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ORIGINAL ARTICLE

Archaeo-metallurgical study on two early historic punch marked coins

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Abstract

A metallurgical investigation was carried out on two early historic silver and copper punch marked coins. The objective was to study the metal composition, and the methods used in making of the early historic coins in India. The inductively coupled mass spectrometry was used to analyze the elemental composition of the coins. Metal formation and its mechanical properties were studied in physical metallurgical laboratory. The study revealed that the coins were not pure metal but an alloy. The silver coin contained copper as a major alloying element with other elements viz., V, Fe, Zn, Sn, Pb, As, Au in trace level while in copper the coin lead was the main alloying element with Ni, Fe, As, Au and Co in trace.

Keywords Dendrite · Eutectic · *Kārṣāpaṇa* · *Lakṣaṇādhyakṣa* · *Paṇa* · *Rūpadarśaka*

1 Historical information

The punch marked coins were found throughout India and formed the part of the coin of exchange in trans-regional trade in early historic period of c.6th century to 2nd century BCE in the north and continued till c.1st century CE in the South. The merchant guilds from the Janapadas started the minting of punch marked coins in silver called *kārṣāpaṇas* and in copper as *paṇa.* The system of issuing *kārṣāpaṇas* and *paṇa* was continued by the royal mint of the Maurya. The tradition continued until it was replaced by coins with royal portraits and titles. The coins issued earlier were cylindrical in shape and was followed by rectangular or irregular, square and circular coins. The *Arthaśāstra* of Kauṭilya uses the term *rūpa* for coins and the officer who examined the coin was known as *rūpadarśaka*. The mint master or *lakṣanādhyakṣa* was in charge of the *lakṣanas* (symbols) to be imprinted on the imperial coins and was in charge of the manufacture of the silver coins (*rūpyarūpa*). It also states the composition of silver coins in the ratio of three parts of silver, one part of copper and one sixteenth part of any one of the metal viz., *tīkṣṇa*, *trapu*, *sīsa*, and *añjana*. The *Arthaśāstra* mentions that the copper coin (*tāmrarūpa*) was made up of four parts of an alloy (*pādajīvam*) (Shamasastry, 1915, chapter xii, book ii).

The punch marked coins were grouped into six classes in accordance with the variations of symbols and marks. They were especially stamped on one side with a group of five punches in a great variety of combinations and on the reverse with one or more punches, different from those found on the obverse. Kauṭilya's *Arthaśāstra* states that the symbols on the reverse side are the marks of punching made by the quality checking officer or *rūpadarśaka* (Shamasastry, 1915). It also states that the coins in circulation were also tested periodically by *rūpadarśaka* from time to time, who punched his test marks each time on them. The increase in number of test marks on the reverse appears to denote the coins being older in circulation (Mookerji, 1960).

2 Earlier studies on punch marked coins

The elemental study of silver punch marked coins had been carried out by different non-destructive methods like X-ray diffraction, EDXRF and external PIXE. The analysis by external PIXE method indicated in variation of silver (Ag) from 56.3 to 81.7% and copper (Cu) from 4.4 to 18.5% and Au, Pb, Fe were found to be major constituent of silver punch marked coins (Rautray et al., 2011). Similar study on silver punch marked coins by EDXRF showed the variation of silver constituent from 35.51 to 89.21% and the concentration of copper from 3.76 to 46.49%, Pb, Fe As, Au, Ti,

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Cr, Co, Ni, and Y in varying concentration at trace level in the studied samples (Vijayan et al., 2004). The elemental study of 132 silver punch marked coins of Karnataka hoard by X-ray diffraction method revealed the variation of silver from 51.08 to 94.27 and the Cu value varied from 4.75 to 45.92% (Rao and Nair, 1991).

The energy dispersive X-ray analysis of copper punch marked coins by an earlier study showed that the percentage of copper in those coins was found between 88.82 and 61.64%. The variation of other elements like Ni 0.01 to 1.76, Zn 0.1 to 1.432 and Pb 0.08 to 6.8%, Sn 0.03 to 0.23, K.02%, P. 0.35% were reported as trace elements (Srivastava et al., 2007). An study of nineteen silver punch marked coins from Narhan (U.P.) by X-Ray diffraction, metallographic and spectroscopy method to determine the metal forming technique and elemental composition, revealed that the coins were worked, annealed and punched and the silver contents ranged from 93.5–96.2%, copper 2.5–3.5%, gold 0.7–1.3% and lead 0.3–0.9% (Agrawal et al., 1990).

3 Studies on two punch marked coins

Two punch marked coins, viz., a silver and copper, taken up for study were irregular in shape and punch marks were seen on both sides. The coins have been analyzed for its elemental composition, and metallurgical properties. The two coins were subjected to quantitative analysis in ICPMS (inductively coupled plasma mass spectrometry) Laboratory at National Institute of Ocean Technology, Chennai. They were tested for hardness and micro-structural analysis at Physical Metallurgical Laboratory, IIT, Madras. The analysis and the results of the study are presented in the coming sections.

3.1 Experimental analysis: coin no. 1

3.1.1 Quantitative analysis

A portion of the silver (Ag) punch marked coin was dissolved and analyzed by ICPMS (Fig. 1). The study revealed that it is a silver based (around 80% Ag) alloy with the major alloying element being copper (Cu) at 19% and also a few elements like V, Fe, Zn, Sn, Pb, As, Au at trace level.

3.1.2 Metallographic preparation

One surface of both the silver and copper coins were grounded on successively finer grades of emery papers (No 1, 1/0, 2/0, 3/0 and 4/0) and then polished on a polishing machine with fine aluminum oxide powder spread over a polishing cloth sprinkled with water. After grinding and polishing, the surface gets a mirror like polish. It is then etched with a suitable chemical reagent for a few minutes to reveal the internal microstructure under a microscope.

3.1.3 Mechanical property

Hardness studies were carried out with a Low Load Vickers Hardness Testing Machine at a load of 1000 g. The hardness indentations can be made on a relatively small area so that different regions on the surface can be tested for hardness.

3.1.4 Micro structural study

Microstructural studies were carried out by metallurgical microscope under different magnifications. The micro photographs are shown in Figs. 2, 3, 4, 5 and 6.

Fig.1 Silver punch marked coin: obverse (left); reverse (right)

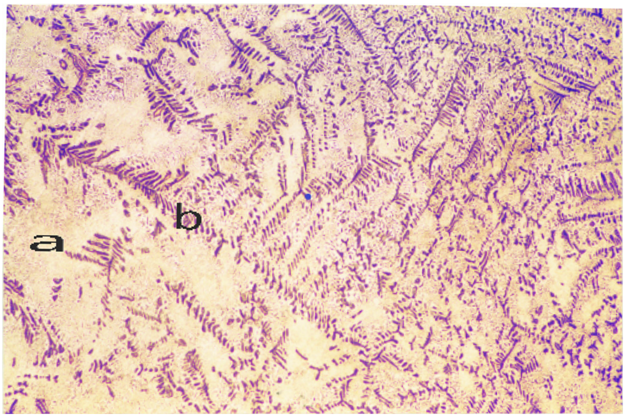

Fig. 2 Micro structure, 50× showing (*a*) white etching primary alpha phase-pure silver and (*b*) dendritic structure (tree like) formed in the silver alloy during the solidification process

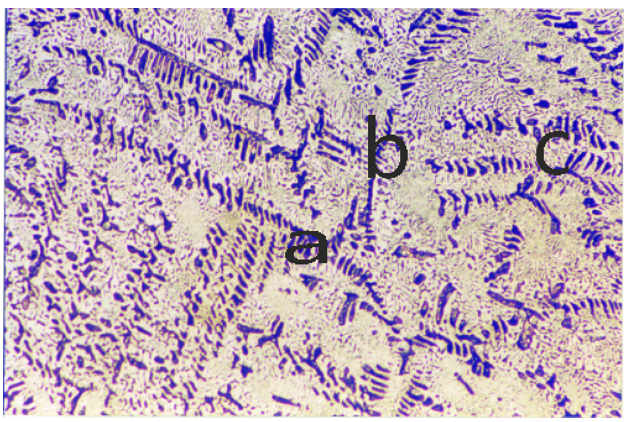

Fig. 3 Microstructure 100× showing (*a*) dark etching beta phase; (*b* and *c*) formation of different size of dendritic structures due to fast cooling

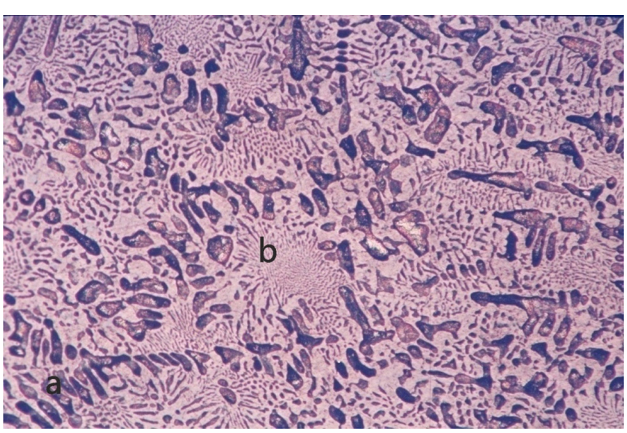

Fig. 4 Microstructure 200× showing (*a*) dark etching beta phase and (*b*) eutectic structure

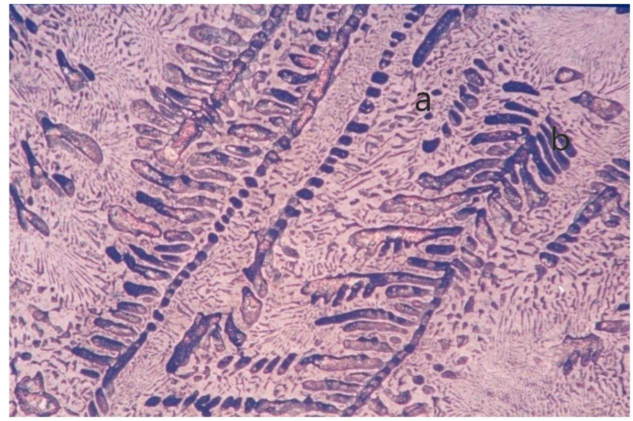

Fig. 5 Microstructure 500× with (*a*) and (*b*) the eutectic structure well resolved to show alternate layers of alpha and beta phases

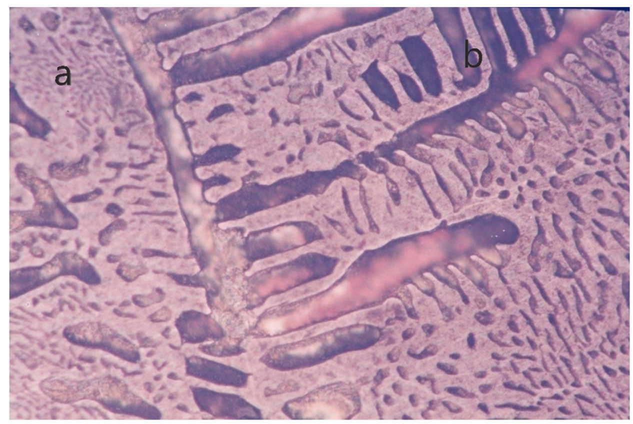

Fig. 6 Microstructure 1000× showing (*a*) the eutectic structure and (*b*) alternate layers of alpha and beta phases

3.2 Results and discussion: coin no 1

The equilibrium diagram of silver–copper alloy for coin 1 is presented in Fig. 7.

Silver and the major alloying addition copper form a silver rich alpha and copper rich beta phase at higher temperature of 779°C during solidification of the liquid alloy. On cooling to room temperature, at slow rate, pure Ag alpha phase and pure Cu beta phases are formed. But during normal casting process, cooling rate is higher, therefore silver rich alpha and copper rich beta phases are formed. The Ag–Cu equilibrium diagram indicates a eutectic transformation at 28.1% Cu beta at a temperature of 779 °C formed from the liquid alloy during solidification. The eutectic structure consists of an intimate mixture of light etching (silver rich) alpha and dark etching (copper rich) beta phases. The microstructure of the coin containing 80% silver consists of grains of primary silver rich alpha phase which is a white etching phase and the eutectic mixture of alpha and

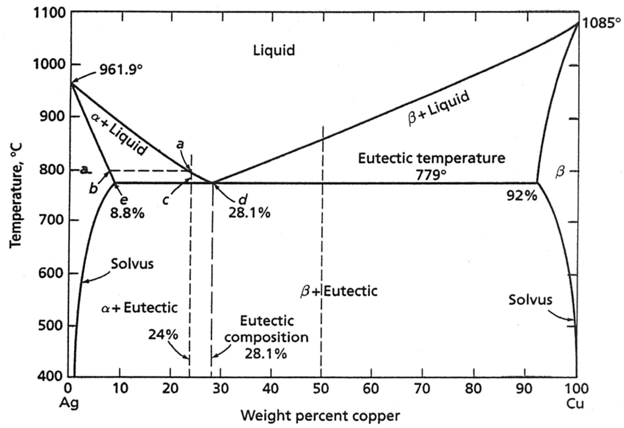

Fig. 7 Equilibrium diagram of Ag–Cu

beta phases and also dark etching beta phase and dendritic structure. The eutectic structure was resolved at higher magnifications to show alternate layers of alpha and beta phases. The presence of a dendritic structure indicates that this is a cast metal coin.

The hardness value of pure silver and pure copper would be around 35 VHN and 60 VHN respectively. The eutectic transformation in silver-copper alloy at 28% Cu results in the formation of an intimate mixture of alpha and beta phases. This eutectic structure has a higher hardness than pure silver. The presence of a large amount of eutectic mixture in the microstructure of Ag–Cu alloy coin as shown in the micrographs has resulted in higher hardness of the coin. However, the hardness value of the silver coin is found to be around 145 VHN, which appears to be much higher than that possible by alloy addition of silver with copper. Therefore, it can be inferred that the coin had been subjected to cold working during the last stages of solidification or later at ambient temperature because plastic deformation by cold working increases the hardness and strength of metals and alloys.

3.3 The experimental analysis: coin no. 2

3.3.1 Quantitative analysis

A portion of the copper (Cu) punch marked coin (Fig. 8) was dissolved and analyzed by ICPMS. The spectroscopic analysis indicated that it was a copper based alloy with 60% copper (Cu) and the major alloying addition being lead (Pb) with 34% along with 3.6% silver (Ag) and 1.8% tin (Sn). Few trace elements like Ni. Fe, As, Au and Co were also revealed in the analysis.

3.3.2 Micro structural study

The micro structural features of copper punch marked coin in different magnifications are shown in Figs. 9, 10 and 11.

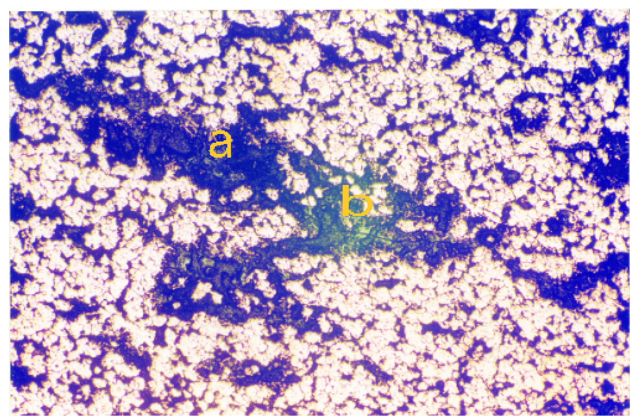

Fig. 9 100× Copper Punch marked coin with with (*a*) lead forming as dark lumpy region and (*b*) Silver (Ag), tin intermetallic compound (Sn) in grayish structure

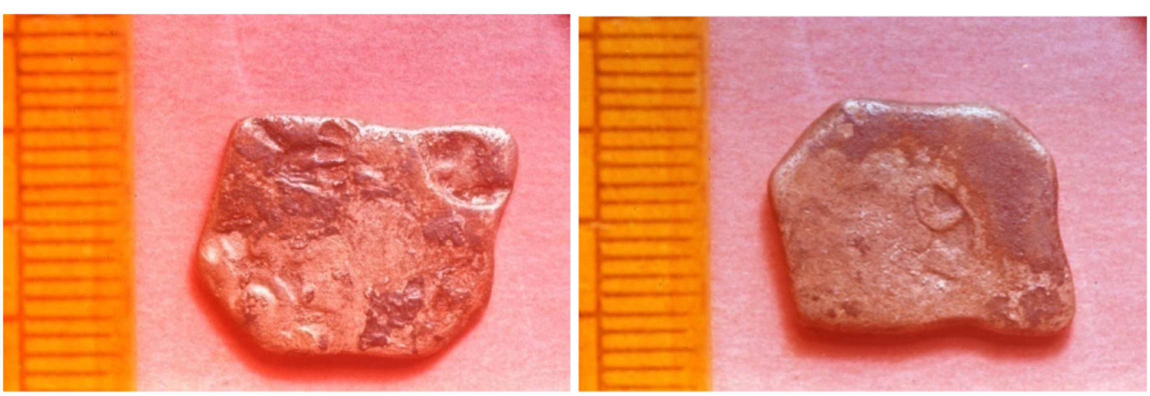

Fig. 8 Copper punch marked coin: obverse (left); reverse (right)

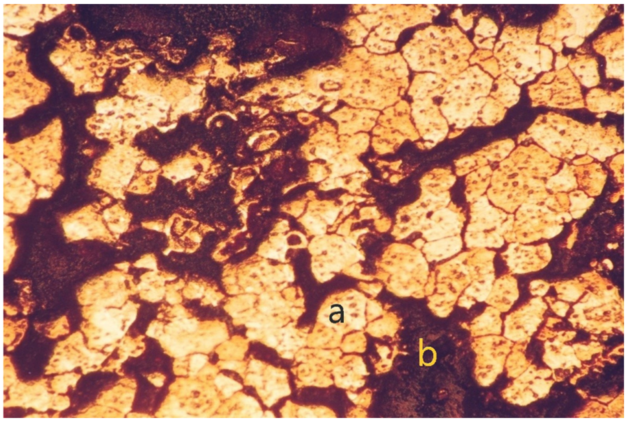

Fig. 10 200× showing (*a*) copper and (*b*) lead as un-dissolved solid solution

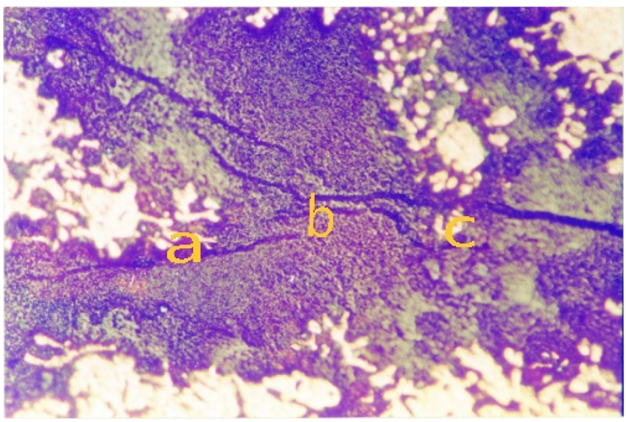

Fig. 11 500× showing (*a–c*) micro cracks observed at higher magnification

3.4 Results and discussion: coin no 2

The equilibrium diagram of copper–lead alloy is shown in Fig. 12.

The Cu–Pb phase diagram indicates a eutectic transformation at a temperature of 995 °C and 36% Pb. Lead is totally immiscible in copper as also copper in lead at room temperature. Therefore lead is seen as lumpy black phase. The eutectic mixture of alpha phase, which is pure copper, is white etching and particles of beta phase, which is pure lead, is black etching and appears as matrix structure. The micro-cracks have developed in the lumpy lead grains.

Normally the hardness of pure copper and lead would be in the region of 60 VHN and 5 VHN. As lead does not dissolve in copper to form a solid solution nor can it form intermetallic compound, the hardness of copper-lead alloy will not increase. Therefore, higher hardness of copper coin indicates that work hardening must have occurred

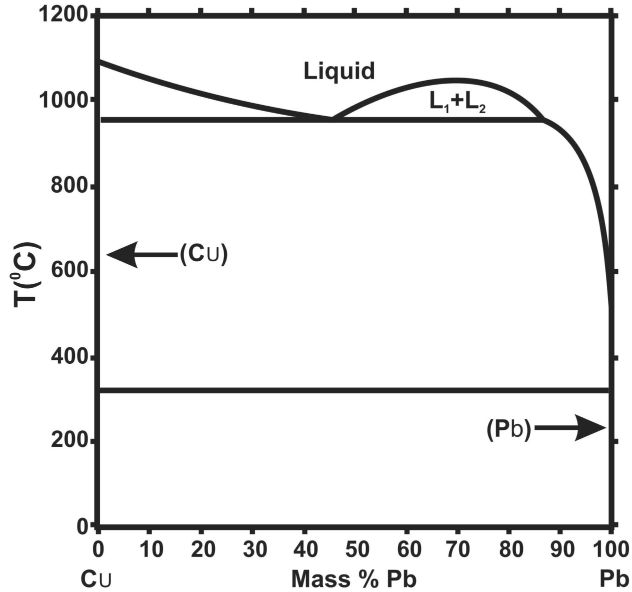

Fig. 12 Equilibrium diagram for Cu–Pb

to increase its hardness to 110 VHN. So it can be inferred that the copper coin had been subjected to cold working by pressing or punching during the last stages of solidification or later at ambient temperature.

4 Conclusion

The microstructural analysis and hardness studies indicate that the two coins were melted and solidified by cooling. The hardness values of both the silver and copper coins (145 VHN and 110 VHN respectively) appear to be higher than normal as for cast metals. Therefore, it can be summarized that in both coins, metallurgical deformation by pressing or punching, had been carried out during the last stages of solidification or later at ambient temperature.

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