METALS AND CIVILIZATIONS
National Institute of Advanced Studies

Proceedings of the VII International Conference on ‘The Beginnings of the Use of Metals and Alloys’
BUMA-VII

Editors:
Sharada Srinivasan
Srinivasa Ranganathan
Alessandra Giumlia-Mair
About this Book
The proceedings of BUMA VII, held in 2009 in Bangalore as part of the renowned international conference series on the ‘Beginnings of the Use of Metals and Alloys’, are published as an edited volume entitled “Metals and Civilisations”. With twenty eight valuable peer-reviewed papers covering inter-disciplinary research, it widens our knowledge of the use of metals in antiquity and several aspects of the archaeology, archaeometallurgy, historical metallurgy, crafts practices and metallurgical heritage of many Asian and some non-Asian countries.

About the Editors

Prof. Sharada Srinivasan
Prof. Sharada Srinivasan is Professor at the National Institute of Advanced Studies and anchor of the NIAS Heritage, Science and Society programme and works in the areas of archaeometallurgy, archaeomaterials, archaeological sciences, art-science interface and performing arts. She is a recipient of the Dr. Kalpana Chawla Young Woman Scientist Award (2011), the Indian Institute of Metals Certificate of Excellence (2007) and Materials Research Society of India Medal (2006) and the Malti B. Nagar Ethnoarchaeology Award (2005). She is a Fellow of the Royal Asiatic Society of Great Britain and Ireland and the World Academy of Art and Science. She did her PhD in Archaeometallurgy from Institute of Archaeology, UCL, London. She has coauthored with Prof. S. Ranganathan a book on ‘India’s Legendary Wootz Steel’ (Universities Press, 2014).

Prof. Srinivasa Ranganathan
Prof. Srinivasa Ranganathan is Emeritus Professor at the Indian Institute of Science and Homi Bhabha Visiting Professor at the National Institute of Advanced Studies. His interests cover physical metallurgy, history of science and heritage science. He is a member of International Advisory Committee of the BUMA Conference series, INSA National Commission for the History of Science and the DST Programme Advisory Committee on Indian Digital Heritage – Hampi. He taught the inaugural course on Science and Civilization in India to IISc Undergraduates in August 2011 and a course on Materials Heritage and Conservation at the Tokyo University of the Arts, Japan in 2012. He is a Fellow of four Indian Academies of Science and Engineering and the World Academy of Sciences (TWAS) and recipient of Lifetime Achievement Awards from the Indian National Academy of Engineering (2014) and Indian Institute of Metals (2012).

Dr. Alessandra Giumlia-Mair
Dr. Phil., M.Sc. Alessandra Giumlia-Mair was first lecturer and then Professor by contract (1992-2001) in Archaeometallurgy and Archaeometry at the Universities Salzburg (Austria), Trieste and Udine (Italy). In 2000 she founded AGM Archeoanalisi, a laboratory specialising in Archaeometallurgy. She worked on European and Asian finds from excavations and from the British Museum, Ägyptische- and Antiken Sammlung Munich, Royal Ontario Museum Toronto, Römisch-Germanisches Museum Cologne, National Museum of Transylvania, National Museum Budapest, National Museum Cyprus, Institute of Aegean Studies Crete, and many museums in Italy. She is Member of the BUMA Standing Committee, Fellow of seven European Academic Societies, published around 200 books and papers on Archaeometallurgy, and edited 12 volumes of Proceedings of International Conferences on Ancient Metallurgy and Archaeometry.
Metals and Civilizations
Proceedings of the Seventh International Conference on the Beginnings of the Use of Metals and Alloys (BUMA VII)

Editors:
Sharada Srinivasan
Srinivasa Ranganathan
and
Alessandra Giumlia-Mair

Published by
National Institute of Advanced Studies, Bangalore
Contents

I Metallurgy and Interactions across the Ancient World

1. Ian Glover
   The Bronze Age to Iron Age transition in Southeast Asia – a comparative perspective

2. Katheryn M. Linduff
   What’s mine is yours: The Transmission of metallurgical technology in Eastern Eurasia and East Asia

3. Alessandra Giumlia-Mair and Béla Kürti
   Hunnic gold in Hungary and the Hunnic-Asian connections

4. Thomas Oliver Pryce, Mercedes Murillo-Barroso, Berenice Bellina and Marcos Martinon-Torres
   Khao Sam Kaeo – an archaeometallurgical crossroads for trans-Asiatic technological traditions

5. Constantin Canavas
   Early use of Iron in Aksum: Trade and technology transfer across the Ethiopian highland

II Iron Technology

6. Eiji Izawa
   Iron lumps formed from the ancient copper smelting: An example from Naganobori, Japan

7. Kazuhiro Nagata
   Mass and Heat Balance of Pig Iron Making by Tatara
8. Anna Bennett  
Manufacture, Use and Trade of late prehistoric iron billhooks from mainland Southeast Asia

9. Gill Juleff  
Crucible steel at Hattota Amune, Sri Lanka, in the first millennium AD:  
Archaeology and contextualisation

10. Huang Quansheng  
A New Discovery: Manganese as a Flux Agent at the Song Dynasty [960 -1279 A.D.]  
Iron Smelting Sites in Xingye County, Guangxi, China

11. Vibha Tripathi  
Metallurgical innovations and pattern of adaptation of iron in early cultures of India

12. Ashok Kumar Vaish and Shiwa Dhar Singh  
Improvements in traditional Indian iron making technology

13. Ramamurthy Balasubramaniam*, Sharada Srinivasan and Srinivasa Ranganathan  
Ancient Indian iron and steel and modern scientific insights

III Copper Technology

14. Xiaocen Li, Yali Yun and Rubin Han  
Scientific Examination of Metal Objects from the Third Excavation of Haimenkou Site, Western Yunnan

15. Maria João Furtado, Rui J.C. Silva, M. Fátima Araújo and Francisco M. Braz Fernandes  
Multiphase microstructures on late imperial Chinese brass coins

16. Lian Hai-ping and Yang Yi-tao  
Simulating investigation of the casting techniques for casting ancient  
Chinese bronze coins of Han Dynasty

17. Shuyun Sun and Jianjun Mei  
A Preliminary Study of Solders and Soldering Methods of ancient  
Chinese bronzes (9th-3rd centuries BC)

18. Han Rubin, Liu Ning and Xu Bingkun  
Metallographic Study of 27 Metallic Artefacts Unearthed from two sarcophagus tombs at Beipiao, Liaoning Province

IV Tin and Zinc

19. Prabhakar Upadhyay  
Resource areas of Tin for Ancient Cultures of India (prior to 6th Century BCE)

20. Paul Craddock, Joe Cribb, Noel Gale‡ and Lalit Gurjar  
Sources of zinc in early India: The evidence of numismatics, trade and lead isotope analysis

21. Susan La Niece  
Bidri Ware and its Black Patina
V Crucible Steel and Weapons

22. Brian Gilmour
   New evidence for the early making and heat-treating of crucible steel: Kindi’s iron treatise

23. Alan Williams
   Crucible steel in Medieval European and Indian swords

24. David Edge
   The Analysis of Indian Arms and Armour at the Wallace Collection, London

VI Ethnoarchaeology and Metals

25. Sharada Srinivasan
   Bronze image casting in Tanjavur District, Tamil Nadu: Ethnoarchaeological and archaeometallurgical insights

26. Nils Anfinset
   Documenting Copper Mining and Smelting Technology

27. Nanditha Krishna
   Traditional Jewellery of South India

28. S. Jaikishan
   Caste, Community and Rituals in Wootz Making Centres of Telangana – A Cultural Continuity in the Wootz Making Tradition
Section VI - Ethnoarchaeology and Metals

Chola Nataraja, Kankoduvarithavam, Tanjavur District, Government Museum, Chennai, with 8% tin and 9% lead showing details in high relief suggesting that not much post-cast tooling was done

Sharada Srinivasan
Bronze image casting in Tanjavur District, Tamil Nadu: Ethnoarchaeological and archaeometallurgical insights

Sharada Srinivasan
National Institute of Advanced Studies, Indian Institute of Science Campus, Bangalore
sharasri@gmail.com

ABSTRACT The profusion of metal images made in the Tanjavur region, going back to the early medieval Chola bronzes of the 9th-13th century ranks amongst the finest of Indian artistic expressions. Clusters of artistic and artisanal activities have thrived over generations in the Tanjavur district including metalworking workshops for bronze and bell metal casting of images and ritual objects especially around Swamimalai and Kumbakonam. Ethnometallurgical and archaeometallurgical insights on the making of icons at Swamimalai are highlighted from observations made over the past couple of decades, especially in relation to making comparisons with historical practices of bronze casting going back to Chola times. Since the processes are rapidly undergoing change, to get a better sense of the trajectory of past practices, this paper particularly aims to highlight unpublished observations made by the author going back to her first visits in 1990-1, as background to her doctoral work (Srinivasan 1996) and in relation to observations reported by other scholars going back to the early landmark efforts of Reeves (1962). These observations were particularly made by the author at the workshop of late master craftsman Devasena Sthapathy, in his time the most renowned of Swamimalai Sthapathis. His son Radhakrishna Sthapathy has now inherited this mantle. While Levy et al (2008) give a more recent account of image casting at the workshop of Radhakrishna Sthapathy, this paper attempts to also contextualise the previous trajectory that has not been covered much therein. Since their workshop now goes under the name of Sri Jayam Industries, for the sake of convenience it will be referred here by the same name.

Sthapatis of Swamimalai and social history

In medieval south Indian temple worship, following Hindu agamic traditions, metal images were made as the utsava murti, i.e. images that were exclusively intended to be used in processional worship. While the Imperial Chola who ruled from the 9th to 13th centuries were predominantly worshippers of the Hindu god Shiva, they also patronised Buddhism, Jainism and temples to the Hindu god Visnu and hence a diverse range of images are found from this period. In the lost wax process or investment casting process, the image is cast by first making a model in wax, and then investing it with moulding material to form a mould, which is then heated to expel the wax. Finally the molten metal is poured into the hollow to solidify into the metal icon. The Sankrit phrase 'madhuchchehistavidhanam' refers to the lost wax process and is described in the artistic treatise of the Manasara of the 4th-5th century (Reeves 1962: 29-31).

The Tanjavur district of Tamil Nadu, the former Chola heartland, still has traditional families of Sthapatis or icon manufacturers of the status of silpacari (or art teachers), who make lost wax images. In the 60’s, in her comprehensive work, Ruth Reeves observed over a hundred families engaged in making lost wax images in Tamil Nadu, and as many as fifty of these in the Tanjavur district (Reeves 1962: 101). Today there are far fewer families, mainly clustered around the village of Swamimalai, on the banks of the Kaveri river, and close to Tanjavur (30 km away). Traditionally speaking, South Indian bronzes were most often solid casts whereby the model was made of a single piece of wax with no clay core. This preference, despite the greater amount of metal required compared to hollow cast images, seems to have been based on ritualistic reasons. The process of casting images by the Sthapatis at Swamimalai also generally follows the solid lost wax process, although the hollow casting process is also now more widely in vogue to cast larger images. An early Chola inscription (Sivaramamurti 1963:14) describes the gift of an image of a deity which was ghanamaga or dense and heavy and of a chcheyda rishabha or hollowed bull. In a fine metaphoric poem,
Tamil women poet-saint Andal (c. 800) compares rain clouds to the mould holding wax to be expelled (Dehejia 2002:13): this demonstrates that the process was widely known.

**Alloys past and present**

In recent times the alloying compositions used by the master craftsmen in Swamimalai seem to be more akin to brass, going back to the 60’s and 70’s. Reeves (1962: 108) observed that alloys of 75 wt. % copper, 15 wt. % brass, and 5 wt. % tin were used by South Indian icon manufacturers. In another comprehensive study, Krishnan (1976:17) found that an alloy of twenty parts copper, four parts brass and one part lead was used at Swamimalai. During the researcher’s field visits to the workshop of Sri Jayam Industries in 1990, the late master craftsman Devasenapathy Sthapathy indicated to her that they used an admixture of industrial ingots labelled as ‘15% brass, 82% copper and 3% lead’ for image casting (Fig. 1). Presumably, here brass referred to an alloy of copper and zinc. A small image of Ganesa was cast by him for the researcher in 1990 (Fig. 2). A sample collected by micro-drilling with a 1mm drill bit was analysed by her using Atomic Absorption Spectroscopy at Institute of Archaeology, London in 1992-3 and was found to contain 84 wt. % Cu, 7 wt. % Zn, 5 wt. % Pb and 0.4 wt. % tin. Craddock (2007) reported that during his visits to the Sthapatis of Swamimalai, they claimed to use an alloy that contained zinc, tin and lead, whereas in fact an alloy procured from them was found to have 10% zinc, 4% lead and 1% tin. Although the date of these communications and procurement is not clearly indicated, it also reinforces the idea that in recent times leaded brassy alloys appear to be used.

On the other hand, investigations by the author— as previously reported in Srinivasan (1996, 2004, 2012)—indicated that a majority of the South Indian medieval bronzes were of leaded tin bronze. These investigations were undertaken on micro-drillings extracted from the bronzes using drill bits of 1-1.5 mm of tungsten carbide or HSS and which underwent dissolution for ICP-OES analysis. Analyses by such methods are usually regarded as being more representative of bulk analyses than other methods techniques like XRF. About 80% of 130 south Indian images analysed by the author (Srinivasan 1999, 2004) from the early historic to late medieval period were leaded bronzes with tin contents not exceeding 15% and keeping within the limit of solid solubility of tin in copper. Beyond this limit as-cast bronzes become increasingly brittle due to the increasing presence of delta phase. The average tin content in icons of the Chola period (c. 850-1070 CE) was the highest at around 7% for about 31 images, while a decline in tin to an average of 3.5 wt. % for 11 images is seen by the Later Nayaka period (c 1565-1800 CE) (Srinivasan 2004). In a few pieces, the maximum lead content went up to 25%. Of the total number of images only 15% were leaded brass images. In these brass images, the maximum zinc content went up to 25% zinc and images from the post-Chola period had higher levels of zinc. However, the use of zinc-brass was found also in early artefacts (Srinivasan 2007) such an analysed 5th century votive bowl in the Victoria and Albert Museum (acc no. IM-9-1924) recovered from an early Andhra Deccan Buddhist site, excavated from the Krishna delta with 14% zinc and 10% tin. The lead isotope ratios of this octagonal brass bowl closely matched those of a zinc ingot with a Deccan Brāhmī inscription dated to.
about the 4th century, clearly suggesting the use of metal from the same source, although it is not as yet identified (Srinivasan 1998, 2007).

One may surmise that in medieval south Indian cast images, the use of low-tin leaded bronze, over bronzes with a higher tin content (Sn >20 wt. %), was deliberate rather than incidental, since increasing amounts of tin embrittles the as-cast alloy. For example, an as-cast Maitreya image from Chaiyabhum Province of Thailand, 7th–8th century, in the Philadelphia Museum of Art, found to have a composition of 20% tin, 88% cu, Pb 2% (Woodward 1997: 57–8), has a right arm broken off. In fact, a traditional Kammalar or metalworker from Tanjavur district, Tamil Nadu, from the region of Nacharkoil, who made bells, interviewed in 1991, mentioned to the author that alloys with too much velliam (i.e. tin) were not used for images, as it renders them breakable (Srinivasan 1997). However, a notable and longstanding trend in the selective and specialised use of high tin bronze alloys in ancient South India has been demonstrated from metallurgical investigations, one by the researcher on the making of wrought and quenched high tin bronze vessels from the Iron Age or megalithic period, such as the bowls from Adichanallur and Nilgiris in Tamil Nadu, the Vidarbha megaliths of Maharashtra and Gandharan Grave Culture of Taxila and continuing into recent times, as first observed in the 1990’s (Srinivasan 1994, 1997, 2010). The microstructure and analysis of a vessel from the workshop confirmed it to be wrought and quenched beta bronze of about 23% tin. Indeed, the deliberate use of bronzes of a higher tin content to make wrought and quenched high tin bronzes of about 23-24% tin is seen in the Chola period from the analysis of a platter (Fig. 3) from Government Museum, Chennai. Thus it appears that the functional aspects of working with different types of copper alloys of high and low tin bronze were appreciated in such cases in the past (Srinivasan and Glover 1995).

Although South Indian bronzes are generally described as ‘panchaloha’ or five-metalled icons they are not really found to markedly have five different major alloying constituents. However, as Devasenashthapatii explained in 1990 to the author, this was more a ritual prescription where gold and silver were added in very small amounts on the request of the interested client, as he did for the leaded brass Ganesa image cast for her (since the alloy they used already had, in his opinion, three constituents of copper, brass and lead), and as discussed in more detail later. Such accounts vary even across craftspeople. For example, Mukherjee (1978:127) reported that a mastercraftsman from Nagercoil described panchaloha as ‘an alloy of copper, lead, silver, gold and iron dust’.

Making of the wax model

The modelling of the wax images in southern India generally followed the artistic conventions of the treatises of the Silpaasatra. The use of a traditional measuring system was used as explained by Radhakrishnashthapatii in 2006 (Fig 4) to the author whereby, in the preparation of the wax model the use of the odiolai or the palm frond is made with 124 divisions for the moulding of the male figure and 120 for the female figure.

Reeves (1962:63) mentioned that the wax used for the models consisted of equal parts beeswax, powdered dammar resin with a little ground nut oil or gingelly (or sesame) oil. In Tamil Nadu and Kerala Kunkuliyam generally refers to dammar resin. Krishnan (1976: 10) mentioned that the wax model was made of twenty parts beeswax, twenty parts dammar resin and five parts groundnut oil; these accounts were mostly based on the practice of craftsmen in the Bangalore area. The use of groundnut oil was also noted during the author’s interview of 1990 at Sri Jayam Industries. Furthermore, as told to her in 2014, harder paraffin wax has been used as an additive at their workshop for the past sixty years, as beeswax tends to get soft and loses shape more easily, given that the Tanjavur area can be quite hot with temperatures going up to 40 degrees in summer. As first observed by the author in 1989, for making the wax model, two different grades of wax were used: a softer grade richer in beeswax, used for finer details like ornaments, and a harder grade richer in paraffin for the main body parts of the images. The grade of beeswax is generally known as tein meluhu or ‘honey wax’. Levy et al (2008: 56) also mention the use of equal parts of paraffin wax with resin, employed at this workshop for making the harder grade of wax. Nevertheless, the use of the more traditional harder dammar resin or Kunkuliyam was also observed by the author in the making of models for bells in the Nacharkoil region of Tanjavur in 1991 (Srinivasan 1997). It is believed that
this mixture renders the wax easier to melt out since it has a lower melting point.

The making of the wax model proceeded as follows: a rough model of the torso was made and then progressively built up and refined by warming the parts to be modelled with a heated steel spatula, to make it pliable before working it. The different parts of limbs, attributes and head were separately modelled and several of these were seen stored in buckets of cold water to keep them solid. (Fig. 5) shows wax copies of the well known Rishabhavahana image from Tanjavur Art Gallery being made in Devasena Sthapathy’s workshop in 1990. Then these various solid pieces of moulded wax were heated along the edge over the brazier and attached to the main torso and the contours merged and smoothed over with melted wax. Then the ornaments and other details were added by pressing fine wax threads in place. The finished details of features and decorative details were left for tooling after the casting was completed. The ornaments were made from the softer grade richer in beeswax and darker in colour. The sprue cup and the riser were also made of the harder wax of cylindrical or conical shapes.

As observed by the author at the workshop of Devasena Sthapati in Swamimalai in 1990, the mould was built up on the wax model, using successive layers of clay and leaving it to dry after each coat. The first coat was of very fine alluvial silt (kaliman) from the River Kaveri, very carefully and evenly smoothed down with no coarse inclusions and then left to dry (Srinivasan 1996: 108). The quality of this clay is such that the craftsmen say that even a finger-print can be visible on it, indicating a great ability to pick up details. The next layer was of slightly coarser clay from the river known as vandal mann. Finally, it appeared that a coat of kaliman mixed with mannal, (i.e. coarser siliceous sand) was applied. (Fig. 6) shows the successive layers of moulding clay being packed on the wax model placed on a linen cloth.

Accounts of different scholars suggest various practices at different times and places in the Tanjavur area. For example, while Craddock et al (2007) mention the observance in 1986 of the use of cowdung as being added to moulding clay, tallying with the account of Krishnan (1976: 14), this was not observed by the author at Devasenasthapaty’s nor by Raj et al (2000) and Levy et al (2008); and it might be that it was an earlier practice. In the author’s experience however, the use of cowdung as an admixture especially in the final layer of clay was certainly noticed in other workshops such as at Irinjilakuda in Kerala in 1991, where bells were being made (Srinivasan 1997). This in fact makes a lot of scientific sense, since it would have helped to give a charred carbonaceous inner layer adjacent to the molten metal, which could better absorb the gases to give a better casting, as the prevalence of gases can result in a spongy casting. Both Raj et al (2000: 51), and Levy et al (2008: 56-8, 64) recorded the use of coarser clay from the paddy fields known as padimunn for the moulds. However, in a communication in 2014, Mr Shiva at Sri Jayam Industries, Swamimalai clarified that in recent
times, and only when they wanted to make larger moulds, they used such coarser clays which were also bound with iron bands. During the visits in the early 90s the researcher did not observe the making of such large moulds at the workshop of Sri Jayam Industries, while the workshop itself and its activities seem to have expanded very greatly in the years since then.

De-waxing of the mould, risering and runners

The term ‘de-waxing’ is invoked in this paper to describe the process whereby the wax model, once it is encased within the clay mould, is then melted out to create a hollow cavity into which finally the molten metal would be poured. As practised in recent times, at the workshop of Radhakrishna Sthapaty, (as seen in 2006, 2008 and more recently in 2014), it was noted that a special hearth dug into the ground at a slight incline was designated for this activity. The hearth in which the mould is heated is generally known as ulai. Here, the mould was propped up over four inverted large graphite crucibles, laying it down and along a gradual incline, so that the end with the sprue for pouring was slightly lower than the other part of the mould, to ensure that the wax could flow out smoothly and steadily. The mould was heated from below using coconut husks as a combustible material and it was also packed on top with cowdung cakes (known as raaati), as a fuel to ensure overall uniform heating of the mould so that the wax would drain out completely. A long tray below the mouth of the crucible was kept to collect the melting wax, with a bucket placed below it so that the wax could be collected for re-use as observed in 1990 (Fig. 7). As pointed out in Chandramouli (2004:94) the hollowed mould is described as ‘karuvu’. This term also refers to the foetus or embryo so that there is almost a birthing connotation to the lost wax process. Metallurgy, ritual aspects and aesthetics were finely melded together in these traditional arts and crafts (Srinivasan and Ranganathan 2006).

Some finer details were however noted by the researcher during field visits made in 1990 concerning the de-waxing process at the workshop of Devasenathapati. After the wax had run out from the heated mould, the artisan further waited until the ground nut oil (which had been deliberately added to the prepared wax and which stained the mouth of the mould), had also been burnt off. He could tell this from the gases emanating from it and until the stain had disappeared. The purpose was to ensure that no wax residues remained which could cause problems during casting, and to ensure that the mould was as dry as possible since trapped gases could result in faulty and spongy castings.

Figure 7 Mould just having been dewaxed (1990) in Devasenathapati’s workshop

Risering and pouring practice and comparison with medieval bronzes

The moulds used at Swamimalai usually have two openings, one is the sprue through which the metal is poured in, and the other is called the riser, which is the channel through which the gases escape from the mould during casting and without which the trapped gases could result a spongy casting. Standard graphite crucibles of various sizes are used these days to melt the metals in a hearth provided with a blower. The moulds are often packed in rows into mud with only the mouth being exposed before pouring is undertaken (Fig. 8). In this way, should the mould burst and hot metal ooze out, the associated hazards are minimized. While the metal is poured the impurities or oxidized matter is pushed aside to allow a steady flow. A lighted wick is held at the mouth which made sense to prevent oxidation losses. Interestingly, the 12th century Chalukyan text of the Manasollasa which described the lost wax casting process (Saraswati 1936) also prescribes that before pouring metal into the mould, ‘one should place a burning wick in the mouth of the tube of the heated mould’. The mould is allowed to cool for several hours before breaking it open. In 1990 a casting of a small Ganesa image was done for the author at the workshop of Devasenasthapati’s as a panchaloha icon. For this she and her husband Digvijay Mallah were asked to purchase a small amount of gold and silver of 100mg and 200 mg respectively. This was then heated in a ladle and then the Sthapati held Mr Digvijay’s hand to pour the mixture into the crucible for melting the metal for casting the image (Fig. 9).
Figure 8 Pouring of molten metal into moulds packed in mud at Radhakrishna Sthapathy’s workshop at Swamimalai in 2006

Figure 9 Pouring of small amounts of gold and silver in a ladle into crucible for casting of panchaloha icon at Devasena Sthapathy’s workshop in 1990

As mentioned by the late Devasenasthapati to the author in 1990 at Sri Jayam Industries, in the past the pouring practices differed, and more than one pouring sprue cups were used along the length of the rear of the image (Srinivasan 1996: 113). Indeed, a damaged and unfinished Vishnu which the author examined in 1989 from the Chhatrapati Shivaji Maharaj Vastu Sangrahalaya (CSMVS) Museum, Mumbai, (then Prince of Wales Museum of Western India), also indicated a similar gating design, of feeding the mould through sprues along the rear of the horizontally inclined mould. A long protruding irregular patch of metal at the rear of the torso indicated the use of a main sprue cup in this central region of the image (Fig. 10). Another sprue seems to have been at the back of the head. In addition, as still seen in images being made today, runners connected the attributes held in the arms to the main body which in most images are cut off after casting. The aim of this method appears to have been to achieve adequate risering, and more directional solidification. Furthermore, by pouring with the mould lying horizontal, the problems of the metallostatic pressure of a great weight of the metal used for the solid casting, which might break a vertical mould, would have also been avoided. Studies by Johnson (1972:45-53) on an unfinished 12th century Krishna image suggested a similar pouring practice. The in-situ metallograph undertaken in 1989 with the author’s collaboration with Dr S. Gorakshekar, then Director, Prince of Wales Museum / CSMVS Museum, Mumbai and BARC on the unfinished Vishnu from the same museum showed the heavy impregnation of mould material into the metal fireskin of this damaged image (Fig. 11). In fact late Devasenasthapathy in 1990 mentioned to the researcher that for the panchaloha images, the small additives of gold and silver would have been done through the runner at the back of the head, as it was thought to give lustre to the face of the image.

Figure 10 Unfinished/damaged casting of Vishnu, 13th century, Prince of Wales Museum / CSMVS Museum, Mumbai showing sprue at the rear of the torso

Figure 11 Surface in situ metallograph of the unfinished and damaged Vishnu, Prince of Wales Museum / CSMVS Museum, Mumbai showing impregnation of mould material into metallic areas
Final finishing

A hammer is used to break open the mould and to remove the debris to retrieve the image. After breaking open the mould the present day *stapathis* finish the cast images by chasing and polishing the image and all the finer detailing nowadays is done by chiselling after casting (Fig. 12). This is possible because of the more brassy alloy they use these days. In more recent times, as observed by the author during a trip in 2014 to the workshop of Radhakrishna Sthapathy in Swamimalai, the use of dilute nitric acid was also seen for removing the thick fire-skin formed on the casting.

![Figure 12 Final finishing of cast image with intact runners by craftsman late Vadivelu at workshop of Devasena Sthapathy in 1990](image1.png)

Most early medieval bronzes (8th–10th century) seem to show much less apparent evidence of post-cast tooling or working after casting. The miniature Pallava Somaskanda from Tiruvelangadu, in Government Museum, Madras (Fig 13) perhaps illustrates this point. That this bronze was probably not subjected to any post-cast tooling is indicated by the fact that two runners are still intact on the shoulders of the Siva image, connected to the weapons, while Siva’s figure also shows a bit of metal drip at the base. These would have been trimmed off, if it had been finished. Moreover although intricately executed, the detailing of the ornaments and attire has a certain fluidity, smoothened contours and gentle relief, which suggest that they were executed in the wax rather than cut with files on metal. This image is a copper alloy with 3 wt. % lead and 0.7 wt. % tin. Another example, a superb 11th century Nataraja image from Kankoduvanithavam in Government Museum, Chennai, (the analyses carried out by the author showed it to contain 8% tin and 9% lead) has decorative features that stand up smoothly in high relief (Fig 14) in a way that suggests that minimal post-cast tooling was undertaken and the details were more or less as-cast.

![Figure 13 Pallava Somaskanda image, Government Museum, Chennai, 7th century, with runners still intact, copper alloy with 3 wt. % lead and 0.7 wt. % tin](image2.png)

![Figure 14 Chola Nataraja, Kankoduvanithavam, Tanjaur District, Government Museum, Chennai, with 8% tin and 9% lead showing details in high relief suggesting that not much post-cast tooling was done](image3.png)

Conclusions

The above ethnometallurgical account provides insights into links between the past and present in the long and enduring tradition of image casting in the Tanjaur district, while also throwing some light on the points of departure with changing times. This paper also tries to more comprehensively string together observations of different scholars than it was previously attempted and to gain more insights into the recent trajectory of
this metal craft tradition in the Tanjavur district and in relation to other surviving craft traditions. Finally the aim of this paper was to place it better within the context of the archaeometallurgical studies of medieval bronzes.

Acknowledgements

The author is grateful to late Dr Nigel Seeley, Dr Ian Glover, Dr Anna Bennett, Dr John Merkel and Dr Daffyd Griffiths of Institute of Archaeology, London for their past support, to Dr Gorakshekar, then Director and Dr. S. Mukherjee, current Director, CSMVS (formerly Prince of Wales) Museum, Dr Desikan and Dr Balasubramanian of Government Museum, Chennai and Dr John Guy of Victoria and Albert Museum, London and Dr Paul Craddock, British Museum, Dr. Baldev Raj, IGCAR, R. Krishnamurthy, Digvijay Mallah, Profs S. Settar, S. Ranganathan, R. Narasimha, NIAS, Jean-Marie Welter, Benoy Behl, Peter Vemming and late Janaki Subban.

References

Chandramouli, C., 2004, Arts and Crafts of Tamil Nadu: Art plates of Tanjavur and metal icons of Swamimalai, Census of India.


