Coin Composition - Blank Casting Effects

4.8.2012

During the measurement of the electrical conductivity σ of antique bronze coins the observation was made that it varied along the surface. An investigation was launched to determine if there was any systematic distribution or if it was only attributable to local cavities and cracks or local concentrations of Fe in the patina.

The study was performed with a FOERSTER SIGMASTEST 2.069 eddy-current instrument with variable frequency (60-960 Hz) and a sensor head of 8 mm diameter. The frequency for the measurements was set at 120 Hz to ensure sufficient penetration of the core material. Measurements were performed in 1 mm steps, using an mm-scale ruler, along two orthogonal axes at 12:00 and 3:00 o'clock on the obverse (Fig.1). The measurements on the reverse were taken such that they were along the same axes defined on the obverse.

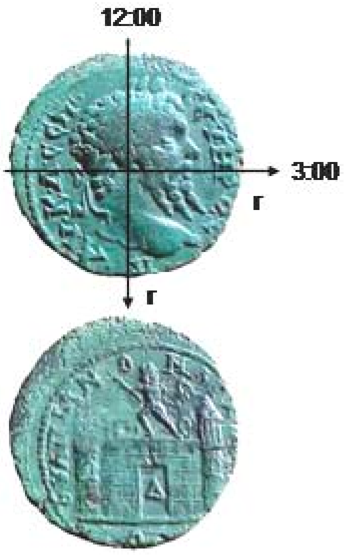


Fig. 1 SHH 2431 Axis Orientation

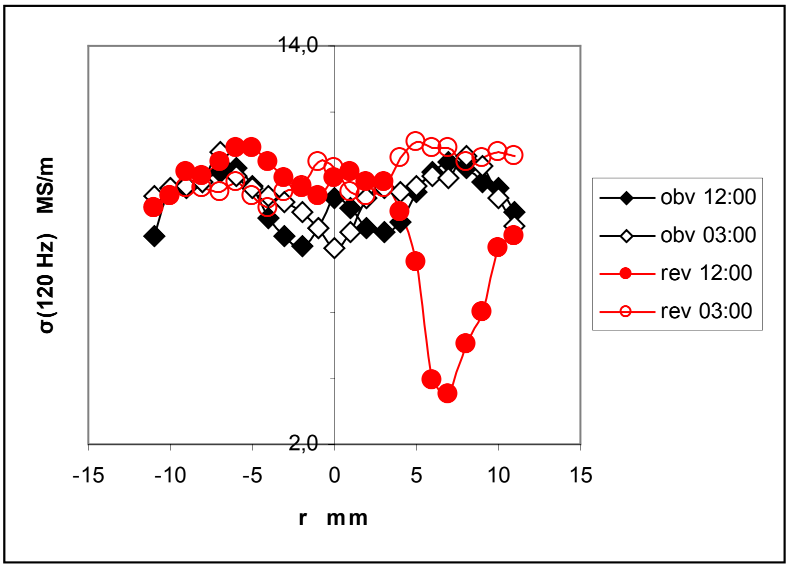


Fig. 2 SHH 2431 Anchialus Thracia Caracalla 193-211 AD

Fig. 2 shows a typical symmetrical distribution for a bronze coin with rather well defined trends. Electrical conductivity σ is low close to the outer diameter (first/last measurements are ≥4 mm from the outer diameter because of the size of the sensor), rising to a local maximum half-way to the centre, where it rises again.

The differences on the two axes in the centre give some indication of the accuracy of the measurement, particularly of the positioning of the sensor. The sharp drop of electrical conductivity at 12:00 o'clock / 7 mm on the reverse is typical of a crack or cavity near to the surface. A large scale has been selected for the σ-axis in Fig. 2 to accommodate this effect. All the following diagramms have the same scale relative to average σ so that the variations are directly comparable.

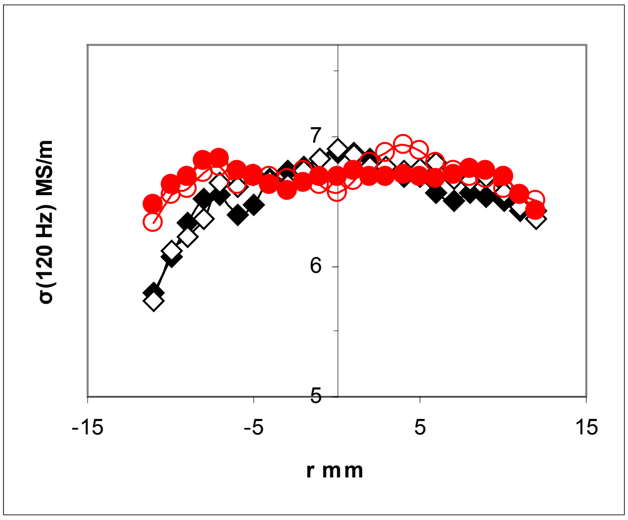


Fig. 3 SHH 2280 Amisus Pontus 120-63 BC

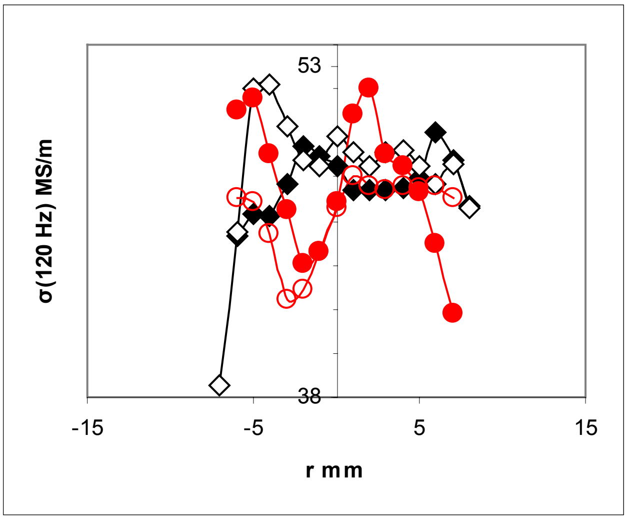


Fig. 4 SHH 4170 Amisus Pontus 120-63 BC

The trends described earlier can also be identified for the coin of Mithradates VI in Fig. 3, however, they are much less pronounced, suggesting a more careful casting of the blank. The coin in Fig.4 is also from a Mithradates VI mint but shows considerably stronger variations. The composition from XRF-Measurements for the core material is assessed at 99.5 % Cu and traces of Sn (0.1 %), Pb (0.2 %), and Fe (0.2 %). The strong variation of σ is probably due to the high sensitivity of high purity copper to small amounts of alloy additives [Kurt Dies, Kupfer und Kupferlegierungen in der Technik, Springer, Berlin, 1967, Abb. 7].

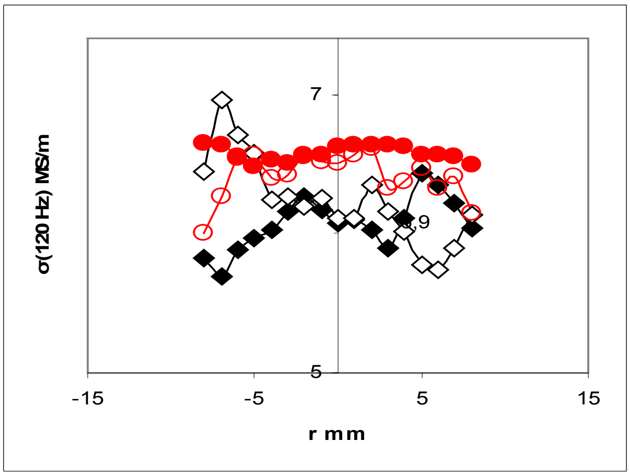


Fig. 5 SHH 1814 Canites Thrace Modern Forgery

To ensure that the observed effects are not caused by the patina, three coins of the same type from Thrace were compared. The data in Fig. 5 is from a modern forgery which was identified by the presence of several identical specimens in the numismatic market. Several copies of this forgery were precision cast in zinc-bronze, all with the same procedure. Fig. 6 shows the measurement results from the copy as cast with the initial zinc-bronze surface material. A second copy was artificially patinated to look identical like the forgery and the data shown in Fig. 7. The similarity can be clearly seen. In fact it can be concluded that the forgery was manufactured by a similar precision cast procedure. The σ-variations are obviously due to the cooling rate of the casting.

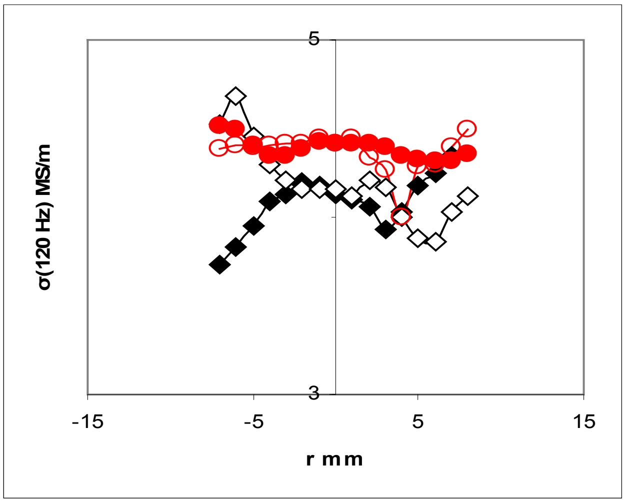


Fig. 6 SHH c4072 Canites Copy as Cast

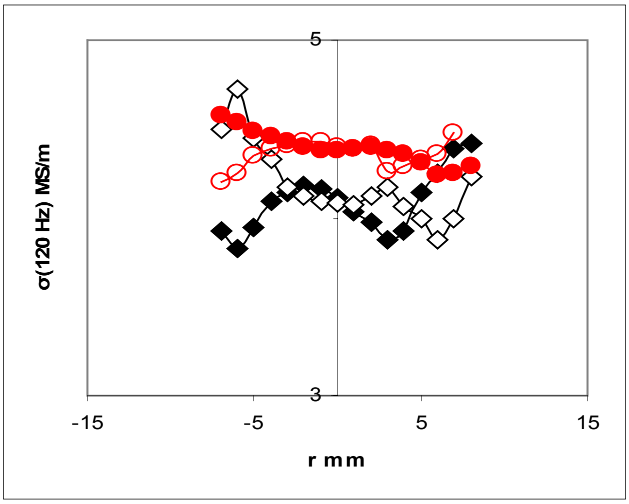


Fig. 7 SHH c4061 Canites Copy Artificial Patina

To check that the variations are not an artefact of the measuring device and method, a reference specimen from an industrially produced cylindrical bar of CuSn8 bronze was also measured. The results in Fig. 8 show clearly the uniformity of the material with a slight symmetric variation caused by the special manufacturing process.

Summarizing the results of the investigation it can be concluded that the cooling rate of the blank casting generates a more or less symmetric variation of metal composition along the diameter which is responsible for the corresponding distribution of the electrical conductivity of the coin.

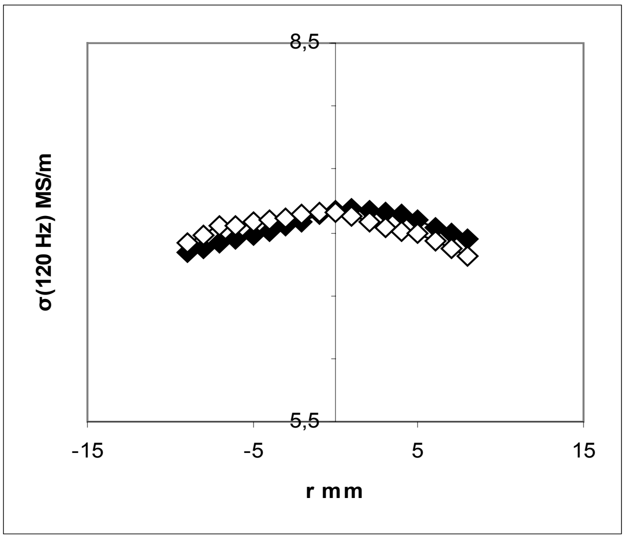


Fig. 8 Reference Specimen CuSn8

Coin Composition - Blank Casting Effects 4.8.2012

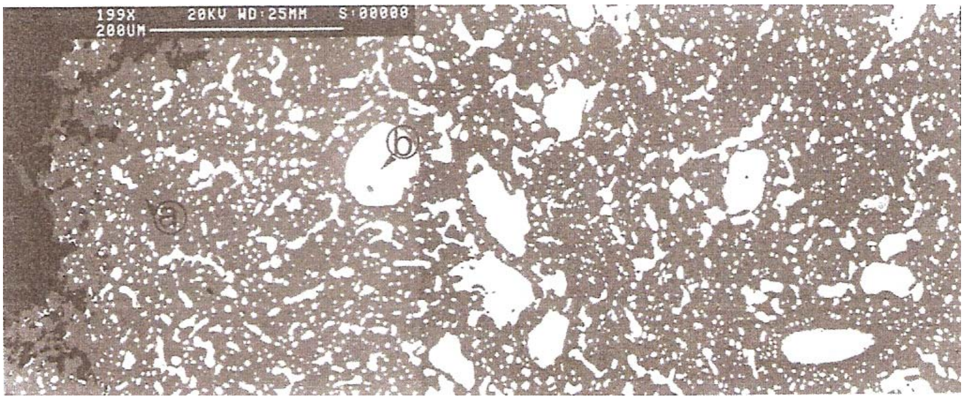
Hall. E. T. 1961
Surface Enrichment of Buried Metals
Archaeometry, 4, 1961. p. 62-67

The composition of the outside of the blank, which cools first, may be different from that of the centre. It may be significant that the enrichment effect some times seems to be more pronounced on one side of the coin than the other. This could be brought about by the metal being poured on to a relatively cold surface, which would make that side of the blank solidify first.

Ingo G. M., L.-I. Manfredi, G. Bultrini, E. Lo Piccolo 1997
Quantitative Analysis of Copper-Tin Bronzes by Means of Glow Discharge Optical Emission Spectrometry
Archeomatry, 39.1, 1997, p. 59-70

Analysis of bronze coins using Inductively Coupled Plasma Atomization (ICPAAS), X-Ray Fluorescence Spectrometry (XRF), and Glow Discharge Optical Emission Spectrometry (GDOES).

The Scanning Back-Scattered Electron (SEM) image of a cross-section of a coin shows higher levels of Pb segregations away from the surface. The authors explain this by the cooling rate of the blank casting. At high cooling rates solidification is so fast that lead is finely and evenly dispersed throughout the matrix. As the cooling rate is reduced lead is redistributed in the bulk material.



SEM of a coin cross-section showing the distribution of lead that forms dispersed islands (white) that are most prevelant in the centre of the coin,
whereas near the exetrnal surface (left) less lead is present than in the inner part of the coin

Hughes, M. J., J. P. Northover, B. E. P. Staniasek 1982 virtual
Problems in the Analysis of Leaded Bronze Alloys in Ancient Artefacts
Oxford Journal of Arcaeology, Vol. 1, No. 3, 1982, p. 359-363

Metallographic and Electron Probe Micro-Analysis (EPMA) of the cross section of a bronze sword show considerable variation of Pb-content. This is attributed to the cooling rate of the casting. At high cooling rates freezing is so fast that Pb is trapped as a fine dispersion throughout the solid. At slow cooling rates there is time for the bulk of Pb to be rejected from the solid ahead of the freezing front and accumulate at the centre of the casting. The extreme segregation of the investigated specimen contained pools of lead up to 250 µm.