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ORIGIN OF HIGH TIN BRONZE ALLOY IN BENGAL, JHARKHAND AND ODISHA: ETHNO-ARCHAEOMETALLURGICAL STUDIES

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This paper highlights the origin of high tin bronze or bell metal in this part of the subcontinent. The earliest copper–bronze technology began in Harappan civilization. Bun shaped copper bronze ingots were discovered in Harappan sites. Similar bronze ingot was discovered in excavation at Tilpi along with furnace remains. Development of high tin bronze technology is an achievement in ancient Bengal including Bangladesh and its neighbourhoods comprising the states of Jharkhand and Odisha. The paper also includes the metallurgy of processing of bell metal and its continuation in tradition.

Introduction

High Tin Bronze or Bell Metal is the most sophisticated alloy of copper and tin series. The earliest copper–bronze technology began in Harappan civilization. Those include adzes, axes, chisels, fishhook, knives, pans and ornaments. The copper bronze objects of that civilization were mostly made by pure copper. 30% of the specimens analysed in Harappa and Mohenjodaro were identified as low tin bronze, bearing less than 10% Sn. The ornaments and tools of that civilization were mostly manufactured by casting technique. The famous dancing girl, a few other statues, models of cart and small vessels were made through precision casting technology, known as *cire perdue* or lost wax techniques. Thus a well developed casting technology was flourished in Harappan culture. Those bronze specimens were lesser than a kg in weight.

Development of high tin bronze technology is an achievement in ancient Bengal and its neighbourhoods. The artefacts of this alloy were also reported from Agiabir of Uttar Pradesh, Jamgadapadar of Odisha, Khuntitoli of Jharkhand and a few other places which were built prior to 500 BCE. The first evidence of this alloy in an archaeological context was reported by Caldwell (1920: 409-411) from an Asura burial in Jharkhand. At Khuntitoli (23° 04' N, 85° 17') in the Ranchi District, a Megalithic post-cremation burial site was excavated by S.C. Roy (IAR 1965-66:10). The excavated findings included copper and bronze objects and a copper-bronze bangle.

The evidence of bun shaped ingots with an uneven puckered top surface from Mohenjodaro, Chanhudaro, Harappa and Lothal indicate that was the raw material

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for further forging. Cold as well as hot forging was also known to the Harappan artisans, but those were limited in quantities where the specimens were initially made by casting and subsequently finished by forging. The technique of forging becomes too tough. Saws and razors of Harappans were made from sheet metal that subsequently forged, to obtain cutting edge. Some of the objects revealed the application annealing after forging.

Casting technology depends first on the development of furnace for melting the metal and secondly for making proper mould to obtain the desired product. Ancient mould types like open moulds and others, were discovered in Harappan sites. Casting of low tin bronze objects was easier to pure copper objects. Forging to thin cross section was also possible for pure copper. Casting was easier for low-tin bronze than pure copper. The increase of Sn content above 10% is difficult for forging due to very short forging zone of 50 to 100 °C. That low tin bronze alloy can be termed as α-bronze, which is only a single phase solid solution of tin in copper. Low tin bronzes are harder and stronger than pure copper. The copper-bronze smelters failed to process bronze objects above 10% Sn alloy by forging; subsequently they realized that alloying with Sn above 20% is again comfortable for casting, but not suitable for forging.

The casting technology further developed in post Harappan period, a few sites were discovered. One of those is located in Daimabad region of Maharashtra, where very heavy castings weighing unto 29 kg were made. That was an achievement over Harappan technology for casting heavy statues. That alloy is easier for casting and all over the world, casting of bells were popularized; so it was named as bell metal or percussion metal. All over the world high tin bronze was applied for manufacturing of bells.

In recent past Meera Mukherjee has initiated overall studies on metal craftsmen of India (Mukherjee 1978). The present paper expands her work pertaining to the metallurgy of *kansha* in this part of the subcontinent.

Technology Transfer from Iron to High tin Bronze

In Eastern and Northern India, the copper hoards – a variety of copper tools in caches were accidentally discovered from a number of sites. Copper hoards were made basically by casting process; a few of those were initially made by casting later finished with forging and annealing. Difficulties in forging were due to its presence in short forging zone temperature range. The basic shape of the ingots was oval or bun-shaped. Casting was satisfactorily possible for oval cross section. The copper hoard specimens were basically made of pure copper and low-tin bronze.

The makers of the copper hoard people were nomadic. They widely moved to sell their products. By that time iron technology was flourished in eastern, northern and Megalithic South India, after 1500 BCE. The makers of copper hoard came with closure association to iron makers. They have observed iron making, forging into thin sheets, visualized carburization and hardening of steel objects by quenching. They further observed the process of tempering to remove brittleness. They found forging and quenching from red hot condition into water. Carburised iron was heated to austenite range and after quenching transformed into martensite.

That copper hoard people observed the technology of iron processing into high tin bronze. They identified the temperature in forging zone- which satisfactorily been forged to thin section. They had visualized the transformation â bronze to â' bronze while quenching. They had no instrument to measure, but by observation they realized it and transmitted that knowledge and skill to their future generation. This is the tradition of utensil making in *Kansa* alloy in this part of the subcontinent.

There was difference in technology between steel and high tin bronze. In case of steel or wrought iron, even a single sheet can be forged from red hot till black condition. In case of low-tin bronze no black hot forging possible due to fast heat removal. The ingots are oval shaped (bun shaped) for high tin bronze.

Initiation of forging with Bun Shaped Ingot

Typology of ingots of copper of Late Bronze Age (LBA) is plano-convex or bun shaped - flat on the top surface and hemispherical at the bottom. It was due to the shape of the bottom of bowl furnace. The Negev furnace of Wadi Arabah produced plano-convex ingots weighing about 3-4 kg. Tylecote (1976: 29-31) referred a bun shaped ingot of pure copper as a result of the liquation of super-incumbent slag. When the melting of one charge completes, it was allowed to solidify and brittle slag broken away. Later the slag was drain off at the end of smelt. Example of one of LBA is recorded that was 145 mm wide. No sign of presence of runner connecting the ingot with the furnace. During 2nd to 6th century CE, one copper ingot was recovered from North Wales, weighing 19 kg (Tylecote 1976:60) i.e. 15-20 kg. That was made of Roman period and much lager to LBA.

In Lothal excavation, bun shaped ingot was found which is similar to that of Mohenjodaro. The Lothal ingot was analysed – indicated 99.81% Cu and no Sn was detected in it (Rao 1985: 520). The excavation conducted in that site had revealed two coppersmith furnaces. The surface is puckered.

In case of India, some of the copper hoard objects on the other hand is enigmatic nothing could be equated about the utilities of those objects. For example one may refer to one of the four similar hoard objects recovered from Aguibani, West Medinipur district now preserved at the State Archaeological Museum, Kolkata. In the collection at Central Museum Nagpur, similar hoard exists, that was collected from Gungeria. All those specimens cannot be interpreted as tools or any utilitarian object – only could be equated as an ingot.

Problem of Forging Overcome by Artisans

Artisans overcome the problems related to casting, forging of high tin bronze alloy and also able to forge into very thin section. A few bronze-making centres developed in the country which is still continuing the traditional process. Forging with very thin section was possible and bunch forging as well as rolling was developed later.

Forging of high tin bronze ingot was a problem. That was overcome by the artisans after late Harappan to early ancient period. The processing of bun shaped ingot thus developed by the artisans to forge high tin bronze is a development in technology. How that problem was overcome by adjusting the shape and fixing the range of forging temperature. The cooling analyses of the various specific geometries are carried out to determine the optimum geometry of the ingot for a given mass of the cast material. During the hot working process, the ingot cools due to convective and radiation cooling and the hot working process restricted to certain temperature.

Earliest Evidence of making of High Tin Bronze

Through excavation and exploration a number of high tin bronze or Bell metal specimens were discovered from this part of the subcontinent. One of such earliest ingot excavated from a site Tilpi in Bengal has been characterized. The site Tilpi (22°15'N, 88°38'E) from which an ingot as sourced is located in the coastal district of South 24-Parganas, West Bengal. The excavation was conducted by the Directorate of Archaeology, Government of West Bengal in March 2006 and March 2007 (Datta *et al.* 2007).

The following objects recovered: 1.Crucibles, 2. Slag, 3. Small metal ingot, and 4. The in-situ Furnace with 8 nos of hearths along with few corroded iron lumps. All the above items at the same site, is an indicators of the presence of a guild. The guild in all probability produced Bell Metal or similar bronze articles. The hearths and crucibles confirmed the expertise of melting and castings for non-ferrous metals.

Traditional Forging Technique in West Bengal

To observe the traditional bronze making an ethnoarchaeological studies were conducted at Khagra, District Murshidabad where detail thermo-mechanical processing was recorded. Besides, in-depth studies were conducted at several places of in this part of subcontinent. For example, Muragachha of Nadia district, where batch forging were studied, in Bishnupur, crucible-cum-mould practice were observed. Thus the technology of high tin bronze making and shaping have been experimented at Khagra and thus experimentally established.

The in-depth studies with archaeomaterials were initiated for this research. First pure copper specimens were analyzed that comprised with copper hoard objects – both cast and forged specimens were analysed. High tin bronze cast ingot, excavated furnace remains and crucibles of Tilpi were studied. High tin bronze forged product – a vessel from Gazole were studied in-depth by Chattopadhyay. The identification of phase and transformation of high tin bronze after quenching is characterised – that would reveal whether it is similar to martensitic transformation in iron and steel; or new phases of identified as β and β' (Chattopadhyay 2013).

Khagra

Applications of ethno-archaeology and quantification have applied with metal specimens in a traditional site Khagra, district Murshidabad. We have observed that artisans used 3.5 kg pure copper in the form of wire and 1 kg tin lump and 3.5 kg scrap in the crucible. Old utensils were heated to red hot temperature then after hammering those broke easily like glass. Total charges were weighed before putting it in the crucible. Turnings and scrapings are charged first then other pieces. The scrap and copper wire were first filled in the crucible put on the furnace. After prolonged heating when the first part was melted totally, then the other part of the charge was put in the crucible. Tin lumps were charged at last. The furnace with crucible inside was then closed with an iron cover. After opening the cover greenish and yellow flame noticed. Note that no flux was added during melting of Bell Metal.

The unique super plasticity of β-Cu phase at high temperature is the key to the success of hot forging of high tin bronze or Bell Metal with respect to poor plasticity shown by low tin bronze (having primarily α-Cu phase). This unique phenomenon of super plasticity @ Cu-23Sn composition having sole β-Cu phase above β-eutectoid reaction temperature, 586 ^{o}C had been utilized to the hilt. A master stroke of those metal-smiths was seven-part Cu and two-part Sn ratio for developing the alloy composition known as *Kansha* in Bengal.

Muragacha

The site Muragacha (23^{o} 33' N, 88^{o} 25' E), is reputed for various type of bell metal production along with various name of bowl, tumbler and others. The forging of bowls are made in batches. Then one bun shaped ingot was forged first, and then subsequently forging were done taking 8 to 10 pieces of those. Forging carried with by three artisans, where senior one gripped those forged sheets with a pincers, and the other two artisans forge the set with a hammer. Thus they obtain 8 to 10 tumblers. Both brass and bronze are forged similar fashion but only bell metal pieces are quenched and tempered. The purposes of forging in batches are done to minimise the heat loss.

Traditional Forging Technique in Odisha

High tin bronze or *Kansha* also well popularised in Odisha. We had selected one of the traditional sites, namely Binka (Chattopadhyay *et al.* 2013).

The processes of manufacturing steps are highlighted as follows:

(a) To begin with, the traditional practice is the preparation of alloy at the initial state where 270 gm tin is added to 1 kg of Cu i.e. 21.26% Sn. Most of the cases Scrap Bell Metal in the form of turnings and old utensils were used. These are collected from market or middlemen provide those to the artisans and give a conversion charges Rs. 150 per Kg. The alloy, or Cu and Sn are taken in an earthen ladle in primitive furnace where coal is the basic fuel. The molten metal is then converted to Chunky section.

(b) Casting of forging stock of Chunky sections: For the *Baithi Khuri* a rough blank of semi-elliptical design was made in an open fine clay mould, using floor moulding. A high tin bronze alloy was melted within a crucible over a coal fire, at Binika as per the conceived replication of the probable ancient environment as far as possible and the molten metal was poured into the vacant mould in a streamline flow to get the casting. The earthen mould was covered with burnt mobile. The two members of the family including a woman are engaged in casting. The male member was pouring the liquid and the female member spreads the paddy husk over the melt such that the husks increase the time of solidification. That avoids breakage while forging. The chunky ingot is about 97 mm in diameter; rim is 5 mm in height and 18 mm in breadth.

(c) Soaking at the top range of forgeability temperature: The casting used as forging stock was heated to a temperature of ~ 700°C to a deep cherry red temperature, and was soaked with adequate caution avoiding any kind of nominal fusion. Five chunky ingots are heated in coal- fired primitive oven. In this traditional workshop there was no use of electricity. Only mechanical machinery is a hand blower. This is the only development over a leather jacketed bellow. Even iron anvil is not used by the Binika artisans, they forge the product over stone anvil.

(d) Thermo-mechanical treatment (TMT) or thermo-mechanical controlled processing (TMCP) of the stock: At first the head of heated bloom was subjected to repeated drop forging over a stone die by means of a 2 kg-point hammer within seconds for the deep drawing operation necessary to develop the bowl. Three artisans are engaged in forging. The master technician controls the entire processing, whereas the other two assistants practices forging. First chunky ingots are forged one at a time to increase into an expanded plate. Then five such plates are taken at a time by the master technicians. This is continuing by subsequent forgings. The forging continued until dull red heat of around 500 °C and the cycle of heating-and-forging recurred number of times to complete the desired shape of the bowl. Both thermal treatment as well as mechanical forming continued simultaneously. Out of five plates top plate becomes the inside bowl, while after finished external bowl is stripped first from the set and final forging, quenching and tempering. After forging outside bowl removed from the cluster and that is finished after reheating and forging. The process further continues with the remaining discs.

(e) Heat treatment of Forged article - Quenching and Tempering: The hot forged article was quenched in water as soon as the forging operation stopped to suppress any kind of possible phase transformation that can occur. After quenching the article spoon was again heated to ~650 °C with adequate soaking for tempering operation (as iron makers normally do) and quenched in water to eliminate any kind of brittleness associated with high-tin bronze. Quenching and tempering operations continued for the forged piece twice to transform the phases of the case and the core respectively. The operation completes after forging and heat treatment.

(f) Modification of Bowl with lost wax casting: The name of *Baithi Khuri* used in Binika is peculiar for the typical bottom at its base. This bottom is made by casting which is added to the bottom of it. The forged bottom is coated with clay. The wax made base lies in the centre which further covered under the clay. After complete drying of the clay, it is heated such that the wax is burnt out with formation of cavity; molten bell metal is poured on it and filled the cavity. Thus the bottom of the *Baithi Khuri* made with clay and in-built wax.

(g) The black skin of the forging layer for the finished bowl was burnished out by a metal scrubbing tool, properly ground and polished for shipment. That is done by hand lathe where the object is fixed with it by using resin. Each specimen is then polished with a scraper or noali.

The Scenario in Bangladesh

Bangladesh has also the tradition of bronze making. Important traditional manufacturing site is located at Dhamrai, Chapai-Nababganj and other sites. Numerous ancient bronze specimens were revealed from Wari-Bateswar and Mahastahan. Unfortunately very few specimens were only analysed.

Dhamrai: The ethno-metallurgical studies were conducted at this site by Ahsan and Paul (1995), Friedman (2001) and much more detailed work by Rupali Aktar and Sufi Mostafizur Rahaman (2004). There research indicates all the steps from melting the scrap in crucible, including the detailed steps of casting by cire perdue or lost wax process, making ingots in crucible to casting in clay or sand moulds. Their work is very much systematic, except detailing the quenching techniques.

Bangladesh melters are facing the problems similar to that of their Indian counterparts. The composition of analysed specimen is 78% Cu, 21.8% Sn and 0.2% Pb.

Mahasthan: Mahasthangarh is one of the most prominent 'urban citadel site' in South Asia. A large amount of the metal objects discovered over fifty years of research on Mahasthan is now scattered in several museums in Pakistan, India, Bangladesh and England. The excavations at Mahasthan by France-Bangladesh joint venture excavations have revealed its first phase of this site in Early Historic period including Mauryan, during 3rd century BCE to 2nd cent CE. During this period the people of this city used the silver coins, bronze mirrors, bronze vessels and iron objects indicating a well developed metallic culture. The site museum of Mahasthan possess good number of bronze objects found in excavation and exploraration. Analysis of an alloy rod: Earliest evidence of Gun metal from Mahasthan:

A copper alloy specimen (MZ.05.2841.1) was obtained from the excavation from Mahasthan in 2005. The specimen was a metallic artifact of the Gupta Period 4-5th cent CE. The analyses indicated gunmetal (Sabikun Naher and Chattopadhyay 2013). The size of the analyzed specimen is length 69 mm, diameter 5.5 mm.

Wari-Bateswar: The bronze vessel obtained at Wari-Bateswar provides one of the earliest evidence of high tin bronze in Bengal. Small fragments of ancient bronze bowl was found there belonging to Sunga period (c. 200-400 BCE). The initial analyses were made by Manowar Jahan, which indicate Sn content of 26.0%, with 71.24% Cu rest materials included Zn, Pb, Ni and Fe (Jahan 1995). The thin bowls made of high tin bronze was analysed by a number of scholars. But because of availability of insufficient specimen the archaeometallurgical analyses could not been completed. Only by EDAX, the phases were identified as á, á+ä and ã; and subsequent composition was made (Chattopadhyay 2011). The thin section of the bowls were perhaps made by batch forging as practiced in Muragacha for making of tumblers.

Mainamati: In Mainamati of Bangladesh, a bell weighing about 500 kg, and a meter in height was recovered from Rupban Kanya Mura dated ninth century CE. That is the largest bell of this part of the subcontinent. Throughout this subcontinent bells are used from early medieval period.

Conclusion

The use of High Tin Bronze in this subcontinent began in Early Historic Period. From excavation and findings of Tilpi, clear evidence of manufacturing of this alloy has been established prior to second century BCE. Some of the scholars had expressed their opinion on import of this alloy from South East Asia. This idea cannot be accepted fully.

In spite of all the finer points so far attributed, for the production of sound cast metal by plane front solidification, the thermo-chemistry of Cu-Sn system betrays the common solidification thermodynamics. To eliminate the sponginess of the alloy for improving the mechanical property hot working or forging remained a probable option in the ancient world. The forging of high tin bronze was achieved for conservation of heat within metal.

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