PRODUCTION AND TRADE OF CRUCIBLE STEEL IN CENTRAL ASIA

Ann Feuerbach*

(Received 11 May 2007)

Crucible steel has generally thought to be an Indian and Sri Lankan product but research illustrates that crucible steel was known, produced and traded throughout Central Asia and Persia for centuries. The following paper discusses the textual and archaeological evidence for its production in Central Asia and how it differs from that of Southern India and Sri Lanka.

Key words: Crucible steel/Damascus steel from Merv and Uzbekistan, Crucible slag, Production and Hyderabad process, Trade of crucible steel, Pulad.

Introduction

While most crucible steel, ‘Damascus’ steel, pulad, or so-called wootz research has dealt with its production in India and Sri Lanka, its production in Central Asia has tended to be overlooked. Research over the last two decades indicates that crucible steel was produced outside of the Indian subcontinent.

The first definitive evidence for the trade in crucible steel come from the 3rd century AD, in a text written by the Alexandrian alchemist, Zosimos of Panopolis¹. Zosimos clearly discusses the production of crucible steel and then states “Such is the premier and royal operation, which is practiced today and by means of which they make marvelous swords. It was discovered by the Indians and exploited by the Persians, and it is from them that they are coming”. Thus, by the 3rd century AD, there is evidence suggesting that the

* Art and Archaeological, Scientific and Technological Investigations LLC (AASLI@att.net) 2347 Bellmore, NY, 11710, USA. Also attached to Hofstra University, Hempstead, NY 11549 USA.
Persians are exporting crucible steel to the Mediterranean world. Another reference to the trade in crucible steel is from the Babylonian Talmud, compiled between the 3rd and 5th centuries AD. Craddock\textsuperscript{2}, reports that during this period, crucible steel from India was being imported into Persia by the Jewish community that lived in Persia during the Sasanian period. There are also Chinese references suggesting that crucible steel was imported into China from Persia during the Sasanian period and from Kashmir during the 10th century AD\textsuperscript{3}. A 14th century Chinese text clearly refers to crucible Damascus steel blades with patterns of spirals, sesame seeds or snow flakes, and a pair of scissors with Islamic writing, both of which come from the land of the ‘Western Barbarians’\textsuperscript{4}. It is likely that the objects were coming from Ferghana Valley of Uzbekistan, the land of the ‘Western Barbarians’ as there is archaeological evidence that crucible steel was being produced in this region on a very large scale for centuries\textsuperscript{5}.

The trade and production of crucible steel was mentioned during the Islamic period. Al- Kindi (9th century AD) and Al-Beruni (early 11th century AD) both mention trade including its production in the Khorasan region\textsuperscript{6}. Centuries later Comte de Ferrieres Sanveboef refers to the finest blades being made in Khurasan during the 18th century\textsuperscript{7}. According to Floor\textsuperscript{8}, “Whereas Qom was a leading producer of swords in Safavid Iran, this role had been taken over by Mashhad and Kerman in Qajar Iran. Nevertheless, it would seem that Shiraz was to overtake its competitors...Ker Porter stated around 1820, that in Shiraz swords and daggers were made, which were excellent for general use. However, they were not as good as those made in Kerman and Khorasan”. Furthermore, Massalski\textsuperscript{9} saw crucible steel still being produced in Bukhara, Uzbekistan during the first part of the 19th century. Thus the textual evidence indicates that Persia and Central Asia, more particularly the Khorasan region, was trading and at some locations producing crucible steel for centuries. Undoubtedly some locations imported steel to forge locally, but archaeological evidence from Merv, Turkmenistan and locations in the Ferghana Valley of Uzbekistan, show that it was definitely also being produced.

**Archaeological Evidence**

There is archaeological evidence for the trade and production of crucible steel objects. Metallographic investigation of blades from the Russian
Northern Caucasus indicated that crucible steel blades were in use there from a relatively early date\textsuperscript{10}. At present, there is no evidence that crucible steel was produced in the Northern Caucasus yet four blades were found from various time periods near Kislovodsk, Russia. Two of the earliest blades from the 3\textsuperscript{rd}-4\textsuperscript{th} century AD were found in association with an early Alani burials at Klin Yar. One of these blades is the earliest known example of a blade that would have had a crucible Damascus steel pattern if it were etched. A third blade was also associated with an 7\textsuperscript{th} century Alani horse burial. The fourth is a 11\textsuperscript{th} century saber from Koltso Gora and is associated with the Saultovo Mauaskaya culture. It is most likely that these were acquired via trade or booty. Other archaeological crucible steel swords are both from Iran which include a 6\textsuperscript{th} or 7\textsuperscript{th} century Sasanian sword now housed in the British Museum\textsuperscript{11} and a late 8\textsuperscript{th}-9\textsuperscript{th} century AD sword excavated at Nishapur, now in the Metropolitan Museum of Art, New York\textsuperscript{12}.

It is from the ‘Islamic’ periods that we have archeological evidence of crucible steel production in Central Asia, a site from Merv, Turkmenistan, and numerous sites from the Ferghana valley in Uzbekistan. The evidence shows well developed craft traditions and indicates that the materials and techniques are not the same as those found at many sites in India or Sri Lanka.

**Merv, Turkmenistan**

A workshop located at the ancient city of Merv in present day Turkmenistan was excavated by the International Merv project, a joint international team from University College London, Institute of Archaeology, along with Turkmen archeologists. Diagnostic pottery found in during the excavations suggested that the workshop was in use during the 9\textsuperscript{th}-10\textsuperscript{th} century AD. Excavations revealed domestic dwellings adjacent to the industrial area. This, together with the relatively small number of furnaces and the quantity of industrial remains indicated a permanent workshop, possibly run by a family. It is estimated that approximately 1250 crucibles were used during the operating life of the workshop. There appears to have only been two phases of construction and the comparatively shallow depth of deposits suggest that the workshop was in use for less than a century and probably closer to fifty years.
The remains of the workshop can still be seen on the surface as a scatter of broken crucibles, furnace wall fragments, slag and pieces of iron (Fig. 1). Since part of the crucible steel process involves breaking the crucible to retrieve the steel product, all the crucibles were broken and can be divided into lids, walls, and base fragments. The lid fragments are flat ceramic disks c. 8 cm in diameter with a thickness ranging from 0.5 to 1 cm. They are all dark gray in color due to carbon in the fabric. They also have a central hole 1 cm in diameter (Fig. 2).

Fig. 1. Remains of the crucible steel workshop can still be seen on the surface as a scatter of broken crucibles, furnace wall fragments, slag and pieces of corroded iron.

Fig. 2. The lids have a dark ceramic matrix and a central hole 1 cm in diameter.
The crucible wall varies in color and thickness, changing from white and c. 1 cm in thickness at the lower part of the wall near the base, to dark gray and c. 0.5 cm, at the upper part of the crucible where it meets the lid (Fig. 3). It appears that the crucibles were wheel thrown. The exterior of the wall and base fragments exhibits a shiny black glaze. The black glaze is thinner, c. 0.1 cm on the upper parts of the wall, and thicker, c. 0.5 cm towards the pad. There are rust colored encrustations on the underside of some lids, and on the interior side of the upper walls of the crucible. These were identified as partially corroded steel prills. Below these rusty encrustations, towards the base, is a glassy green ring identified as slag. The location of the glassy green fin averages around 8 - 10 cm high from the base measured at the inside of the crucible.

![Fig. 3. The crucible wall varies in color and thickness, changing from white and c. 1 cm in thickness at the lower part of the wall near the base, to dark gray and c. 0.5 cm, at the upper part of the crucible where it meets the lid.](image)

The internal profile of the lower part of the wall to the base, below the glassy green slag, is hemispherical with a thin layer of a dark green vitreous slag, which sometimes has a honey-combed pattern or is comparatively smooth (Fig. 4). The interior diameter of the bases varies from c. 6 cm to c. 6.5 cm, although the external diameter is consistently c. 8 cm. The crucible bases have an external bottom profile that is either flat
or slightly arched, probably due to being placed on to the pad while still in a comparatively malleable state. The base of the crucible has a disk shaped attachment, a (so-called) pad, made of a different ceramic fabric. The diameter of the pad is c. 8 cm and it has a thickness of typically between 1 and 2 cm. Pieces of broken crucibles, c. 1 cm$^2$ and 0.5 cm thick are attached to the pad’s perimeter by a black glaze. These are labeled ‘refractory mass’ and are interpreted as part of the furnace floor.

Within the glassy vitrified areas, pinpoint size crystals have begun to form. These were identified by x-ray diffraction as mullite. The crucibles are composed of SiO$_2$ (c. 65%) and Al$_2$O$_3$ (c. 24%) with small amounts of K$_2$O (c. 4%) and CaO (c. 0.5%). Evidence provided by the crucibles, along with information gathered from the excavation of the furnace, provides evidence of the redox conditions inside the furnaces.

All that remains of the furnace are roughly two-thirds of the circumference consisting of vertical walls 30 to 40 cm high. The average diameter of the three furnaces at the exterior walls was between 70 and 95 cm across, while the interior ranged from c. 30 to 50 cm producing an initial wall thickness of about 10 cm. The furnaces walls were relined thus reducing the interior diameter of the furnace over time. The smaller furnace could hold a maximum of 7 crucibles while the larger could have held 20 maximum.
The design and operation of the furnace can be suggested by comparing the visual archaeological evidence to known furnace parameters (Fig. 5). Although no archaeological evidence remains of the top part of the furnace, it is reconstructed as a closed top domed furnace with a central tuyère rising up from the floor of the furnace, and with a side exit flue, based on the following evidence. Three of the furnaces had a central air pipe rising out of the center of the floor of the furnace. This is interpreted as the tuyère and presumably this was attached to bellows needed to blow air into the furnace to raise the temperature high enough for the crucible steel process to work. The air would have come through the tuyère at the bottom of the furnace and traveled up through the charcoal. It is unlikely that the necessary temperatures, at least over 1050° centigrade suggested by the presence of mullite and probably over 1450° centigrade would have been reached and maintained, presumably for hours, using an open top furnace.

![Diagram of furnace](image)

**Fig. 5.** The design and operation of the furnace can be suggested by comparing the visual archaeological evidence to known producer gas furnace parameters.

One of the furnaces had a section of wall that splayed out from the body of the furnace. The internal walls of the splayed area exhibited a high degree of vitrification, equal to the thickest glaze at the bottom part of the furnace near the floor. This indicates that hot air and ash from the fire was somehow directed into this area. If the exit flue was directly above the
tuyère and there was no roof, the air would have blown out of the furnace top and would not have vitrified the splayed area nor heated the crucibles sufficiently. By having the flue on the side, the air would come up out of the tuyère, circulate around the crucibles and fuel before leaving through the flue, thus more evenly distributing the heat around the crucibles. The furnace works both as an updraft and a down draft furnace. Therefore, to satisfy the archaeological observations, and for the furnaces to reach and maintain the necessary temperatures, the top of the furnace had to be closed. A domed roof is suggested rather than a flat one because it is the most efficient shape for heat distribution and is mechanically more stable. In addition, there is archaeological and ethnographic evidence of pottery kilns that support the suggested furnace reconstruction.\textsuperscript{13}

After the firing and the cooling of the furnace, the furnace was broken into on one side and the crucibles were removed. The sharp breaks in the black glaze around the crucible pad imply that the glaze was brittle when separated from the rest of the furnace floor. In addition, the evidence of slow cooled steel prills in the crucible indicate that the crucible contents, and therefore by association, the crucibles themselves were slowly cooled. The furnaces were then refined and used again.

One of the major questions the research endeavours to answer is what materials were placed into the crucible to produce the steel ingot. Apart from the prills and the one crucible steel ingot, all other pieces of iron alloys found in and around the workshop were completely corroded, even beyond the identification of relic structures, therefore it was not possible to ascertain if these lumps were wrought/bloomery iron, cast/pig iron, or steel. They are, however, believed to be part of the crucible charge. Lumps of heated iron ore with varying amounts of slag like material were found adjacent to the site and small fragments of the same material were found inside the crucible pit. However, no associated metal was found. Therefore, the only directly linked evidence of what went into the crucible are the products: crucible slag, prills, and the ingot. The heated ore and its associated slag-like material is the only iron rich material. That what was not inside the crucible can be studied and might hint at the crucible charges nature.

Crucible slag was found attached to the interior of the crucible walls and as loose pieces detached from the crucible wall. Their non-deteriorated
appearance suggests a high resistance to weathering. The slag ranges in appearance from a shiny, translucent ‘bottle’ green to a darker, duller bluish green. Most samples match the former description and there is no correlation between the color and the elemental composition. The average elemental composition of the majority of crucible slag is as follows: SiO₂ average 50% (range 45-53%), Al₂O₃ 16% (range 13-18%), FeO 1.5% (range 0.2-2.4%), Ca 16% (range 9-21%), K₂O 3.5% (range 2-6.4%), MgO 2.8% (range 1.4-4.2%), Na₂O (0.2%), TiO₂ (0.5%), but with a noticeable difference of Manganese: low MnO 2% (range 0.1-4%) high MnO 12% (9-17%).

The crucible slag contains the non-metallic material remaining from the crucible charge. There does not appear to be any straightforward correlation between the ratios of specific elements, which could suggest that the elements were added together as the components of a particular mineral, except the possible deliberate addition of a manganese rich substance. The slag is homogeneous within a given sample indicating a long enough firing at a high enough temperature to homogenize the slag. The function of the crucible slag would have been to provide a layer to prevent oxidation. Verhoeven noted that the presence of slag was not a necessary aspect of the crucible steel process, however, those ingots that did not have a slag covering, cracked during forging (Verhoeven, pers. com.), thus a coating of slag was beneficial to the process.

Iron and steel remains were primarily found as two groups: as individual lumps, and as prills associated with the crucibles and/or crucible slag. By far the majority of remains were completely corroded, however uncorroded prills were found preserved in the slag and areas of preserved metal were identified surrounded by corroded metal. There is an apparent relationship between the amount of manganese in the slag and in the prill in that slag. The more manganese there is in the slag, the more manganese is in the prill. However, while the manganese content in the slag differs greatly, from around 2% to around 12%, that in the prills it differs from not being detected to as high as 0.3%. The presence of manganese even in this low percentage is significant because it would promote the development of a pattern, if the ingot were forged in such a manner as to produce the pattern.

Approximately a hundred individual lumps of corroded iron or iron-alloy with an average size of c. 1 cm³ were recovered from the crucible pit.
during the excavation. Around a dozen of these lumps were sectioned but were completely corroded even beyond the point of identifying any relic structures. There was, however, a corroded ingot. The crucible steel ingot is virtually entirely corroded but still contained two small island of preserved metal. Etching in Nital revealed that the preserved metal is hypereutectoid steel, around 1.2-1.4% carbon consisting of prior austenite grain boundary cementite and cementite needles with a coarse pearlite matrix. Many of the prills are of hypereutectoid steel with a slow cooled pearlitic structure and idiomorphs were observed, all indicating slow cooling.

By estimating the area inside the crucibles, and the ingot, the average weight of steel produced by each crucible was approximately 2 kg. The estimated total number of crucibles was 1250, multiplied by the estimated average weight of the ingot, 2 kg, suggests that at least 2500 kg of steel were produced during the occupation of the workshop.

In order to suggest the crucible charge, volume analysis was used. It is argued that the volume of the crucible (c. 770 cm³) was the smallest volume necessary to produce the desired product, a steel ingot c. 250 - 300 cm³, from bloomery iron and a carbonaceous material. Determining conclusively whether a metallic iron-carbon alloy was added to the bloomery iron as part of the crucible charge, or carbonaceous material, or indeed both, is difficult without more research on different types of crucible steel production remains from historic and archaeological contexts. However, considering the volume calculations and the lack of replication experiments specifically addressing these points, presently the strongest argument is that the crucible charge consisted of 2 kg (2.4 kg) of bloomery iron broken up into pieces, which took up a volume of around 360 cm³ (425 cm³) with room for 410 cm³ (345 cm³) of plant matter. Experiment revealed that a handful of material had a volume of roughly 110 cm³ (327 cm³ = three handfuls bloomery iron, 350 = 3 handfuls of wood). Therefore, it is concluded that roughly four handfuls of bloomery iron was placed in the crucible with about four handfuls of wood, or a 1:1 volume ratio.

The presence of phosphorus in the prills and ingot is important to consider because of its effect on the forging properties of the steel. Crucible steel experiments by Verhoeven and Pendray noted that even low levels of phosphorus in crucible steel cause the ingot to be ‘hot short’ (crack during
forging), thus requiring low temperature forging. Low temperature forging can produce spheroidal cementite in hypereutectic steel, such as that found at Merv. The presence of manganese in some of the prills and the ingot suggest that, if repeatedly forged at low temperatures, a 'Damascus' pattern would appear if the blades were etched. As etching blades was performed in this region at this time, as stated by textual evidence, it is likely that blades produced from ingots produced at Merv, had a characteristics 'Damascus' pattern.

The charge could utilize less desirable areas of blooms with a high slag content and transform it to a high quality steel ingot. The extensive reuse of grog, trimming and broken crucibles indicate recycling. No ore or high refractory clay sources near by so had to be imported, perhaps from the mountain of Afghanistan which have the correct geological environment. There is evidence that the craftsmen at Merv used techniques that would conserve clay, including the use of grog and quartz temper, in addition to trimming the base of the crucible and adding a pad made of a separate, less refractory, material, thus suggesting that access to the clay was limited, and/or the price of this special clay was high. The extensive use of crucible fragments in the production of new crucible as well as in the pads and furnace floors indicates that the craftsmen were concerned about the supply of clay, and thus employed recycling measures. The crucible steel process was effective and efficient with a high success rate that is reflected in the low number of failed crucibles or failed crucible products uncovered during the excavation.

**Uzbekistan Remains**

Archaeological remains from the production of crucible steel were discovered in Uzbekistan during the 1960s but were originally identified as glass production remains\(^{15}\). These were re-examined and identified as crucible steel remains by Papachristou (*sic*) and Swertschkow (1993). Papakhristu and Rehren (2002), and Rehren and Papakhristu (2000) have continued to study these remains. Sites where the remains of crucible steel production have been found include Akhisket, Pap and Kuva.

The reports by Papachristu (*sic*) and Swertschkow (1993), Papakhristu and Rehren (2002), and Rehren and Papakhristu (2000) describe the 'standard'
crucible as tubular, 8-9 cm in diameter and 28 cm high. The lids are hemispherical with one central hole and are luted to the top of the crucible wall but lids with more holes were also found. The bases' external profiles are flat or slightly arching and the inner surface is hemispherical. The walls' thickness decreases from 15 mm to 10 mm near the base to 8 to 5 mm near the top. The walls' exterior is corrugated and glazed, while the interior exhibits the impression of a woven textile pattern. The interior pattern is thought to have originated during the forming of the crucible with the use of a textile core, possibly filled with sand, upon which the clay was pressed and then scraped to produce the corrugated pattern on the exterior.

According to Papakhristu and Rehren's study (2002), the crucibles contain mullite, cristobalite and glass, with a quartz temper, which is almost 50% of the ceramic volume. The elemental composition of a few Akhsiket crucibles was also studied by Papakhristu and Rehren (2002) by ICP to determine the bulk compositions. The results indicated that the crucibles have around a 2:1 ratio of silica to alumina and these two elements added together yield about 95% of the total composition of the matrix. Other elements included FeO (0.5%), TiO₂ (0.7%), with MgO, CaO, K₂O at or below 0.5% and Na₂O at 0.2%16. The crucibles exhibit no signs of sagging and could withstand temperatures up to 1650° centigrade17.

The crucibles’ slag is stated as their most distinctive feature18. The slag is located in the interior of the crucible 15-20 cm above the base, is 2-8 cm thick and over half its volume is composed of vesicular bubbles ranging in size from a few millimeters to 2 cm in diameter19. The appearance of the slag varies and ranges from translucent to opaque. It can be relatively homogenous or contain many inclusions. The color can be brown, gray, light green, dark green, turquoise, shades of blue or contain areas with all of the above colors. SEM-EDS analysis of inclusion free areas were reported as follows20: 60% SiO₂, 20% Al₂O₃, 15% MnO, 1% K₂O, 3% CaO, and 2% FeO.

Rehren and Papakhristu (2000) have proposed the contents of the crucible charge using mass balance calculations. They concluded that the majority of the iron in the charge came already in the metallic state but a significant part of the iron also arrived as iron oxide. Their strongest hypothesis is the use of raw or partially consolidated bloom in the charge along with
charcoal$^{21}$. The result was a crucible steel ingot weighing around 4.5 kg. Unlike the crucible steel production remains from Merv, the number of crucibles produced at Akhsiket$^{22}$ is estimated at well above 100,000 testifying to production on an industrial scale. This level of production must have exceeded the demands of the local population and the steel must have been primarily produced for trade. Given the high number of crucible found, this would result in an average annual production of 1100 kg of crucible steel a year for four hundred years$^{23}$.

The crucibles from Merv and various sites in Uzbekistan share many common characteristics. They are cylindrical with a diameter c. 8-9 cm and are roughly 20 cm at Merv and 28 cm in Uzbekistan in height. The crucibles have a flat base and were placed on the floor of the furnace. The lids have a hole in the center and were luted on to the body of the crucible. The clay used is highly refractory and fires to a light gray to white color. Quartz is used in the crucibles for temper, and the exterior side of the walls has an exterior ash glaze. The crucibles have an interior layer of slag, which has a low percentage of FeO (below 4%). The product was an ‘egg’ shaped ingot composed of slow cooled high carbon steel.

However, there are differences in the materials and process as well. The lids differ in shape; those from Merv are flat while those from Uzbekistan are domed. The Merv crucibles sat on a pad but the Uzbek crucibles did not. The upper areas of the crucible wall and lid of the Uzbek crucibles are not black, but the Merv crucibles are, indicating different furnace design and firing conditions. The crucibles from Uzbekistan are a few centimeters larger than those from Merv. Another difference is the method used to shape the crucible. The Merv crucibles were shaped on a rotating device, whereas the Uzbek crucibles were formed over a mould. The different percentages of elements in the ceramic matrix indicate that the clay came from different sources. Both crucibles have quartz temper but the Uzbek crucibles contain much more (c. 50%) compared to those from Merv (c. 10%) and the Merv crucibles also contain grog. The exterior glaze is neither as thick nor consistent in color on the Uzbek crucibles as in the Merv.

The slag is also different. The slag in the interior is much thicker in the Uzbek crucibles and is therefore referred to as a slag cake, rather than
a fin. At Merv there are two main groups of slag, a high and a low manganese group. Also the calcium content of the Merv crucibles is much higher (14% - 18% CaO), than the Akhsiket slag (2% - 4% CaO). This suggests that the materials put into the Merv crucible were calcium rich and may suggest freer flowing smelting slag, a different ore source, or different crucible charge. The steel ingots from Akhsiket would have been larger, and almost twice the size of those from Merv. The minor/trace elements present in the Merv and Uzbek prills and crucible steel ingots differ, particularly in the amount of copper. The Merv prills have around 0.3% Cu, while the Uzbek metal has between 0 -0.1%.

Although there are many differences between the remains from Merv and those from Uzbekistan, the differences are minor; therefore overall the remains are considered to be more similar than different.

**Comparison with Hyderabad Process**

The processes found in Islamic Central Asia have some similarities with the process discussed by Voysey\(^4\) and studied by Lowe (e.g. 1989a, 1989b), from the 1820's in Hyderabad, Deccan region. The materials and process used here appears to be a mixture of Central Asian and the Indian influences. The shapes of the Hyderabad crucibles are similar to those from Central Asia; both are cylindrical and flat bottomed, except that the Hyderabad crucibles are shorter. However, the interior diameter of the Hyderabad crucibles\(^5\) ranges from 2.5-12 cm. The lids of the Hyderabad crucibles are made out of a lump of clay but some crucibles have a 'triple crucible' cover, consisting of three small crucibles luted together\(^6\). The interior surface of the Hyderabad lids is covered with small iron prills\(^7\) similar to those observed in the interior walls and interior surface of the lids on the crucibles from Merv. Central Asian and Hyderabad crucibles have gravel or similar debris embedded into the bottom surfaces\(^8\). The flat bottoms and debris indicate that both the Central Asia and Hyderabad crucibles sat on the floor of the furnace, whereas the South Indian crucibles were stacked. Voysey mentions the use of ground furnace and ground crucibles being used as grog in the crucibles. Lowe notes that the temper used in the crucible lids is different from the body. The lids have grog, quartz and feldspar as temper\(^9\), whereas the temper in the crucible body is rice husks, which is similar to other Indian
crucibles that also use rice husks. Lowe\textsuperscript{30} reports that composition of the ceramic matrix is around 70\% SiO\textsubscript{2} and 30\% Al\textsubscript{2}O\textsubscript{3} thus indicating that the clay is more similar to the Central Asian crucibles. The crucibles are relatively refractory and contain fewer impurities than the South Indian crucibles made of ordinary ferruginous clay. It is the carbon from the rice husks and the reducing atmosphere inside the furnace which gives the Hyderabad crucibles their black colour, making them superficially appear more similar to the South Indian crucibles than they truly are. Voysey\textsuperscript{31} reported that the crucible charge contained \textit{kanch} and two different types of iron. The first is described as a ‘porous reddish grey bloom’, while the second was ‘moderately compact and of a brilliant white fracture’. These have been understood by Allan and Gilmour\textsuperscript{32} to be ‘small pieces of fused glassy furnace waste [slag] together with two pieces of white cast iron and three pieces of bloomery iron’. Voysey and Lowe\textsuperscript{33} state that the crucibles were removed from the furnace while hot, a southern Indian and Sri Lankan characteristic.

Perhaps the reason for this mixture is due to a Persian influence in the production of crucible steel in the region. Voysey mentions that Haji Hosyn was from Isfahan and was importing the metal to Persia because, although the Persians knew the process, they were unsuccessful in making it. Additionally, around the same time, de Rochechouart states that the workers at Lucknow, Uttar Pradesh, were all Persians\textsuperscript{34}. The similarity of the process found in Hyderabad, those mentioned by Islamic writers, and to Massalaski’s description of the process as it was undertaken in Iran, was also noted by Bronson\textsuperscript{35}.

Based on the similarities of the archeological evidence used to produce crucible steel in Central Asia and Hyderabad, it suggests that this variation of the crucible steel process was perhaps developed in Central Asia, and then Persians influenced the Indian production methods and techniques in certain areas of northern India. Only additional research on archaeological and historical remains of crucible steel production in India will help us understand the variety of method and material used to produce the famous steel. In conclusion, it appears that Zosimo’s statement that crucible steel “was discovered by the Indians and exploited by the Persians”, was accurate in the 3\textsuperscript{rd} century as well as the early 19\textsuperscript{th} century.
NOTES AND REFERENCES

3. Laufer, 1917; also see Wagner’s article in this journal
4. David, 1971; also see Wagner’s article in this journal
5. Papakhristu and Rehren, 2002
6. Hoyland and Gilmore, 2006
8. Floor 2003, p. 236
9. Massalski, 1841, pp. 297-300
12. Allan and Gilmour, 2000, p. 54
13. see Wulff, 1966, pp. 159-160
15. Abdurazakov and Bezborodov, 1966
16. Papakhristi and Rehreu, 2002
17. Abdurazakov and Bezborodov, 1966
18. Rehren and Papakhristu, 2000, p. 57
19. Rehren and Papakhristu, 2000, p. 57
20. Rehren and Papakhristu, 2000, p. 58
21. Rehren and Papakhristu, 2000, p. 62
22. Rehren and Papakhristu, 2000, p. 65
23. Ibid, p. 65
24. Voysey 1832, pp. 245-247; Bronson, 1986
25. Lowe, 1989b, p. 732
26. Lowe, 1989b, pp. 733-734
27. Lowe, 1989b, p. 734
29. Lowe, 1989, p. 246
30. Lowe, 1991, p. 10
31. Voysey, 1837, p. 247
32. Gilmour, 2000, pp. 72-74
33. Voysey and Lowe, 1989b, p. 732
34. Floor, 2003, p. 240
35. Bronson, 1989, p. 44

BIBLIOGRAPHY


David, P. 1971, Chinese connoisseurship: the Ko Ku Yao Lun, the essential criteria of antiquities, Faber and Faber: London.


Laufer, B. 1917, Sino-Iranica, Field Museum Anthropological Series 15.3, Chicago.


