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Of Faces and Phases: High-Tin Bronze Metallurgy and South Indian & Tamil Innovations

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Abstract

Generally speaking, as-cast binary copper-tin alloys with over 15% do not seem to have been widely used in antiquity as they get embrittled at higher tin contents due to the increasing presence of the intermetallic delta phase compound. Nevertheless, the use of the unusual and skilled binary bronze alloys of a higher tin content, are reported from various contexts in Indian antiquity and skillfully manipulating the high temperature intermetallic compounds properties of bronzes. In particular the specialized use of the hot forged and quenched high tin beta (23%) bronze was used to skillfully make vessels with finds reported by the author from numerous peninsular and south Indian megalithic contexts such as from Adichanallur and Nilgiris in Tamil Nadu ranking amongst the early such finds known (Srinivasan 1994, Srinivasan 2010) and with continuing traditions particularly in Kerala. Another exotic high tin-bronze craft tradition that thrived in Kerala is the making of mirrors exploiting the silvery delta compound of bronze of around 33% to get a good reflective surface (Srinivasan 2008). The broader Asian context is also touched upon in relation to the use of bronze and higher tin bronze. Thus the historiography of usage of bronze in the Indian and south Indian context is 'elucidated in this illustrated talk, tracing the numerous 'faces, ranging from celebrated lost wax statuary bronzes such as of the Chola period to the mirrors, and the 'phases', the unique properties of which were skillfully exploited to fashion the intriguing artefacts, not to mention the related historic 'phases'…As further highlighted the Coimbatore region and outlying areas played a significant role being connected as it was to different geographic areas from hills to plains and connecting trade routes.

Archaeometallurgical background in southern India: legend of wootz steel

The Indian subcontinent nurtured numerous skilled metallurgical traditions in antiquity as testified by the remarkable 'Rustless Wonder' of the Gupta era Iron pillar of the 4th century which stands in the Qutb Minar complex. The southern Indian region is also one that supported an array of innovative and skilled metallurgical traditions such as the legendary 'wootz' or 'ukku' steel, the making of which by crucible processes is recorded in numerous western traveller's accounts at least from the 16th century onwards (Srinivasan and Ranganathan 2013). For example, French traveler Tavernier in the 17th century spoke of the repute of Golconda wootz which was traded to Persia to make the fabled Damascus steel blades, especially prized in the Islamic world for their fine 'watered' patterns and cutting edge. Subsequent studies have shown wootz was found to be a high carbon steel of about 1.2-1.5% carbon, which could be made by carburizing wrought iron, and with the wavy pattern resulting from the etching of the forged blade contrasting dark pearlite phase with light cementite. Interest in wootz spurred several 19th-20th century metallurgical inventions including some of the work of Faraday. Scientific investigations have also pointed to aspects of interest to modern metallurgy such as the superplastic properties of ultra-high carbon steel of 1.5%. The region of Tamil Nadu seems have been one of the pioneering regions in the making of crucible steel as suggested from finds related to ferrous crucible metal processing and higher carbon steel remnants from Kodumanal going back to the megalithic period, c 3rd century BCE (Srinivasan 2007, Rajan 1990, Sasisekaran 2004). Kodumanal, which is close the historic Chera capital of Karur mentioned in Sangam Tamil literature (3rd century BCE to

3rd century CE) is not far from the Coimbatore region. The term 'ukku' may be linked to the word found in Tamil Sangam literature for spear or 'ekku' and also means 'boiling over' conveying crucible processes. Crucibles found at Mel-Siruvalur near Tiruvannamalai in Tamil Nadu studied by the author contained metallic remnants (Fig.1) that corresponded astonishingly well with modern hyper-eutectoid ultra-high carbon steel structures (Srinivasan 1994), suggesting that highly reducing and high temperature pyro-metallurgical conditions were reached. The region of Salem, also near Coimbatore was renowned for its iron and steel works as seen in the 19th century accounts of Walhouse who mentioned the renown all over India of the bladesmith, Arunachalam.

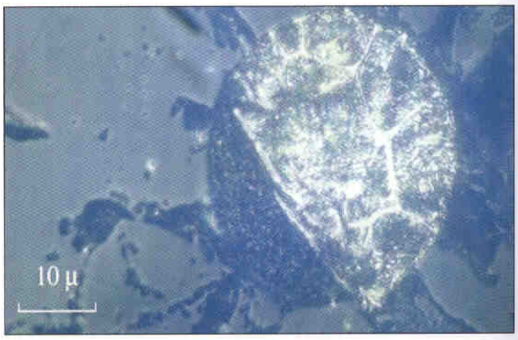

Fig 1. Ultra-high carbon steel in crucible remnants from Mel-siruvalur, Tamil Nadu

Master-pieces of Chola bronze casting from Tamil Nadu

From an artistic point of view, Tamil Nadu has been renowned around the world for its breathtaking statuary bronzes harking back to the 10th-11th century Chola period, which rank amongst the most sought after museum artefacts. The Nataraja bronze icon, depicting the dancing Hindu God Siva, and often described as the cosmic dance of Siva, has been extolled in the writings of celebrated global figures such as sculptor Rodin and scientist Carl Sagan. The CERN Cosmic Lab has a fine installation of a Nataraja bronze along with plaques quoting geologist-turned art historian Ananda Coomaraswamy who described the Nataraja bronze as 'poetry but nonetheless, science' and quantum-physicist FtitjofCapra who was moved by the Nataraja image to write that 'Siva's dance was the dance of sub-atomic particles'. This bronze made by master-sculptor Rajan, was gifted by the Government of India, through the efforts of IGCAR, Kalpakkam.

South Indian were cast by the cire perdue or lost wax process which is still followed in traditional foundries in the Tanjavur district and in Swamimalai (Reeves 1962, Srinivasan 1996, Raj 2001, Levy and Levy 2008, Srinivasan 2015). From an archaeometallurgical point of view, investigations of the author of over a hundred medieval south Indian bronze images by ICP-OES, showed that they were predominantly of leaded bronze with some being of leaded brass (Srinivasan 1996). For example, a superlative 11th Chola Nataraja bronze from Kankoduvanithavam in Government Museum, Chennai had around 8% tin and 8% lead (Fig 2). Fig 3 shows the micro-structure of a leaded low-tin bronze of the 13th century period of

Fig 2.Chola bronze icon of Nataraja, 11th century, Kankoduvanithavam, Government Museum Chennai found to have 8% tin and 8.75% lead

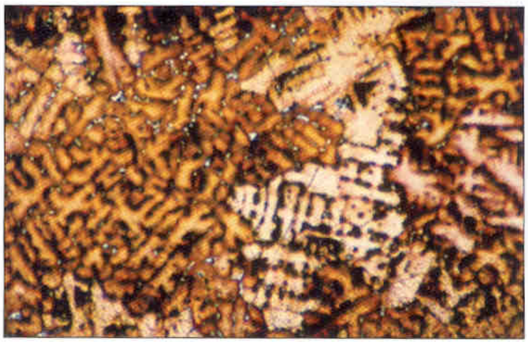

Fig. 3 : Photomicrograph of 13th century late Chola bronze statue of Vishnu, Komal, in Government of Museum, Chennai showing (400 X)

dendritic as-cast bronze. In the solid cast medieval south Indian images analysed by the author the tin content never exceeded 15 percent. This is at the limit of solid solubility of tin in copper, forming the alpha solid solution. Beyond this as-cast bronze gets brittle due to the increasing presence of alpha plus delta eutectoid phase. Interestingly, this can be inferred as being a deliberate rather than a random choice, since the deliberate and informed use of the properties of higher-tin bronzes was also made in southern Indian antiquity, skillfully overcoming their brittleness as indicated in the next sections. The 'Kongu' region of Coimbatore also produced several interesting medieval bronzes of a provincial school.

Wrought and quenched high-tin beta bronze vessels from megalithic Tamil Nadu

Fig 4 : Beta high-tin bronze (24%) vessel from Nilgiri cairns, Government Museum, Chennai (ca 1000-500 BCE), in the hill range close to Coimbatore

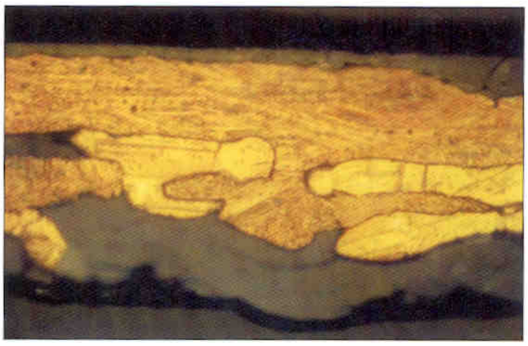

Fig 5 : Micro-structure of beta high-tin bronze (24%) vessel from Nilgiri cairns, Government Museum, Chennai (ca 1000-500 BCE) showing beta phase needles from forging and quenching a bronze of 24% tin at temparatures of around 650-750 degrees centigrade. 400 X

Fig 6 : High-tin beta bronze vessel (23% tin) from Payangadi, Kerala made in 1991 showing the brilliant golden luster from polishing of beta bronze

Fig 7 : Micro-structure of the recently made high-tin beta bronze vessel from Payangadi Kerala showing the presence of quenched beta phase needles from hot forging in the range of formation of plastic beta phase. (Magnification 400x)

Although bronzes in general are not very workable, there is astonishing evidence for finds of bronzes from megalithic burials and cairns in Tamil Nadu that were made of extremely finely hot forged and quenched high-tin bronze of a composition close to that of the pure beta intermetallic phase of bronze. Metallurgical investigations by the author on very thin vessels from South Indian burials and megaliths of Adichanallur and Nilgiris (c. 1000-500 BCE) (Fig.4) (Srinivasan 1994, Srinivasan and Glover 1995, 1997) indicated that these were wrought and quenched binary high-tin beta bronzes, i.e. unleaded copper-tin alloys with 23-25% tin. These were fabricated by extensively hammering out such an alloy between 586-7980 C when a plastic beta intermetallic compound (Cu_5Sn) of equilibrium composition of 22.9% tin forms. This was followed by quenching which resulted in the predominant retention of needle-like beta phase, as seen in the microstructure of a vessel from Nilgiris (Fig. 5), which prevents the formation of embrittling delta phase and hence these alloys are also known as beta bronzes due to the retention of the beta phase. The alloy takes a golden polish and has musical properties. In contrast low-tin bronzes have limited workability. The ethnographic studies between 1991 and 1998 in Palakkad district of Kerala identified rare surviving crafts traditions for making wrought and quenched high-tin bronze vessels in Kerala with similar micro-structures indicating similar processing techniques (Fig 6, 7, 8). (Srinivasan 2010, Srinivasan 2013). The bronze-smithing communities of both Tamil Nadu and Kerala are known as Kammalar. The Palakkad region lying adjacent to the Coimbatore region was linked to it via the Palghat pass. These ethnographic studies have also contributed to a revision in the understanding of this technological tradition of making wrought and quenched high-tin beta bronze vessels as one that could have been longstanding one in the Indian subcontinent.

Fig 8 : Forging of high-tin beta bronze ingots in Paridur, Kerala observed in 1998 by the author.

Fig 9 : Aranmula mirror showing late mirror-maker Janardhan Achari

As background into the history of technology, it may be mentioned that it had previously not been well appreciated that the Indian subcontinent could have supported early traditions of working higher tin bronze due to to the relative scarcity of tin, when compared to more tin-rich regions such as southeast Asia or China (Rajpeetak and Seeley 1979). However, the wrought and quenched high-tin bronzes from South Indian megaliths and iron age burials of Adichanallur and Nilgiris (ca 1000-500 BCE) are rather distinctive in that they also rank amongst the most highly forged such examples yet known anywhere in the world with rim thinnesses of less than 0.2 mm as also indicated by the micro-structures, enough to suggest that they more likely represent a well developed local tradition rather than being imports. Craddock and Hook (2007) also reported studies on examples from the Nilgiri Cairns in the British Museum collection. Leshnik (1974) also pointed to the finds of a binary higher tin bronze vessel of 21% from a megalithic burial in Mauli Ali, in Coimbatore district. We may note that the Nilgiris hill range is also rather close to Coimbatore which has the nearest city in the plains to it. Subsequently, scholars have also been open to the idea of Indian developments having an impact on the Southeast Asian region (Murillo-Barraso et al. 2010), while examples of decorated high-tin bronzes from Thailand from the 4th century have been assigned an Indian, or probable northwestern Indian provenance (Glover and Shanaj Husne Jahan 2011)

Exotic high-tin delta bronze mirror craft from Aranmula Kerala

An extraordinary surviving traditional high-tin bronze craft is the making of 'delta' high-tin bronze mirrors in Aranmula village in Kerala. Fig 9 shows Janardhan Achari late mirror maker looking into a mirror made by him indicating its remarkable reflective properties. The author's technical investigations (Srinivasan and Glover 1995, Srinivasan 2008) first established that the Aranmula mirrors were made of an alloy which can be described as a high-tin delta bronze, i.e. 33% tin-bronze, so-called because of the match with the composition of pure delta phase, an intermetallic compound (Cu31Sn8) of 32.6% tin; and to identify that the mirror-effect was obtained by optimizing its presence. The predominance of delta phase yields an ideal mirror material (Fig. 10) as it is a very hard and stable compound which can hence be polished with the best possible mirror effect, free of distortion with reflectance across the entire spectrum. Its brittleness is offset by casting a very thin blank in a two-piece crucible-cum-mould (Srinivasan and Glover 1995). A mirror sample from the Nilgiri cairns studied by Breeks had 30% tin while a sample from Sonepur in eastern India (c. 500 BC-500 AD) reportedly has 32.4% tin, closely matching the delta bronze composition of the mirror alloy. The crystalline geometry of the delta phase is one of the most perfect of icosahedral symmetry (Srinivasan and Ranganathan 2006). Interestingly, the Aranmula craftsmen and Acharis also claim descent from the Sankarakoil region of Tamil Nadu. The medieval Geniza documents of Jewish merchants indicate that the region of the Malabar was well known for the making and trading of metalware and vessels.

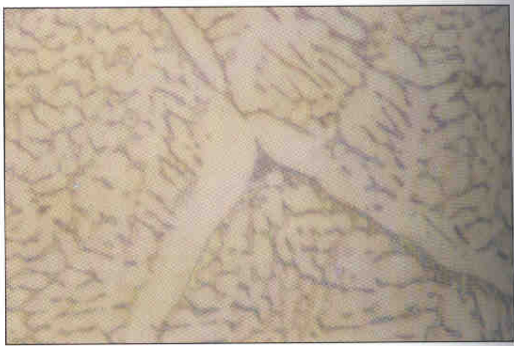

Fig 10 : Micro-structure of recent Aranmula mirror procured in 1991 showing predominant presence of silvery delta phase and lesser bluish alpha plus delta eutectoid network

Conclusion

The above studies suggest the some exceptional innovations and early exploitation of the properties of intermetallic compounds of bronze in the Indian subcontinent and in southern India. The above finds increasingly pointing to early high-tin beta bronzes from the Indian subcontinent from the Iron Age (c 1000-500 BCE onwards) as ranking amongst the very early such alloys known with the megalithic examples from Tamil Nadu being some of the most remarkable ones. These also may suggest that the efflorescence in bronze image casting witnessed in medieval Tamil Nadu was not without precedent. The regions around Coimbatore from the Nilgiris to Salem also saw distinctive and outstanding contributions in these areas including high-tin bronzes and iron and steel making. The surviving delta bronze mirror making tradition of Kerala is also a unique tradition that has few parallels around the world. This craft has been given a Geographical Indicator patent but also merits being listed in the UNESCO Intangible Heritage Lists.

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