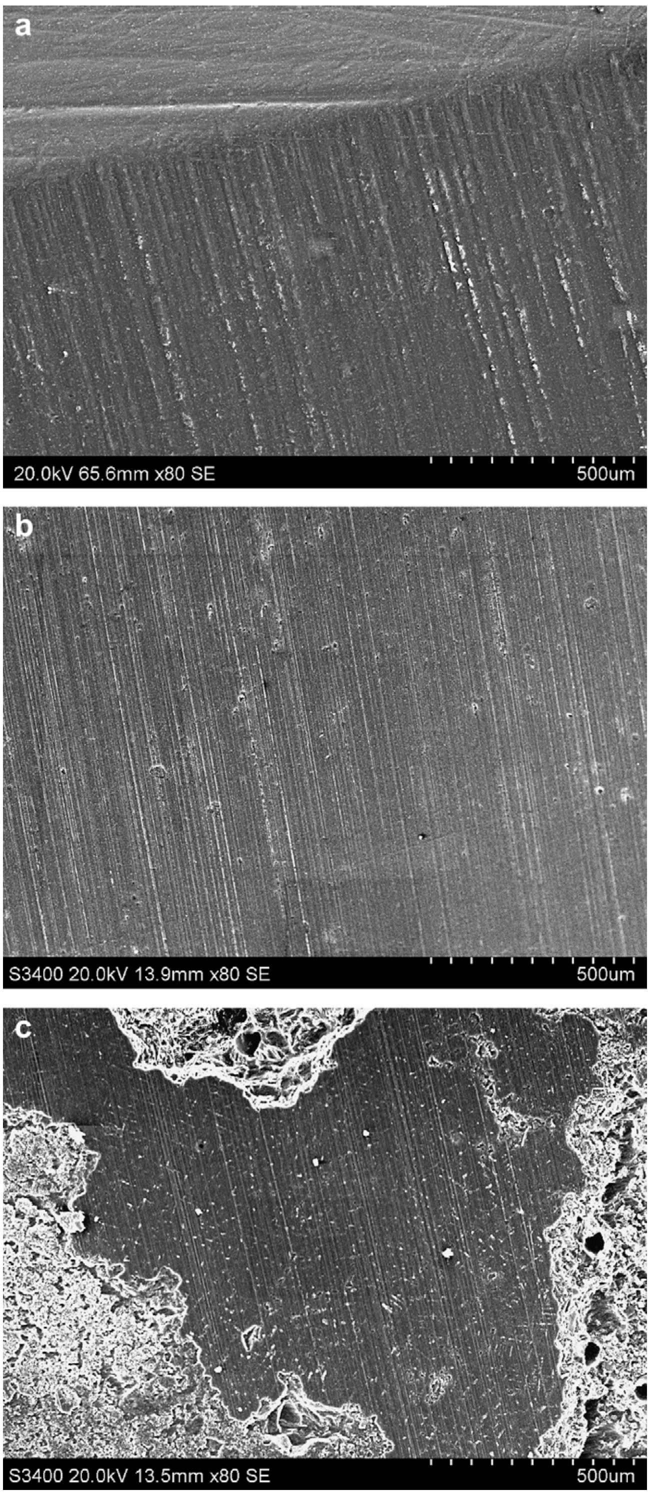

Fig. 16. Details of the silicone casts of the grinding marks on lances, swords and arrowheads, taken at the same magnification to facilitate comparison. From top to bottom, (a) lance 860, (b) sword 854 and (c) arrow 2118 (the bright crusts on the latter are impressions of corrosion products). Compare to coarser filing marks on a trigger in Fig. 7(b), taken at the same magnification.

5.3. Discussion

Anecdotal visual evidence on Shang and Zhou bronze vessels indicates that they were subject to filing and grinding finishing techniques. However, while their casting technology is abundantly discussed in the literature (e.g. Liu, 2009; Han and Ke, 2007; Ma, 1986; Barnard, 1961), these finishing marks are rarely studied, which makes a detailed history of this technology difficult to reconstruct. In particular, until further analytical and experimental data are available, it may not be possible to ascertain whether iron or steel files could have been employed on these bronze weapons. But these marks are almost certainly not made by loose abrasive materials.

Of particular importance, however, is the positive identification of the use of rotary mechanical tools on a systematic and industrial scale, for the grinding of tens of thousands of bronze weapons. Rotary wheels were used in jade carving long before they were used on bronzes (Dong, 2006: 104; Sax et al., 2007: 25). Rotary abrasive methods were probably used in jade carving by the end of Neolithic period in the Hongshan culture, which dates from about 5000BC (Dong, 2006: 104). Evidence of rotary incising wheels has also been found on a Shang dynasty ceremonial jade blade now in the British Museum (Sax et al., 2007: 25). However, during the subsequent Zhou, Qin and Han dynasties, hand-held tools continued to be preferred to make designs that are often intricate and minute. It would appear that it was not until the Tang dynasty (AD 618–907) that rotary incising wheels become commonplace in jade carving (Sax et al., 2007: 25).

As regards bronzes, it appears that rotary wheels were used on metals as early as the Shang and Zhou dynasties (Dong, 2006: 44–45). Bronze masks unearthed from Guanghan Sanxingdui (广汉三星堆), and dating from the Shang dynasty, were cut with square holes on the forehead or on the cheek side (Chen, 2000: 48–49). One of the big masks from pit 2, measuring about 65 cm in height and 138 cm in width, with a 10 cm long rectangular hole on the forehead, is thought to have been cut using a rotary wheel, because the four corners of the hole display intrusive crossing lines typical of wheel cutting (Dong, 2006:44–45). This would constitute the earliest example of the use of rotary mechanical means discovered so far on Chinese bronzes.

The rotary incising wheel is supposed to be slightly different from the rotary grinding wheels, even though they were both mechanical devices. The wheel shape and the results intended to be achieved would be different, but the rotary incising wheels and grinding wheels both involved the same mechanical principles.

Rotary grinding wheels appeared to have also been used on bronze weapons from the Warring States era based on the observations of the surface traces. Dong (1999) has argued that the Yuewang Goujian (越王勾践) sword, reputed to have been owned by the king of the Yue state, had its blades probably trimmed and ground using rotary wheels, because the lines are all parallel. The handle of the sword has a circular feature that seems to have been ground with a lathe, which was probably not balanced (Dong, 1999: 83). Furthermore, two gears from the following Han dynasty (202BC–212AD) show a similar mark, suggestive of mechanical means of manufacture (Dong, 1999: 84). The weapons from the Terracotta Army constitute the earliest evidence of the use of such rotary means in mass production.

6. Conclusion

Examination of the inscriptions and other tool marks on the surfaces of bronze weapons of the Terracotta Army has increased our understanding of the organisation of production during the creation of this unique assemblage, while contributing technical insights into the history of the bronze making craft and its adaptation to Qin Shihuang's commission.

As highlighted in previous work, the textual information recorded on the inscriptions of halberds and lances allows us to deduce a chronology for their fabrication, indicating that they were produced in two different stages, both predating the unification of the Qin (Qin Kingdom) and Qin Shihuang's ascent to the throne as an emperor (Qin Empire). In addition, the various names of supervisors, workshops, officers and workers, as recorded in the inscriptions, allow inferences as to the craft organisation and the relationship between weapon production and the changing political situations. Future work, comparing this and other assemblages, will facilitate an understanding of the singularity of the industry that worked directly for the mausoleum.

The tool marks in the inscriptions reveal the use of a variety of hand-held chisels to individually mark the weapons. Besides noting aspects related to quality control, it is suggested that the individualised symbols on the crossbow triggers may have been added to guide the assembly of joining parts, given the repetition of the symbols on several parts of the same triggers. In this sense, the fact that the inscriptions took place after the filing and grinding of the surfaces indicates that triggers were only inscribed once their makers, or their supervisors, were satisfied with their quality and the possibility of an effective assembly of the various parts.

Excess material such as casting seams or surface imperfections were removed from both triggers and arrow tangs employing files that were used for manually and painstakingly abrading their surfaces. Although the material employed for chisels and files remains uncertain, we suggest that at least some of these tools could have been made of cast iron or steel, since their extensive use, as documented here, broadly coincides with the development of ferrous metallurgy in China.

Finally, the marks left by the grinding that ensured that the surfaces of all the bladed weapons remained lustrous, and their blades sharp, demonstrate the use of rotary wheels on an unprecedented scale.

Altogether, the sophistication and sheer amount of specialised labour invested in just the finishing touches of these bronze weapons further highlights that no resources or skills were spared in the production of the First Emperor's Mausoleum. Without a doubt, further studies of this unique archaeological site will continue to yield surprises.

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