

## ARCHAEO METALLURGICAL STUDY ON SELECT PALLAVA COINS

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The Pallavas of Kāñcī issued coins made of copper, lead and copper alloys with either the device of bull or lion on the obverse and a triangle with a dot in the centre, conch etc on the reverse. One of the coins under study bears the legend Murārī, a title of Mahendravarman I in *Grantha* characters above the standing bull. These coins were given to us by Sri S. Raman (Madras). The provenance of these coins was not known. But according to S. Raman, these were procured by him from a coin collector at Trukkoilur (South Arcot District). Four of the six coins under study shows the standing bull device, the other symbols present on the coins include the bust of a king, wheel (*cakra*), Ujjain symbol, moon, a vase and to the left of the vase a lamp-stand above on the obverse. Two of the six coins (one copper alloy and one copper coin) were subjected to SEM-EDAX, and all the coins were subjected to metallographic study, micro hardness, spectroscopic studies and ferro magnetic analysis. The findings indicate that the coins were subjected to cold working, casting and forging operations in the course of their making. While the purity content in the copper coin is as high as 99.7%, the copper alloy coins indicate the presence of tin in the value ranging from 18 to 25%, iron was present in all the copper alloy coin and varied from 12% in coin no. 6 to 0.75% in coin no.5.

**Key words:** Casting, Grantha, Forging, Murārī, Ujjain symbol

### INTRODUCTION

Coins in South India and especially in Tamilnadu date back to the early historic times (c.3<sup>rd</sup> century BC-2<sup>nd</sup> century AD). Different techniques for manufacturing coins were evolved, quite early in South India, and had reached a reasonable degree of perfection by the time of the Śāthavāhanas (c. 2<sup>nd</sup> century BC to 2<sup>nd</sup> century AD) (Chattopadhyaya, 1977). The Eran type corroded bronze punch marked coin from the Suler (Coimbatore district) megalithic burial was the earliest coin so far discovered

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and has been assigned to 3<sup>rd</sup> or 2<sup>nd</sup> century BC on stylistic ground (Rajavelu et al., 1995). The early coins were mostly made of copper or silver with symbols punch marked on them. The punch marked coin popularly known as *karṣapaṇa* had its origin to the Janapadas around 6<sup>th</sup> century BC. The *karṣapaṇa* issued by the Nanda and Maurya dynasties from Magadha formed the source of development for the new coinage system under the Magadha empire (Krishnamurthi, 1977). Punch marked coins were discovered in Tamilnadu in the riverbeds of Vaigai (Madurai) and Amaravathi (Karur) and these were identified as the coins issued by the Pandya and Chera dynasties of the Sangam era (c. 3<sup>rd</sup> century BC to 2<sup>nd</sup> century AD, Vijayaragavan, 2000). The punch marked coins were followed by square coins of copper and its alloys or silver. Most of the early square coins issued contain the emblem of issuing dynasty on the obverse with or without any legend.

As for as Sangam age coin is concerned we have come across coins bearing the names of four Chera kings from Karur viz, Makkotai, Kuttuvan kotai, Kollippurai and Kol-irumpurai (impure silver) and one Pandya king Peruvazuthi (copper) from Madurai. The legends were in Brahmi characters on the obverse. The macro analysis of Makkotai Coin indicates close similarities with contemporary Roman silver coin (Krishnamurthi, 1977). The Pallavas of Kāñcī issued coins with bull or lion emblem on the obverse. The excavations at Kāñcīpūram from 1970 to 1976 brought to light eleven coin moulds belonging to the Śāhāvāhana and Pallava dynasties. The coin moulds of the Pallavas illustrates bull and lion emblem on them. These moulds were made of red ceramic and were found at a depth of 4.90 mts in a trench laid near Kāmākṣhī Amman temple (Raman et al., 1995). These were single matrixed coin moulds used for preparing one coin only.

### EXPERIMENTAL STUDIES

Six Pallava coins consisting of two copper and four copper based alloy were metallurgically analysed to study the alloy composition and method of manufacture. The coins were worn out/broken and irregular in shape. The coins from their morphology indicate that they were small, round, and die struck.

#### **Coin No.1 : Tin Bronze Coin**

*Coin weight*: 1.1661 grams

*Diameter* : 19 mm

*Thickness* of the coin: 0.94 to 1.2 mm

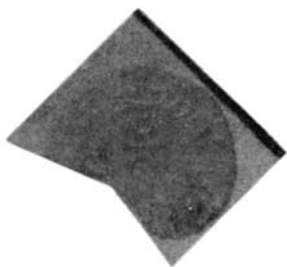
*Colour* of the coin: Greenish black in appearance (due to long exposure) before polishing and yellowish white after polishing the surface.

*Observe*: The bust of the human with a headgear (crown?); behind the bust is a parasol (or throne?); a small necklace around his neck and another on his chest; it appears to be a representation of a king seated on a throne. A border can be seen around the head of the figure; at the end of border, to the left of the figure, traces of a legend can be seen (Fig.1); since the coin is broken at the bottom and the obverse is partially worn out, it is not possible at present to read the legend.

*Reverse*: Completely worn out. The coin under study is broken and the shape is irregular. The colour of the coin is greenish black. The diameter is about 19 mm and the thickness varies from 0.94 mm to 1.2 mm. The weight of the broken and worn out coin is 1.1661 gm. The coin was subjected to energy dispersive X-ray analysis (EDAX), microscopic examination and micro hardness study. The quantitative compositional analysis of the metal was done on spectroscopic equipment and ferro magnetic analysis on a Ferritescope. For the sake of convenience, the side with the legend and the figure is taken to be obverse (Fig.1), since practically nothing is visible on the other side.

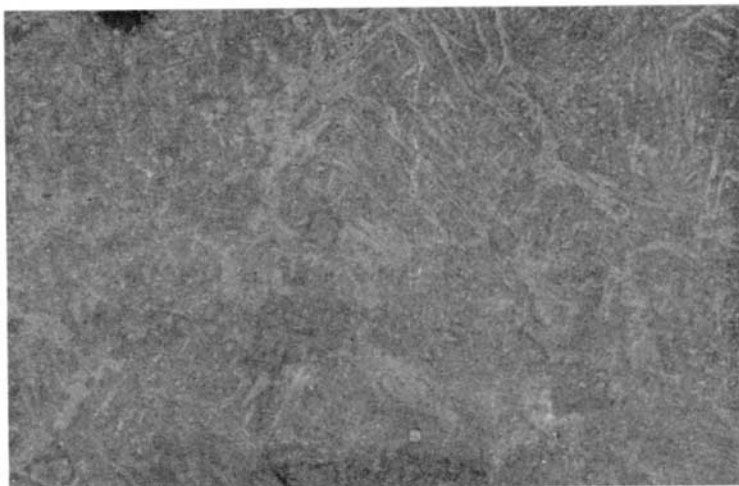
*Observations*: The spectroscopic analysis of the coin revealed that the coin is a copper alloy containing large amount of tin. Other than copper, tin formed the second major element in the composition and is around 22%. Iron and sulphur are impurities and are around 4% and 0.06% respectively. The chemical composition of the coin revealed that the metal is a high tin bronze.

*Microstructural Study*: One side of the coin was metallographically polished and etched with ferric chloride solution. Microscopic study was carried out at different locations by scanning the surface. The microstructural examination confirmed the results of the chemical analysis and showed that the copper alloy contains large amount of tin. The study also revealed a widmanstatten structure surrounded by a network of copper rich alpha phase (Fig.2). The average grain diameter is found to be around 40 to 100 microns. The microstructure (Fig.3) consisted of eutectoid mixture of copper rich solid solution and tin rich solid solution along with particles of greyish white appearance, which are compounds of copper and tin. A part of the coin surface has become oxidised due to corrosion and microstructure in this region revealed islands of non-corroded metal. The presence of a coarse grain structure along with numerous



### Coin 1

**Fig. 1:** Copper alloy coin, obverse side, the bust of a king



**Fig. 2:** Microstructure showing widmanstatten structure surrounded by copper rich alpha phase, 500x.



**Fig. 3:** Eutectoid mixture of copper rich solid solution and tin rich solid solution, 200x.

shrinkage cavities in a flowery dendritic pattern indicates that the coin was made by casting i.e. by solidification of the molten metal in a mould. It appears that the die forging of the metal with the impression of the figure was carried out at an elevated temperature before the solidified metal has cooled to room temperature. After the die forging, at about 700°C the metal was cooled fast by air cooling. This was revealed by a widmanstatten structure in the micrograph (Fig.3).

*EDAX analysis:* The EDAX analysis was carried out on two spots of the unpolished surface of the coin. The study revealed the presence of iron, silica, tin and oxygen.

*Hardness Study:* Micro-hardness studies were carried out on the coin at a load of 100 gram. The hardness value in the martensitic region measured around 300 VHN. The alpha phase network had a hardness value of 200 VHN. The corroded regions of the coin showed a value of 350 VHN.

### **Coin No. 2 : Copper Coin**

*Coin weight:* 0.7770 grams

*Diameter :* 15 mm

*Thickness of the coin:* 0.5 to 0.84 mm

*Colour of the coin:* Greenish brown in appearance before polishing and bright reddish brown after polishing the surface.

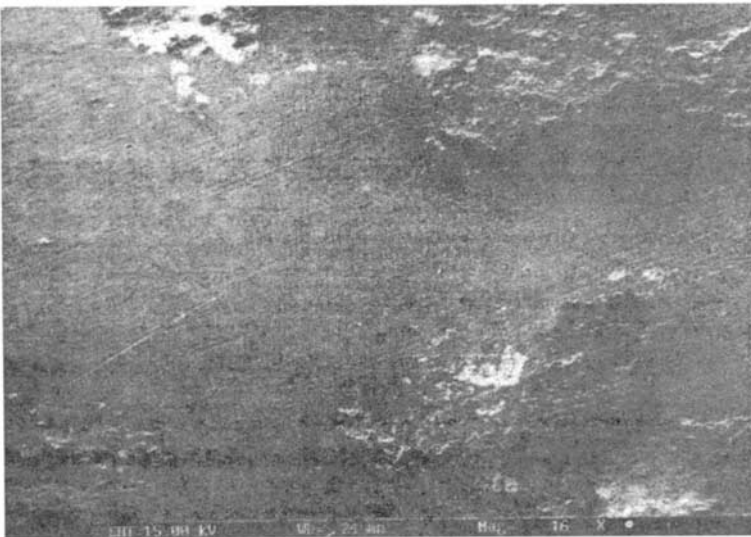
*Observe:* The obverse side of the coin illustrates a standing bull, Ujjain symbol and moon is depicted above the bull (Fig.4).

*Reverse:* Completely worn out. The coin is circular in shape; however due to damage the shape of the coin is slightly altered. The coin was subjected to energy dispersive X-ray analysis (EDAX), microscopic examination and micro hardness study and quantitative compositional analysis. The spectroscopic analysis revealed that the metal was essentially copper with purity content of 99.8%. The other major element in the coin consisted of tin with a percentage of 0.5%. Impurities and other elements were found to be in very small quantity with sulphur around 0.12%.

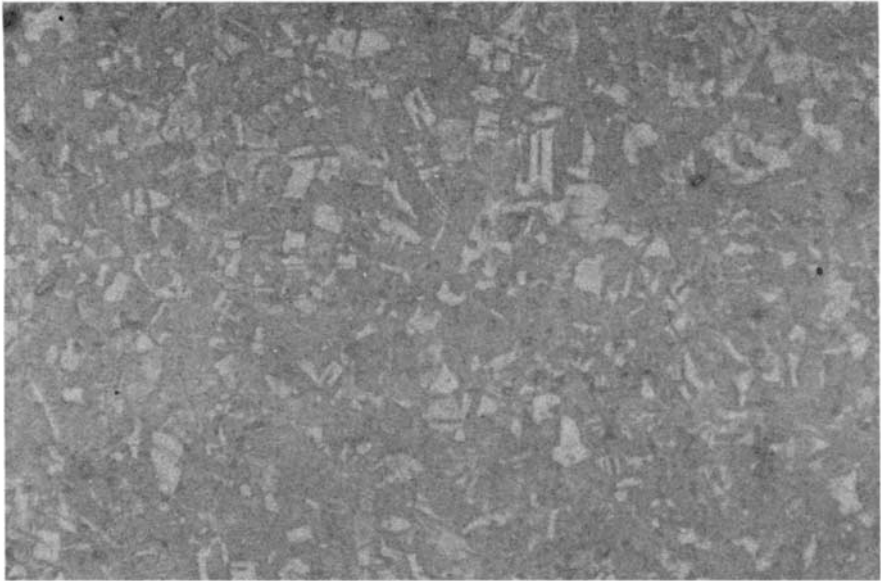
*EDAX Analysis:* The EDAX analysis was carried out on two spots of the unpolished surface of the coin. The study revealed 100% pure copper. The SEM micrograph of the surface of the coin is shown in Fig.5.

**Coin 2**

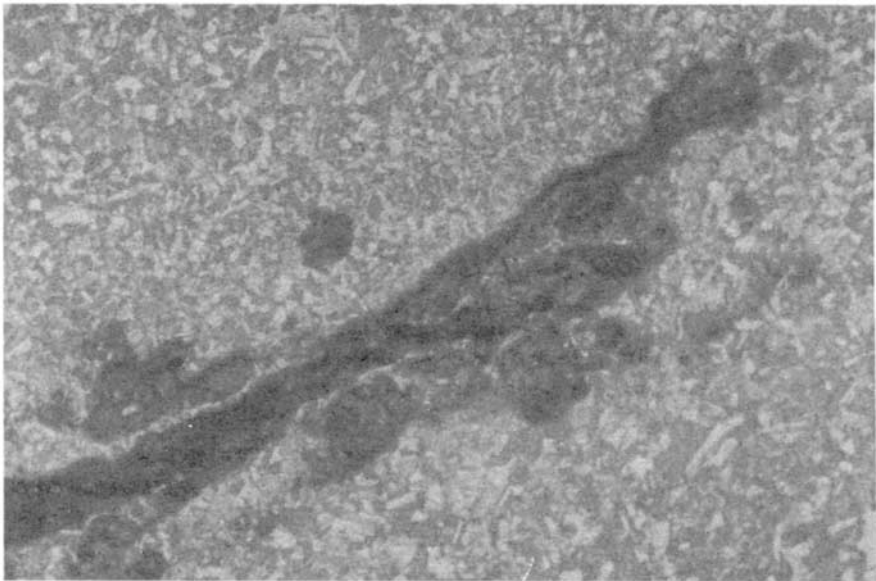
**Fig. 4:** Copper coin, standing bull on the obverse side. Reverse side is worn out.



**Fig. 5:** SEM micrograph of the surface of the coin.



**Fig. 6:** Micrograph showing compound of copper and tin, 200x.



**Fig. 7:** Micrograph revealing coarse and very fine grained structure. A crack is seen in the middle, 100x.

*Microstructural Study:* The microstructural examination of the coin reveals that the size of the grains varied widely in different locations. The microstructure of the coin mainly consisted of equi-axed grains of single phase with twin bands. Numerous small particles of bluish white colour were found distributed in the matrix, and appears to be a compound of copper and tin (Fig. 6). The micrograph (Fig.7) shows very fine- grained structure in one segment and coarse grained structure adjacent to it. A crack developed in the coin was also observed. The coin appears to be folded in one part as shown in Fig.4.

*Hardness Test:* Micro-hardness was carried out on the coin at a load of 100 gram. The hardness value in the single-phase region varied from 57 to 60 VHN.

*Analysis:* The chemical and EDAX analysis of the coin showed that the coin was made of pure copper with small amount of tin and sulphur. The micro structural study revealed equiaxed grains of copper indicating that the coin was made by forging and not by casting. The presence of recrystallized grains of very fine size in one region and coarse grain in another region confirm that the metal was subjected to cold working and subsequent annealing treatment by re-heating of the metal. The impression of bull on one side could have been produced by hot forging process with a die.

### **Coin No. 3 : Tin Bronze Coin**

*Coin weight:* 1.4555 grams

*Diameter:* 20 mm

*Thickness of the coin:* 2.24 to 1.95 mm

*Colour of the coin:* Greenish black in appearance before polishing and yellowish white after polishing the surface.

*Observe:* Completely worn out (Fig.8)

*Reverse:* Completely worn out. The worn out coin is nearly circular in shape and a small segment is found to be chipped off. The coin was subjected to microscopic examination, micro hardness study, quantitative compositional analysis and ferro magnetic studies.

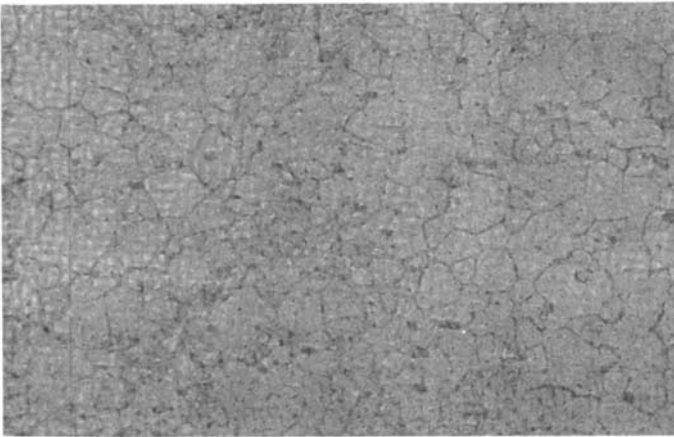
The coin is a copper based alloy containing large amount of tin, which formed the second major element in the composition of the metal and is around 18%. Iron is the third important element and its content is around 2.5%. The other elements present include nickel 0.18%, silicon 0.08% and sulphur 0.01%.



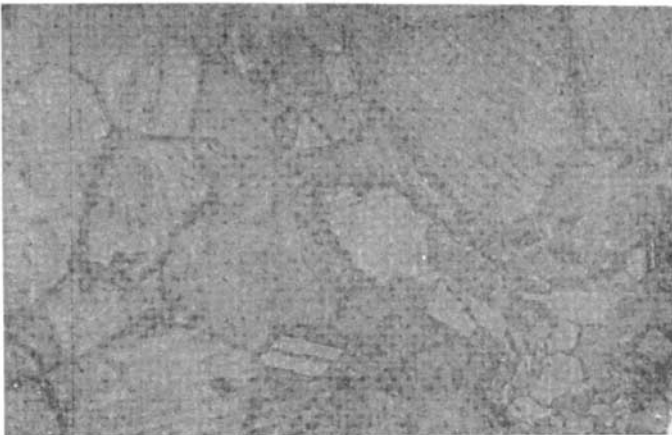
**Coin 3**



**Fig. 8:** Copper alloy coin, completely worn out.



**Fig. 9:** Micrograph showing crack along the grain boundaries, 200x.



**Fig. 10:** Martensite structure with fine acicular structure within the grains, 1000x.

*Microstructural Study:* The microstructural examination of the metal revealed a fine-grained equi-axed structure with many pores. A crack has developed in the coin and is found to propagate along the grain boundaries (Fig. 9). The microstructure appears to contain martensite structure with fine acicular structure within the grains. Twin bands are found present in some grains. Precipitated particles of copper tin compound can be seen distributed along the grain boundaries (Fig.10).

*Hardness Test:* Micro-hardness studies were carried out on three regions of the metal with a load of 100 gram. The hardness study in the martensite region revealed a hardness value of 240 to 248 VHN.

The metal was a high tin bronze. The process of manufacture appears to be hot forging a cast metal to get the shape and fast cooling by quenching in water. The microstructure and hardness value of the coin supports this view.

#### **Coin No. 4 : Copper Coin**

*Coin weight:* 1.3388 grams

*Diameter :* 17 mm

*Thickness* of the coin: 1.36 to 1.26mm

*Colour* of the coin: Greenish brown in appearance before polishing and bright reddish brown after polishing the surface.

*Observe:* A standing bull (Fig.11)

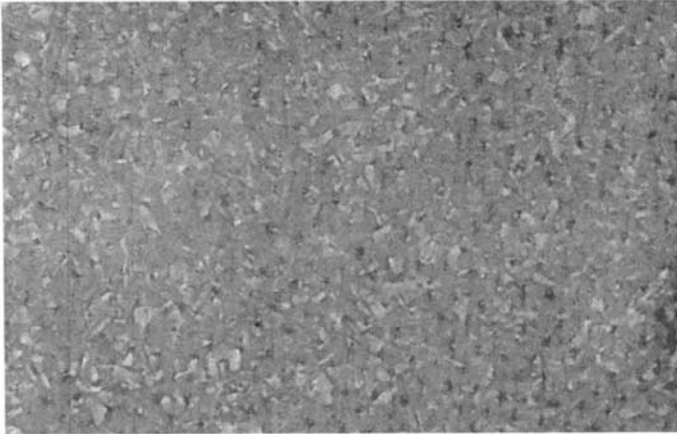
*Reverse:* Conch in the middle. The worn out and damaged pure copper coin was subjected to microscopic examination, micro hardness study and quantitative compositional analysis. The spectroscopic analysis revealed that the metal was a copper coin with purity content of 99.6%. The other major elements in the coin consisted of iron 1% and sulphur 0.17%.

*Microstructural Study:* The microstructural study revealed recrystallized grains of copper, which are very fine and equi-axed. Numerous twin bends were also observed. A large number of greyish white particles consisting of compound of copper and tin were found to be distributed in the matrix (Fig. 12). Many reasons in the coin were found corroded and corrosion products was noticed in the microstructure also (Fig.13).

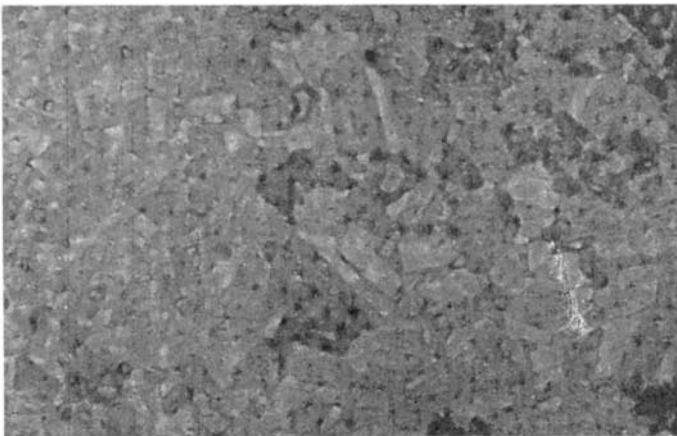
*Hardness Test:* The micro-hardness studies of the coin were carried out on the equi-axed reasons of the coin and hardness value was around 62 to 65 VHN.

**Coin 4**

**Fig. 11:** Copper coin, standing bull on the obverse, reverse side completely worn out.



**Fig. 12:** Compound of tin and copper distributed in the matrix, 100x.



**Fig. 13:** Micrograph showing corroded region, 500x.

The microstructure and hardness study of the metal indicates that the copper coin was produced by cold forging and annealing process. An impression of a bull with legend Murari in Grantha character was stamped on one side and a conch on the other side of the coin by hot forging. Iron sulphide particle appears to be present in the matrix.

### **Coin No. 5: Tin Bronze Coin**

*Coin weight:* 0.7142 grams (half coin)

*Diameter :* 15 mm

*Thickness of the coin:* 1.33 to 1.46 mm

*Colour of the coin:* Greenish black in appearance before polishing and yellowish white after polishing the surface.

*Observe:* A wheel (*cakra*) with spokes (Fig.14)

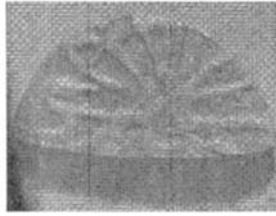
*Reverse:* Completely worn out.

A broken coin, semi-circular with an impression of *cakra* on one side was analysed. However the shape of the coin can be inferred to be circular based on its present form. Spectroscopic analysis revealed that the coin was a high tin alloy with a tin content of 25%. Iron and sulphur other than copper were the other elements present in the metal.

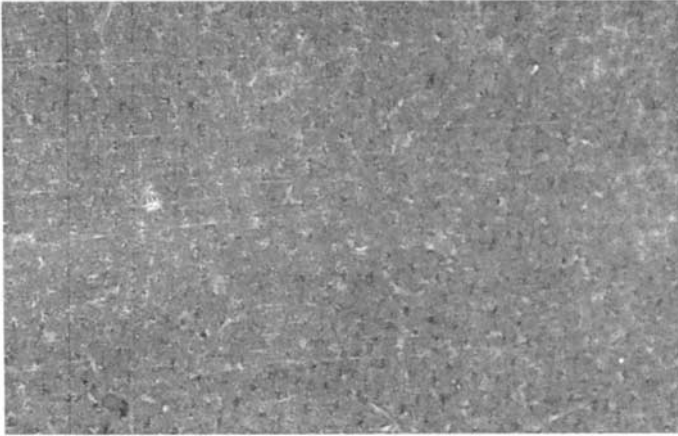
*Microstructural Study:* The microstructural revealed a matrix of fine martensite and a very fine globular particles of an intermetallic compound of Cu and Sn (Fig.15). Along the grain boundary, a thin network of copper rich alpha phase is observed (Fig. 16). The particles of intermetallic compound have formed a flowery pattern in some places.

*Hardness Test:* The micro-hardness with a load of 100 gram was carried out on the surface of the coin. The study revealed a hardness value in the region of 340 to 380 VHN.

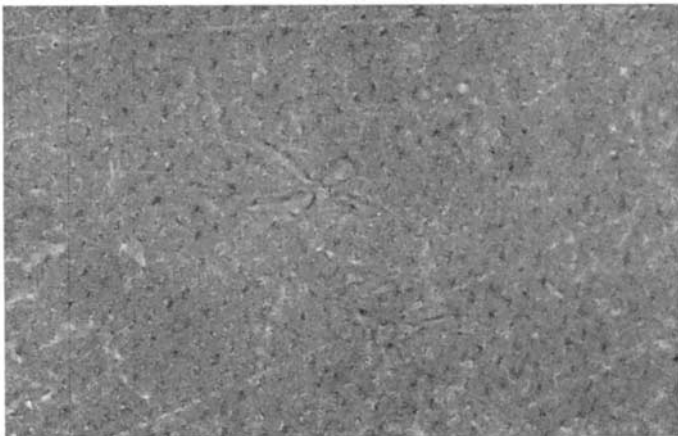
The microstructure contained very fine particles of second phase in a matrix of martensite. This indicates that the coin has been subjected to some heat treatment. The impression of *cakra* appears to have been produced by hot forging. The presence of flowery pattern of intermetallic compound indicates that the metal was cast and then forged in hot condition immediately after solidification of the metal.

**Coin 5**

**Fig. 14:** Copper alloy coin, a wheel with spokes on the obverse.



**Fig. 15:** Fine Martensite and very fine globular particles of an intermetallic compound of Cu and Sn, 200x.



**Fig. 16:** Network of copper rich alpha phase, 500x.

**Coin No. 6: Copper based alloy Coin**

*Coin weight:* 1.3391 grams

*Diameter:* 15 mm

*Thickness of the coin:* 1.365 to 1.265 mm

*Colour of the coin:* Greenish black in appearance before polishing and Yellowish white after polishing the surface.

*Observe:* A moving bull, and above it a legend in Grantha script is seen in (Fig. 17). The legend reads as *Murārī* and study of the legend indicates that it was the title of the Pallava king Mahendra Varman I (c. 580 to 630 AD). The title was found in one of his inscription from Mahendravācī (SI Volume 12, 1986). Though the title was found in the inscription, this is the first time it was found in one of his coins recorded so far. While the other three copper based alloy samples of the Pallavas indicate a tin based alloy with an iron content varying from 4% in coin no.1 to 2.5% in coin no.3 and 0.75% in coin no.5, the coin no.6 was an alloy of iron and copper with minor amounts of tin, zinc and silicon.

*Reverse:* A conch was depicted in the middle of the coin (Fig. 17).

The copper based alloy coin was subjected to microscopic examination, micro hardness study and quantitative compositional analysis and magnetic analysis.

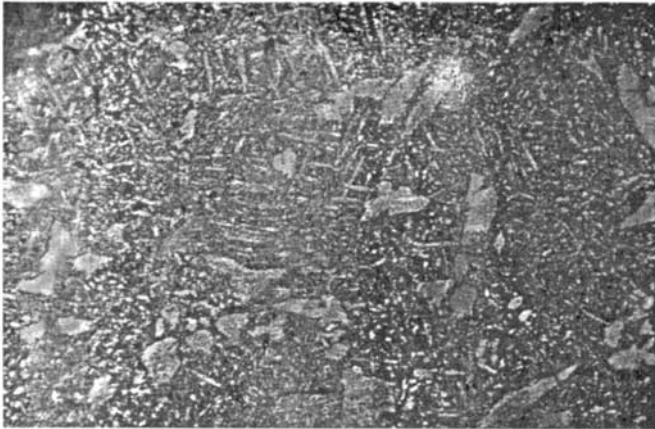
The coin is an unusual copper based alloy containing considerable amount of iron and silicon. Small quantities of tin and zinc were present. The chemical composition of the coin was analysed spectroscopically. The results showed that iron formed the second major element with about 12%, tin 0.84%, zinc 0.13% and silicon 1.03%. Copper formed the major element and is about 86%.

*Microstructural Study:* Microstructural examination revealed dendrites of copper rich alpha phase in a matrix containing an intimate mixture of copper rich and iron rich solid solutions (alpha+theta) due to eutectoid transformation (Fig. 18, Swatzendruber, 1992). A widmanstatten type of structure in some locations of the coin can be seen. While etching particles of intermetallic compound made up of copper and tin were also seen. Small cavities developed due to shrinkage during solidification can be observed as black spots (Fig. 19).

*Hardness Study:* Micro-hardness examination was carried out at loads of 50 and 100 grams. The dendrite structure of alpha revealed a hardness of around 140 VHN. The eutectoid mixture is found to be harder with a hardness value of about 295 VHN. Intermetallic compound of copper and tin showed a hardness value of 135 VHN.

**Coin 6**

**Fig. 17:** Copper alloy coin, standing bull with legend Murārī on the obverse, conch on the reverse.



**Fig. 18:** Copper rich alpha phase in a matrix, 200x.



**Fig. 19:** Black spots developed due to shrinkage during solidification, 200x.

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