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Technological Characteristics in Manufacturing of Cast Coins

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***Abstract**:*

For many years the investigation of silver numismatic material only involved the classification of coins by their historical and cultural origins. The investigation of the chemical composition and manufacturing technology of coin material has long been associated with several difficulties.

This article is dedicated to the determination of the characteristic features of the manufacturing of cast coins of the Samanid dynasty discovered within the territory of Volga Bolgaria.

The studies were conducted with the use of scanning electron microscopy and allowed to investigate the laminar chemical composition and structure of the transverse fractures of the coin material.

As a result, a non-typical structural lamination was discovered, allowing to distinguish 3 coins out of the total number of samples with a laminar structure. Materials of the article can be used by experts in the field of material science during the investigation of metal archaeological findings.

Keywords: *Silver-Containing Coins, Casting, Structure, Scanning Electron Microscopy, 10th Century, Samanids, Volga Bolgaria, Semenovskoe Settlement, Bilyar Settlement.*

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1. Introduction

An important place in the complex studies of Volga Bolgar settlement belongs to the issue of historical, cultural, technological and territorial origin of non-ferrous and noble metal archaeological findings (The Great Bolgar, 2015; Muslimov, 1996). As a historical and cultural object, coins represent an indicator of wide trade and economic relations of Volga Bolgaria with neighboring and remote regions.

A study of coin manufacturing features and a historical interpretation of the artifacts will allow to determine the characteristics of the elemental composition depending on their origin and circulation period, as well as their distribution across Volga Bolgaria representing a large medieval trade and cultural centre (Valeev, 1995; Fedorov-Davydov, 1996).

Coins were discovered in its territory during excavations conducted in Semenovskoe and Izmerskoe villages in the Republic of Tatarstan (the Russian Federation). Izmenrskoe village is located on the confluence of the two largest rivers of Eastern Europe – the Volga and the Kama (Kazakov, 2001; 2002; Archaeological Map of the Tatar ASSR, 1986; Gaynullin *et al.*, 2012).

One of the most thoroughly studied settlements with numerous archaeological findings included in the system of trade and craft centres is Semenovskoe I village. It is located on one of the numerous islands in the Kama Mouth which formed because of the establishment of Kuibyshev reservoir (Begovatov *et al.*, 2013a).

The island is located on the left bank of the flooded Krasnaya river, right tributary of the Volga. Numerous artifacts dated 10th century have been discovered in the territory of this archaeological site during many years: Cufic dirhams, beads, silver and bronze twisted bracelets, amber, silver ingots; ceramic, bronze and iron articles (Begovatov *et al.*, 2013b). The Cufic coins of Semenovskoe I village correspond to a wide range of reigning Samanid emirs from Ismail ibn Ahmad (892–907) to Nuh ibn Mansur (976–997) (Begovatov *et al.*, 2013b).

A preliminary study of six coins from Semenovskoe I village (Khramchenkova *et al.*, 2015; Begovatov *et al.*, 2013a) conducted with the use of scanning electron microscopy allowed to distinguish a single coin characterized by a cast structure with 3 diffusion bonded layers. The presence of non-deformed multidirectional crystals of various sizes in its layers indicates an unusual coin blank manufacturing technique – a three-stage filling technology of sheet manufacturing (Khramchenkova *et al.*, 2015). The coin was minted in Ash-Shash during the reign of emir Nasr bin Akhmad in 942 (330 A.H.).

This technology is rather peculiar because it requires profound knowledge of the nature of the substance and its behavior in various media and physical states.

2. Materials and Methods

The work contains the results of studies conducted with the use of optical and electron microscopy obtained for 3 fragments of coins dating back to various time periods. Fragments of the following material were selected as study objects:

- coin No.51 minted in Ash-Shash during the rule of Caliph Muttaqi Nasr bin Ahmed in 942 (330 A.H.) (Bosworth, 1996; Levin, 2010) discovered during excavations at Semenovskoe I village;
- an imprint of Nasr bin Ahmed coin No.57 dated 942 (301-331 A.H.) (Bosworth, 1996; Levin, 2010) (Izmerskoe village);
- coin No.124 issued in Samarkand during the rule of Mansur bin Nukh in 973 (363 A.H.) (Bosworth, 1996; Levin, 2010) discovered during excavations at Semenovskoe I village.

The studies of coin fractures (Khramchenkova *et al.*, 2016) were conducted using the optic and electron microscopy technique with Axio Observer Z1, Axio Imager.Z2m and AURIGA CrossBeam equipment and Inca X-Max energy-dispersine spectrometer at KNRTU-KAI (Kazan).

The preparation technique was as follows:

- the sample was secured on an aluminium holder using electrically conductive carbon adhesive tape;
- the secured sample was placed in the chamber of an electron microscope;
- probing was performed on a selected area of the sample surface.

Electron-microscopic analysis included the use of the VPSE method (detection of secondary electrons in low vacuum mode) for the visualization of general surface morphology during panoramic photography, and for the performance of quantitative and qualitative microprobe analysis (20 kV, 800 pA).

Microprobe X-ray spectral analysis of the samples with the use of INCA X-Max energy-dispersive spectrometer (with 127 eV sensitivity) includes the determination of sample composition and the plotting of spectra and element distribution maps.
Photographs were taken with AxioObserver Z1 optical microscope for the visualization of composition determination areas.

3. Results and Discussion

Eleven coins of the Samanid dynasty were additionally studied to confirm the theory of the uniqueness of the three-layer coin manufacturing technique. Coin fragments like coin No.51 in terms of their structure were singled out from the general collection of samples, one of which is a copy of the Nasr bin Ahmed coin No.57

dated 942 (301-331 A.H.), and the other one is a virtually undamaged Mansur bin Nukh coin No.124 dated 973 (Samarkand, 363 A.H.).

- *Coin No.51* features a 30-35 μm thick incoherent superimposed outer layer. On the outside the layer consists of pure silver, whereas in the contact area between the inner and outer layers it contains 5.19 % of silver. The inner layer of the coin has a cubic granular structure and apart from silver contains approximately 4 % of copper and 2 % of lead. The granules are represented by thoroughly remolded conglomerates. The inner portion of the coin also features inclusions of a copper alloy composed of 87.5 % of copper and 12.5 % of silver (Khramchenkova *et al.*, 2015).

The coin has a three-layer structure. The diffusion bonding of the layers is strong. The thickness of the surface layer 1 reaches 60-70 μm, and that of the inner layer varies within a wide range of 80-90 to 280-300 μm, whereas the thickness of the surface layer 2 also varies within a broad range depending on the inner layer (Sharov, 2016). The inner layer of the coin has an evident coarse-grained cast structure with a grain size of 60-140 μm. The surface layers feature a porous and fine-grained structure with a grain size of 20-40 μm.

The cast nature of the coin is indicated by a high level of diffusion between the layers of the coin and their different structure. The outer layers of the coin evidently featured a high heat exchange rate, as they bear traces of gas micro porosity. The inner layer of the coin had a lower heat exchange rate, hence its homogeneous coarse-grained texture. The most probable manufacturing technique of these coins is cutting-out from a laminar cast sheet. The sheets were presumably manufactured in the following three stages:

1. A layer of high-quality molten silver was poured and cooled in a medium with a high temperature gradient.
2. Silver with a large content of copper and lead impurities was poured on top of the initial layer, and cooling proceeded much slower than at the first stage.
3. High-quality silver was poured on top of the non-solidified inner layer of the previous metal.

This explains the high non-uniformity of the inner and outer layers in terms of thickness.

- *Nasr bin Akhmed coin No.57 dated 301-331 (942)* composed of fine silver. Its silver content (according to the overall spectrum) amounts to 85.24 %, copper content – to 4.43 %, and lead content – to 0.95 %. Copper is dissolved in the central layer of the coin. Their chemical composition does not significantly differ from that of the inner layer – 88.71 % Ag in the inner layer, and 83.31 % Ag in the outer layer.

The inner layer of the coin features no clear traces of plastic deformation, and the coin was most probably crafted from a cast plate. It is also possible that the coin was manufactured using the pouring technique similarly to coin No.51.

Compared to the first coin, sample No.57 is a copy or imprint. It has a dendrite structure with a clearly defined direction of direction of dendrite formation, which indicates the highest temperature gradient. Presumably, the outer layer 3 was the basis on which the intermediate metal portion was poured. The cooling rate of the intermediate layer was extremely low, which contributed to the formation of dendrite structure.

The thickness of the outer layer 1 is 40-50 μm, the inner layer 2 – 50-55 μm, and the inner layer 3 – 55-65 μm. The approximate cross-sectional size of the outer layer grain is 20-30 μm. In general, despite the similarity of the manufacturing technologies of copy No.57 and coin No.51, their equivalence is disapproved by the mechanisms of their structural formation. It should also be noted that unlike coin No.51, copy No.57 was subjected to heavy etching.

- *Mansur bin Hukh coin No.124 (Samarkand) dated 363 (973)* made of fine silver. Its silver content (according to the total spectrum) amounts to 66.42 %, copper content – to 14.59 %, and lead content – to 1.80 %. The mechanical mixture of silver and copper in the central layer of the coin is homogeneous. The purity of the silver matrix in the coin reaches 90.91 %. As seen from Figure 8, the silver matrix contains rare impurities in the form of dissolved copper and Pb-Cu. However, one side of the coin is contaminated with a lead and copper compound, which is presumably accounted for by transfer from the minting plate.

Unlike the first coin, sample No.124 features a dendrite structure with a defined direction of dendrite formation, which indicates the highest temperature gradient. Presumably, the outer layer 3 was the basis on which the intermediate metal portion was poured. The cooling rate of the intermediate layer was extremely low, which contributed to the formation of dendrite structure. The approximate cross-sectional size of the visible dendrite formations is 20-30 μm. The growth direction of the crystals of outer layer 3 is perpendicular to the fraction plane. The cross-sectional size of outer layer grain is approximately 10-15 μm.

Thus, despite a general similarity of the manufacturing technology of copy No.57 and coin No.51, their equivalence is disapproved by the mechanisms of their structural formation. It should also be noted that unlike coin No.51, coin No.124 was subjected to heavy etching.

4. Conclusions

The conducted studies of coin fractures demonstrated that coins No.51 and No.124, as well as the imprint No.57 could have possibly been manufactured using similar techniques. Coin No.51, unlike the two other samples, features an equiaxial coarse-grained structure of the intermediate layer, which indicates a homogeneous variation of the temperature gradient, and that it was presumably manufactured in a non-stop mode, i.e. liquid metal was poured on the inner layer before the latter cooled down.

Coin No.124 and imprint No.57 were presumably manufactured by pouring on a slowly cooled (for instance, stone or clay) platform, and after crust formation the non-cooled metal of the intermediate layer was most probably poured over with the subsequent portion of metal. After cooling of the two layers, the cast sheet was removed from the platform and poured over with a portion of metal on the back surface.

Therefore, samples No.124 and No.57 feature a dendrite structure of the intermediate layer with a defined direction of crystals to the 1st side of the coin. Besides, coin No.51 was not subjected to heavy surface etching. The outer layers of coin No.124 and imprint No.57 are thoroughly etched and feature a porous structure. All the aforesaid facts suggest that this technology was not widely used, as only 3 of 15 studies coins of the Samanid dynasty have a laminar structure.

The structure of coin No.51 and imprint No.57 is significantly different and despite the year of manufacture and the proximity of the discovered artifacts it can be stated that both samples were crafted with the use of a similar process, but in totally different conditions. Coin No.124 and imprint No.57 feature a similar structure and were presumably crafted using a well-proven formulation. However, the periods of their manufacture are very much different, as coin No.124 was minted circa 973, and the imprint - in 942.

Thus, an extensive period between the minting of these coins and the variations in their structure suggest the establishment of a minting craft school. Further studies of coins dating back to the period of Samanid reign are required.

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