SCIENTIFIC CULTURE
www.sci-cult.com

SCIENTIFIC CULTURE, Vol. 6, No. 2, (2020), pp. 11-22
Open Access. Online & Print

DOI: 10.5281/zenodo.3724842

A SYSTEMATIC SCIENTIFIC ANALYSIS FOR THE DETECTION OF FORGED COPPER BASED COINS

Ziad Al-Saad & Mohammad Rababah

Faculty of Archaeology and Anthropology, Yarmouk University, P.O Box 566, Jordan

Received: 09/03 /2020
Accepted: 03/04/2020
Corresponding author: Ziad Al saad (zalsaad@gmail.com)

ABSTRACT

Ancient coins forging and counterfeiting have recently witnessed an alarming increase. This makes authentication of these coins and detection of fakes of paramount importance. Therefore, this research aims at proposing a systematic step by step scientific testing methodology that can be used by museums to check the authenticity of their own coin collections or coins brought to them from different sources. The proposed methodology is based on subjecting the coin to be tested for its authenticity to a series of sequential tests to determine its physical and chemical properties and manufacturing technology using non-destructive scientific techniques including optical microscopy and Energy-dispersive X-Ray Fluorescence. A coin can be declared as forgery if it fails to pass any of these tests. To test the efficacy of the proposed testing protocol, a collection of 23 presumably Byzantine copper-based coins were used. Twenty-one coins were proved to be forgeries at different stages of the testing process. Only two coins passed all the tests.

KEYWORDS: Byzantine Coins, Forgery, Authentic, Fake Detection, Scientific analysis, Chemical composition, Jordan.

1. INTRODUCTION

Ancient Coins are one of the great archaeological survivors due to their artistic and cultural values. Coins are an invaluable source of information on cultural practices, important individuals, and ancient international relations (Whitting, 1973; Hill, 1977; Grierson, 1982; Sear, 1987; Cooper, 1988).

Forgery of coins has existed for almost as long as the concept of coinage. Coins were first invented about 650 BC, on the eastern shore of the Aegean Sea. Since then, Ancient Counterfeiters and their counterfeit coinage appeared, and it has been with us ever since (Peters, 2002; Prokopov and Manov, 2005).

Authentication of coins has become an important issue due to the increase in the number of fake coins with a similar look to authentic ones. Due to the recent advances in replication technology, the detection of counterfeit coins becomes a real challenge for coins collectors and museums. Professional counterfeits have been especially produced with the intended purpose of fooling experienced coin collectors and specialized museum curators. These forgeries are a real problem as it is almost impossible to tell the difference between the copy and the real thing. Internal thefts in museums become easier. For example, around 400 original rare Greek coins from a museum collection in Jordan were recently replaced by professionally counterfeited coins and only accidently discovered (Omari, 2016). Furthermore, the authenticity of coins in the museum's collection can be doubtful as these coins may come from sources other than archaeological excavations such as donations, confiscation, and buying from private collectors.

Recent years have witnessed an enormous increase in the scale and quality of forged coins due to the advances in replication technologies. Therefore, accurate detection of counterfeit coins becomes highly important than ever. Many researches have been carried out on the detection of ancient coins forgeries and counterfeiting. However, most of these researches focused on gold and silver coins due to their high value and the relative ease of detecting forgeries (Fierascu, et al., 2017; Aydın, 2014; Rodrigues, et al., 2011; Masjedi, et al., 2013; Aydin, 2013). The case of copper coins is less straightforward when compared to silver and gold coins as these coins were mostly made by alloying copper with different proportions of tin, zinc and lead and sometimes arsenic from different geological sources. This makes their characterization and spotting their fakes more problematic and less accurate (Robbiola and Portier, 2006; Canovaro, et al, 2013). Some of the studies on detection of forgery of copper coins employed destructive analytical techniques, an approach that is totally unacceptable to museums (Mezzasalma, et al., 2009; Salem and Mohamed, 2019).

There is a lack of standard, reliable and easy to apply authentication methodology for copper-based coins. Therefore, this research aims to develop a systematic scientific testing protocol that can be easily adapted and applied by museums for the detection of copper coins faking. The developed approach combines physical and chemical methods combined in an integrated manner.

2. PROPOSED METHODOLOGY OF COINS AUTHENTICATION

The proposed methodology for testing the authenticity of coins is based on the integrated combination of a series of sequential scientific testing methods for the identification and determination of coin, stylistic, physical, chemical and technological properties. Testing starts with a visual examination of the coin under a Binocular Microscope. Surface qualities of the coin, including surface texture, text spacing, seams, markings, and edges are carefully examined. Comparison with the specific details of a similar authentic coin should show if there are mismatching or incongruities which may hint for a forgery. Stylistic analysis of the coin obverse and reverse should follow for a coin that passes the visual examination test. This includes a precise description of the coin design elements, including the portrait and images, as well as the mint date and other inscriptions with special attention to any possible modern alterations.

Stylistic analysis results should be compared with attributes of authentic coins of similar denomination and date. A coin can be declared a forgery if it fails to pass this test. A coin that passes this test can be subjected to a series of physical measurement tests including weight, density, diameter, and thickness. Physical parameters should be compared with the standard reference for that type of coin. A coin that fails to pass any of these tests can be classified as a forgery. A coin that passes all the tests will be then subjected to a manufacturing technology test. This includes checking for how the coin was made. Ancient coins were made by striking. Most modern counterfeits are made either by casting, electrotypes or Spark-Erosion. Fortunately, all these modern techniques leave evidences that can be easily detected (Kroh, 1990). Indications for casting include: soft or missing details, round, mushy boundaries where the devices and legends meet the coin's field, a seam around the edge where the two sides of the mould joined together, small pits into the coin's surface or small bumps rising up from it, both caused by air bubbles created during the casting process, slightly concave obverse and reverse and smaller diameter caused by shrinking of the molten metal as it cools, and the absence of flow lines or lustre from striking. Indications of an electrotype counterfeit include: edge seam in the form of a straight line, discoloration and/or indention from the solder on the edge of the coin where the two halves are joined, and over smooth surfaces. Indications of Spark-Erosion are smooth surfaces and lumpy devices. Determination of a coin die-axis and compare it with the die-axis of known authentic coins can be very useful as ancient coins were often consistent in their die-axis (PCGS, 2000; Dannreuther, 2004) Patina analysis can give important information of whether the patina is natural due to the corrosion process or artificially applied by a forger. The microscopic examination of patina uniformity, colour and thickness can give a strong indication for natural or artificial patina. The cracked thick patina on coins is a good sign of authenticity (Garbassi & Mello, 1984). A coin that passes manufacturing technology test will be qualified for the final stage of testing; chemical composition analysis. The chemical composition of ancient coins can assist the discrimination between genuine and forged coins. For determination of the chemical composition of ancient coins only non-destructive analytical techniques are considered as permanent damage caused by sampling is not allowed in the case of valuable ancient coins. There is a wide range of non-destructive analytical techniques that can be used for the compositional analysis of ancient coins. (Riederer, 1986; Craddock, 2009; Charalambous, 2015) This includes Neutron Activation Analysis (NAA), Proton Activation Analysis (PAA), X-ray fluorescence (XRF, both wave length-dispersive [WD] and energy-dispersive [ED]), Proton induced X-ray emission (PIXE) and Electron probe microanalysis (EPMA) These analytical methods have both advantages and disadvantages and each method has certain detection limits along with some limitations. Most of the techniques are recognized as surface methods for the chemical analysis of coins since only a surface layer of limited depth (from a few micrometres up to a few tens of micrometres) is analysed.

Proper interpretation of the chemical composition of a coin, in terms of its major, minor and trace elements, can lead to important information regarding its manufacturing technology, date, geographical source of metals used in its making and minting place. This information, in addition to the comparative analysis with the chemical composition of similar genuine coins, can be conclusive for the determination of the coin authenticity.

A coin that successfully passes all the previously mentioned tests is most probably authentic. However, it is strongly recommended to consider further testing using may be by more precise and advanced techniques before the coin authenticity is finally established. It should be emphasized that the proposed testing protocol is meant to be used for detection of forgeries rather than proving authenticity of coins.

3. SAMPLES AND METHODS

3.1. Samples

In order to test the efficacy of the proposed testing protocol, 23 presumably Byzantine copper coins (figure 1) that were purchased from private collectors by the Numismatics Museum of the Jordan Ahli Bank were used. The coins minting dates span 111 years under the rule of seven emperors beginning from Anastasios I (491 A.D) until the emperor Phocas (610 A.D). The coins were minted at different minting canters. Table 1 provides some details about the coins used in the study.

Table 1: Some Details of the Coins Used in the Study

Emperor Name	Date	Sample No
Anastasios I	491-518 AD	1-2-3
Justin I	518-527 AD	4-5-6-7
Justinian I	527-565 AD	8-9-10-11-12
Justin II	565-578 AD	13-14-15-16
Tiberius II	578-582 AD	17-18-19
Maurice Tiberius	582-602 AD	20-21
Phocas	602-610 AD	22-23

Figure 1. The Coins Tested in this Study

3.2. *Testing Methods*

For easy referencing and implementation of the testing protocols, tests are sequentially numbered as follows:

Test no. 1: Stylistic Analysis

Stylistic analysis of the coins was done by examining the coin under Optical Microscope (Leica DM2500) and by recording full-colour, digital enlarged images of the obverse and reverse of each coin. Transcription of the legend and the description of the writing form in addition to a precise description of the images and portraits for each coin were done. Coins attribution and classification of the examined coins were done by comparing with published similar coins and checking the images against a repository of Byzantine coins (Online Catalogue of Byzantine Coins, 1998).

Test no. 2: Physical Analysis

2.1 Weight

For the measurement of the coins weight, an analytical balance (PRECISSA 310c) was used. The sensitivity of the balance is 0.1 mg.

2.2 Diameter

A calliper was used to measure the diameters of the coins. The minimum scale of the calliper rule is 1 mm. The calliper jaws were slided to the closed position and calibrated to zero (usually by pressing a "set" or "zero" button.) Then jaws were slowly slided open until they are touching the edges of the coin across from each other. The measured coin was snug between the jaws (but not too tight) and the result was read.

2.3 The Specific Gravity (SG)

The SG of the samples can be calculated by applying the following equation: “SG = mass/volume”

Because the samples were of small sizes, calculating the precise volume was extremely hard. SG for the samples was calculated according to the following procedure:

1- Filling container with 100 ml of distilled water.

2- Measuring the weight of the container filled with water.

3- Immersing the piece inside the container and measuring the total weight of the container, the piece, and the water.

4- The difference between the weight taken in step 3 and in step 2 is equal to the coin's volume because the weight unit (1 mg for instance) of distilled water equals one unit of volume (1 ml for instance). SG will be the weight divided by the volume = g/ml^3.

Test no. 3: Manufacturing Method

The coins surfaces were examined under an Optical Microscope (Leica DM2500). The coins were inspected for signs of manufacturing technique including bubbles, pimples, seams, pitting, discoloration and file marks on the edges.

Test no. 4: Chemical Composition

For the removal of surface encrustations and corrosion from the coins surfaces, laser ablation technique was used. Laser with pulse durations shorter than100µs was employed to eject corroded particles from the surface. Energy-dispersive X-Ray Fluorescence spectrometer (EDXRF) was used for the determination of the elemental compositions of the coins. For that purpose, Malven Pananalytical

Epislon 4 fitted with state-of-the-art elemental screening software was employed. It performs non-destructive quantitative analysis of elements from carbon (C) fluorine to americium (Am), in concentrations from 100% down to sub-ppm levels With simultaneous multi-element capacity.. Excitation of X-rays was accomplished at a fixed angle of 45" with respect to the sample and with an air-cooled side window X-ray tube (Si-Pin detector with 180 eV of resolution at MnKα ,and aRh-anode MnKa) with a rhodium target that can be operated at a maximum voltage of 50 kV and a maximum current of 0.35 mA. Two exposures in the order of 100 to 200 seconds were applied. Certified alloy standards disks were used for calibration and correction.

4. RESULTS AND DISCUSSION

4.1 *Stylistic Analysis*

Table (2) presents the results of the visual and stylistic analysis of the coins. The content of each coin was analysed to determine the name of the Byzantine Emperor, date of minting and minting place. The inscriptions were deciphered and the images and portraits appear on the obverse and reverse of the coin were fully described and analysed. The stylistic analysis results were compared with reference repository of authentic Byzantine coins and with attributes of similar published coins. (Sutherland, 1955 ; Grierson, 1982 ; Online Catalogue of Byzantine Coins, 1998). The comparative analysis proves that all the coins except 6 (No. 4, 5, 6, 8, 10, 14 and 23) have their devices (Inscriptions and images) and fields coincide with the corresponding authentic coins. This means that these coins pass this test and are qualified for the next round of testing. Coins No. 4, 5, 6, 8, 10, and 23 have some missing inscriptions. Since this may have been caused by circulation wear, it was decided that stylistic analyses alone were not conclusive to judge the coins authenticity and further testing was required.

Table 2: Results of analysis of writings and inscriptions on the coin surface test

No	Emperor Name	Date	Mint place	Category of Coin	Obverse	Reverse
1	Anastasios I	498-518	Constantinople	Folis	Diademed, draped and cuirassed bust right, DNANASTA SIVSPPAVC	C: M, BV: cross, L; R: stars, EX: CON
2	Anastasios I	498-518	Constantinople	Folis	Diademed, draped and cuirassed bust right, DNANASTA SIVSPPAVC	C: M, BV: cross, L; R: stars, ND: A EX: CON
3	Anastasios I	498-518	Constantinople	Folis	Diademed, draped and cuirassed bust right, DNANASTA SIVSPPAVC	C : M, BV :cross, L ; R :stars, ND: Γ , EX :CON
4	Justin I	518-527	Constantinople	Folis	Diademed, draped, and cuirassed bust right, D N IVSTI - [N]VS PP AVC	C : M, BV :cross, L ; R :stars, ND:B, EX :CON
5	Justin I	518-527	Constantinople	Folis	Diademed, draped and cuirassed bust right, D N IVSTI - [N]VS PP AVC	C: M, BV: cross, L: star, R: cross, ND: A, EX: CON.
6	Justin I	518-527	Antioch	Folis	Diademed, draped, and cuirassed bust right, D N IVSTI - [N]VS PP AVC	C : M, BV :cross, L : star, R :crescent, ND:Γ, EX :ANTX
7	Justin I	518-527	Constantinople	10 Nummi	Diademed, draped, and cuirassed bust right, D N IVSTI- NVS P P AVG	C : I , BV :cross, L ; R :stars, EX :CON
8	Justinian I	527-538	Constantinople	Folis	Diademed, draped, and cuirassed bust right, D N IVSTINI-ANVS PP AVG	C : M, BV ; R :cross, L : star, ND: G, EX : CO[N]
9	Justinian I	539	Antioch	Folis	Diademed, draped, and cuirassed bust right, D N IVSTINI-ANVS PP AVG	C : M, BV :cross, L ; R :stars, ND:A, EX : ΘΥΠΟΛς
10	Justinian I	527-538	Carthage	Half Folis	Diademed, draped, and cuirassed bust right, D N IVSTINI-ANVS PP AVG	C: K, BV; ND: star, L: cross, R: [...]
11	Justinian I	527-538	Antioch	5 Nummi	Diademed, draped and cuirassed bust right, DN IVSTINI- ANVSPP AVC	C : Є, R :B
12	Justinian I	527-538	Constantinople	5 Nummi	Diademed, draped, and cuirassed bust right, D N IVSTINI-ANVS PP AVG	C : E, R :Γ
13	justin II	565-578	Constantinople	Folis	L: Justin II, holding in right hand globus cruciger andEmpress, R: Sophia holding cruciform sceptre in right hand across right shoulder, D N IVSTI - NVS PP AVG	C : M, BV :cross, L :ANNO, R : III, ND: G, EX : CON
14	Justin II	571	Constantinople	Folis	L: Justin, R: Sophia, seated facing on double-throne, both nimbate, Justin holding globus cruciger, Sophia holding cruciform scepter, ONIVSTI NV[SPIVI]	C : M, BV :cross, L :ANNO, R : III, ND: G, EX : CON
15	Justin II	566	Constantinople	Half Folis	Justin on l., and Sophia on r., seated facing on double throne, both nimbate; he holds gl. cr., she holds cruciform sceptre; rarely with cross between thier heads , DN IVSTINVS PP AVG	C : K, BV :cross L :ANNO, R :I, ND: B"
16	Justin II	565-578	Antioch	Folis	L: Justin, R: Sophia, seated facing on double-throne, both nimbate, Justin holding globus cruciger, Sophia holding cruciform scepter, ONIVSTI NVSPIAC	C : M, BV :cross, L : ANNO, R : Xand star, ND: Γ, EX : THEUP
17	Tiberius II	580	Nicomedia	Folis	Crowned bust facing, wearing consular robes, mappa in right hand, eagle-tipped scepter in left, d m TIb CONS_TANT P P AVG	C : M, BV :cross L : ANNO, R : VI, EX : NIKOA

18	Tiberius II	582-574	Constantinople	Half Folis	crowned and cuirassed bust facing, holding cross on globe and shield, DM TIB CONTANT PP AV	C : XX, BV :cross, EX :CON
19	Tiberius II	580	Antioch	Folis	Bust facing, wearing crown with cross, and consular robes; in right hand, mappa: in left, eagle-tipped sceptre ,dm TIS CONSTANT PP AVG	C : m, BV :ctoss, L : ANNO, R :U, EX : THEUP
20	Maurice Tiberius	588	Constantinople	Folis	Helmeted, cuirassed bust facing, shield in left hand, globus cruciger in right, d N MAV TIBER P P AVG	C : M, BV :cross L :ANNO, R : uI | II, ND: E EX : CON
21	Maurice Tiberius	594	Antioch	Half Folis	Facing bust, crowned with trefoil ornament, in consular robes, with mappa and eagle-tipped scepter, d N MAur C N P AuT	C : K, BV :cross L :ANNO, R : IIX, ND: R
22	Phocas	603	Constantinople	Folis	Phocas (on left) and Leontia (on right) standing facing; the emperor, wearing crown with pendilia, holds globus crucigeR : the empress, nimbate, holds cruciform scepter, DMFOCAEP-PAVG	C : m, BV :cross, L : ANNO, R :I, EX : CON
23	Phocas	603	Nicomedia	Half Folis	crowned, mantled bust facing, holding mappa and cross, DN FOCAS PERP AVG	C : XX, BV :cross, R :II II EX : NIKO[A] or NIKO[B]

4.2 *Physical Analysis*

4.2.1 Weight and Diameter

Table 3 presents the results of the weight, diameter and specific gravity of the studied coins. The obtained results were compared with reported weights and diameters ranges of authentic Byzantine copper coins published in the literature (Grierson, 1982 ; Online Catalogue of Byzantine Coins, 1998).

Table 3. Weight, Diameter and Specific Gravity of the Coins

No	Categories of coins	Weight (g)	Diameter (cm)	Specific Gravity (g/ml3)
1.	Folis	17.03	2.7-3.0	9. 40
2.	Folis	21.04	2.90-3.35	9.37
3.	Folis	18.58	2.90-3.07	8.71
4.	Folis	17.60	2.91-3.11	8.90
5.	Folis	18.33	2.91-3.11	9.12
6.	Folis	17.53	3.05-3.42	9.14
7.	10 Nummi	2.68	1.45-1.60	8.7
8.	Folis	15.68	2.70-3.22	8.38
9.	Folis	18.45	4.01- 4.10	8.39
10.	Half Folis	8.42	2.00- 2.40	8.74
11.	5 Nummi	2.35	1.45-1.55	8.01
12.	5 Nummi	1.59	1.40-1.67	8.70
13.	Folis	14.49	2.72-3.10	8.96
14.	Folis	14.96	2.9-3.37	8.94
15.	Half Folis	8.41	2.30	9.94
16.	Folis	7.75	2.05-2.35	8.9
17.	Folis	11.79	2.62-2.9	9.19
18.	Half Folis	6.85	2.36-2.5	9.16
19.	Folis	11.58	2.75-2.92	9.21
20.	Folis	11.52	3.10-3.25	8.72
21.	Half Folis	4.64	2.10-2.50	8.79
22.	Folis	12.20	3.00-3.42	9.13
23.	Half Folis	5.29	1.92-2.22	9.20

Based on the results of this test coins can be classified into three groups:

Group 1 includes coins No. 1, 3, 4, 5, 6, 10, 11, 12, 13, 14, 15, 18, 19,20, 22, and 23. The weight and diameter of these coins conform to the weight and diameter averages of the Byzantine authentic respective denomination. These coins can be labelled as passing these two tests and are qualified for the next round of testing.

Group 2 includes coins No. 17 and 21. These coins have a slight variation in their diameter and weight in comparison with the authentic respective Byzantine denomination (Coin 17 diameter lower by 1.8% and coin 21 weight lower by 7.2%). Taking into consideration the decrease in diameter and weight of ancient coins attributed to circulation wear and corrosion, such a slight decrease is expected, and consequently, these two coins could not have been declared as forgeries and further testing was decided required before a final conclusion is reached.

Group 3 includes coins No 2, 7, 9, and 16. The coins of this group have significant differences between their weight and diameter and the average weight and diameter values of the respective Byzantine denomination. The weight of coin No. 2 exceeds 5.2% of the average weight of the Byzantine 40 nummi. There was no published example of weight increase of this value. The weight of coin No.7 is less by 40% and its diameter is less by 20% in comparison with the weight and diameter of Byzantine 20 nummi. There is no reported weight and diameter deviation of these values which can be considered a strong indicating that this coin is a forgery. The weight of coin No. 16 is less by 22.5% and its diameter is less by 24%. These significant discrepancies between the measured values and those of reference denominations strongly indicate that these coins can be declared as forgeries with no need for further testing.

4.2.2 Specific Gravity

Specific gravity measurements shown in table 3 appear to be of no value for the estimation of the quantitative composition of ancient copper-based coins. Specific gravity can only be applied with better accuracy to binary alloys. Ancient coins made of copper-based alloys like the sample used in this study were usually made of various percentages of ternary and sometimes quaternary alloys. Chemical analyses show that the coins used in this study are not an exception. They were made of various percentages of copper alloyed with various percentages of tin, zinc, and lead. In addition, corrosion, which is most likely in ancient copper-based coins, lowers the specific gravities. This makes specific gravity values difficult to be correlated with the coin chemical composition and therefore difficult to be utilized as an authentication indicator of copper-based coins.

4.3 Manufacturing Technology

The results of the microscopic investigation of the coins for evidence of their manufacturing technology are reported in Table 4.

Table 4. Manufacturing Technology Examination

No	Evidence detected	Manufacturing Technology
1	File marks on the edge, images and letters are not clear, pits caused by air bubbles	Casting
2	Concave obverse and reverse, a seam around the edge, letters and images are not sharp	Casting
3	Crystallized minerals on the surface, no pits or pumps, no file marks or seam on edge.	Striking
4	Double striking, , no pits or pumps, no file marks or seam on edge	Striking
5	Uneven surface, no pits or pumps and no seam on the edge	Striking
6	crystallized minerals on the surface, no pits or pumps, no file marks or seam on edge	Striking
7	Oval shape, file marks on edge, pits and pumps caused by air bubbles.	Casting
8	Double striking, , no pits or pumps, no file marks or seam on edge	Striking
9	Crystallized minerals on the surface, no pits or pumps, no file marks or seam on edge	Striking
10	Double striking, , no pits or pumps, no file marks or seam on edge	Striking
11	A seam around the edge, some missing letters, pits caused by air bubbles.	Casting
12	Crystallized minerals on the surface, no pits or pumps, no file marks or seam on edge	Striking
13	Crystallized minerals on the surface, no pits or pumps, no file marks or seam on edge	Striking
14	Crystallized minerals on the surface, no pits or pumps, no file marks or seam on edge	Striking
15	File marks on the edge, images and letters are not clear, pits caused by air bubbles	Casting
16	Crystallized minerals on the surface, no pits or pumps, no file marks or seam on edge	Striking
17	No pits or pumps, no file marks or seam on edge, no sharp edges of letters	Striking
18	Crystallized minerals on the surface, no pits or pumps, no file marks or seam on edge	Striking
19	Crystallized minerals on the surface, no pits or pumps, no file marks or seam on edge	Striking
20	Crystallized minerals on the surface, no pits or pumps, no file marks or seam on edge	Striking
21	No pits or pumps, no file marks or seam on edge, no sharp edges of letters	Striking
22	No pits or pumps, no file marks or seam on edge, no sharp edges of letters	Striking
23	No pits or pumps, no file marks or seam on edge, no sharp edges of letters	Striking

Coins can be classified into two groups based on their manufacturing technologies:

- Group 1: Coins No. 1, 2, 7, 11, and 15 show evidences that they were produced by lost wax casting. The common characteristics of these coins including grainy or pitted surfaces, with some depressions caused by trapped gas bubbles as depicted in figure 2, lightly concave obverse and reverse, smaller diameter caused by molten metal shrinking, and a seam around the edge where the two sides of the mould joined together. These coins were made by making an impression of a genuine coin creating a mould, and pouring molten metal into the cavity. Coin casting was a technique often associated with forgers, who would cast moulds of existing coins as an easy way of producing counterfeit coins without any major investment. Therefore, the coins of this group can be declared forgeries.

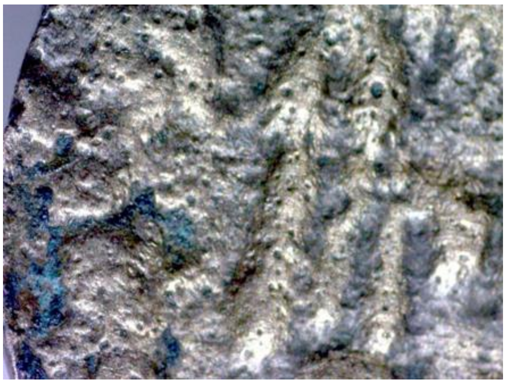

Figure 2. Magnified Image (x25) of Coin no. 2 , as an example of coins made by casting

Groups 2 includes coins No. 3, 4, 5, 6, 8, 10, 12, 13, 14, 16, 17, 18, 19, 20, 21, 22, and 23. Microscopic investigations indicate that these coins were manufactured by striking techniques. Surface evidences that indicate that these coins were individually hammered between dies that were carved or engraved by hand include; crystallized minerals on the surface, low or almost no porosity because of the hammering effect which make the metal molecules firmly compacted, absence of marks of cutting tools on the edges, and the soft surface of the inscriptions without any sharp edges (figure 3). Although striking was the common technique used for the production of coins in ancient times including the Byzantine period, modern die struck fakes are common as well. The dies are carved, usually using modern tools or moulded in hard plastic, and flans are made and "coins" struck in an ancient manner. Therefore, these coins cannot be declared authentic based on this result. The elemental analysis of these coins is critical to show whether their chemical compositions conform to ancient technologies of metal production of the Byzantine period or not. Chemical compositional analyses are vital for distinguishing ancient authentic struck coins from modern struck fakes as will be shown in the next section.

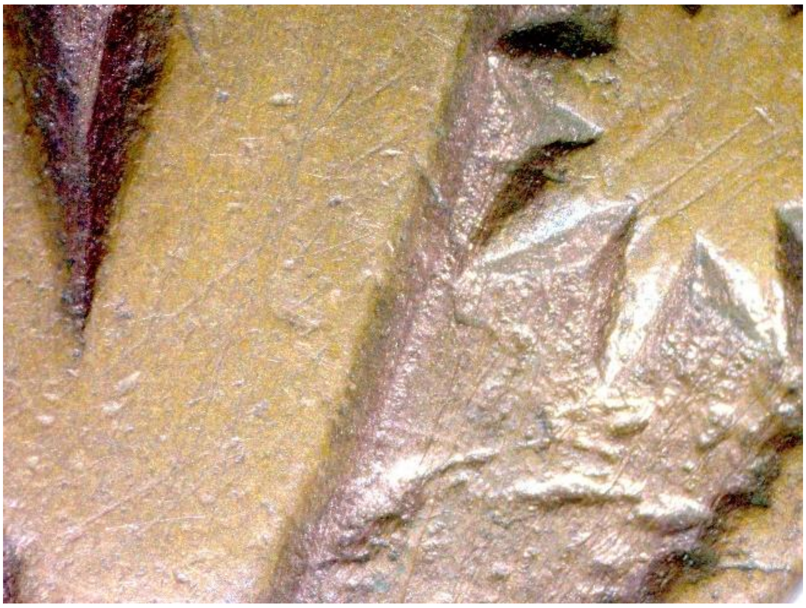

Figure 3: Magnified Image (x25) of Coin no. 6 As An Example of Coins Made by Striking

4.4 Chemical Composition Analysis

The percentages of the major, minor and trace elements forming the studied coins are presented in table 5.

It is quite clear that the coins were made of combination of wide variation of alloying elements that came from different sources, even in the case of coins produced by the same mint. The chemical composition of each coin is judged based on the nature and percentages of the major, minor and trace elements in comparison with the chemical compositions of reference authentic coins of the same mint. In addition the established knowledge of Byzantine metal technology is of high value for this judgement. Byzantine coinage is generally considered to have begun with the reign of Anastasios (491-518 AD) due to his monumental reform of the bronze coinage in 498 AD. Every Byzantine emperors minted their own coins, from either Constantinople, the capital, or in mints in major provinces such as Italy (Ravenna), Sicily (Syracuse), Anatolia (Antioch), and North Africa (Carthage and Alexandria) (Grierson, 1982 ; Sear, 1987).

Studies exist of the metal contents of Byzantine coinage of the fifth and sixth century from the full range of mints, namely Constantinople, Antioch, Nicomedia, and Carthage (King et al, 1992 ; Padfield, 1972). There is almost a consensus among scholars based on the chemical analysis of a large number of Byzantine copper coins from different mints that the copper coins minted in Constantinople and Antioch were essentially made of copper while coins minted of Pentanummia of Constantinople, Nicomedia and Carthage were made of bronze with an added lead of various percentages.

Table 5: Chemical Composition of the Coins

No	Category of Coin	Date	Mint place	Cu	Sn	Pb	Zn	Fe	As	Ag	Sb	Co	Ni
1	Folis	498-518	Constantinople	68.5	3.2	26.6	0.01	0.2	0.01	0.06	0.01	0.02	0.4
2	Folis	498-518	Constantinople	74.6	2.3	22.3	0.02	0.3	0.05	0	0.02	0.01	0.02
3	Folis	498-518	Constantinople	89.54	8.9	0.51	0.02	0.21	0.37	0.08	0.04	0.17	0.06
4	Folis	518-527	Constantinople	75.9	5.6	5.3	0.05	0.3	0.08	0.04	0.03	0.01	12.6
5	Folis	518-527	Constantinople	83.49	3.9	11.5	0.02	0.16	0.37	0.09	0.03	0.17	0.06
6	Folis	518-527	Antioch	83.78	2.6	12.6	0.03	0.17	0.28	0.09	0.03	0.16	0.05
7	10 Nummi	518-527	Constantinople	78.42	1.85	18.6	0.01	0.19	0.32	0.1	0.04	0.18	0.04
8	Folis	527-538	Constantinople	72.32	2.6	2.6	20.75	0.61	0.12	0.26	0.3	0.07	0.21
9	Folis	539	Antioch	64.26	2.1	2.3	29.6	0.72	0.1	0.28	0.34	0.06	0.26
10	Half Folis	527-538	Carthage	84.19	11.5	1.4	0.04	0.6	0.17	0.30	1.00	0.03	0.65
11	5 Nummi	527-538	Antioch	80.16	9.8	0.10	6.50	0.50	0.01	0.06	0.05	0.01	2.00
12	5 Nummi	527-538	Constantinople	86.96	9.30	0.80	0.03	0.64	0.14	0.32	1.42	0.02	0.27
13	Folis	565-578	Constantinople	90.45	8.55	0.5	0.20	0.07	0.06	0.14	0.2	0.1	0.08
14	Folis	571	Constantinople	91	2.7	3	2.6	0.08	0.06	0.13	0.17	0.1	0.07
15	Half Folis	566	Constantinople	67.2	8.7	22	0.3	0.07	0.08	0.14	0.15	0.08	0.09
16	Folis	565-578	Antioch	89.4	3.5	2.7	2.9	0.09	0.05	0.12	0.19	0.15	0.6
17	Folis	580	Nicomedia	93.23	5.1	0.6	0.05	0.06	0.08	0.3	0.16	0.12	0.07
18	Half Folis	582-574	Constantinople	82.81	2.6	13.6	0.06	0.08	0.09	0.32	0.15	0.13	0.04
19	Folis	580	Antioch	80.63	2.16	15.2	0.4	0.07	0.08	0.32	0.17	0.16	0.6
20	Folis	588	Constantinople	87.80	9.01	0.7	0.03	0.6	0.08	0.2	1.2	0.03	0.25
21	Half Folis	594	Antioch	86.91	6.65	3.92	0.02	0.58	0.07	0.212	1.21	0.04	0.23
22	Folis	603	Constantinople	84.12	1.81	12.3	0.03	0.6	0.6	0.31	0.06	0.02	0.06
23	Half Folis	603	Nicomedia	93.31	5.26	0.71	0.02	0.05	0.06	0.34	0.06	0.02	0.08

Judgment on the authenticity of the analysed coins is made based on the conformity of the chemical composition of the coins with the chemical composition of their respective authentic coins of the same mint and denomination.

The analysed coins were minted at four minting centres: Constantinople, Antioch, Nicomedia, and Carthage. For the purpose of comparative analysis coins of the same mint are treated together:

- Group 1: Coins minted at Constantinople: 15 coins (coins No. 1, 2, 3, 4, 5, 7, 8, 12, 13, 14, 15, 18, 20, 22)

The coins of this group are characterized by large variations in the percentages of their major, minor and trace elements indicating that these coins were made from different metal alloys composed of metals from different sources. Copper percentages range from as low as 67.2% to a maximum of 91%. Tin percentages vary from 1.8-12.3 while lead percentages vary from 0.5-26.6%%. Coin No. 8 has a zinc content of 20.75% indicating that this coin was made of brass which was quite unusual for Byzantine copper coins traditions. Although all coins in this group were, based on their inscriptions, minted by the same mint, the big variations in the percentages of the metal alloys used in their manufacturing strongly indicate that this very doubtful. Lead contents vary between 3-26.6%, a degree of variability which is difficult to be explained on a technical basis since it does not seem to be related to obvious changes over time or changes to mint practice. The significant differences in lead content are more resulted from genuine variability in alloy content. The compositional irregularity of the trace elements in these coins is a strong evidence that these coins were made from metals smelted from different geographical sources with different smelting efficiencies. Furthermore, the chemical compositions of the coins do not conform to Constantinople's pattern of copper coins by any means. Byzantine coins minted at Constantinople after Anastasias reform in 498 AD were made of almost pure copper. Studies proved that this tradition continued in the sixth and seventh century, a period when the analysed coined was presumably made (Padfield, 1972). There is no doubt that all the coins in this group can be labelled as forgeries with very high confidence.

- Group 2: Coins of Antioch (coins No. 6, 9, 11, 16, 19, 21)

The chemical compositions of these coins show similar irregularities in their chemical composition as in group 1. The coins were made of ternary alloys of Cu-Sn-Pb and in some cases quaternary alloys with significant percentages of zinc. Antioch followed the same minting policy as Constantinople for making copper coins from pure copper (King et al, 1992) which leads to the conclusion that these coins are forgeries. This conclusion is further supported by the presence of unusually high zinc contents in Byzantine coins. Zinc content of coin no. 9 is 29.6%. The presence of more than 28% of zinc in a copper alloy could have been only achieved in the 19th century. The method of brass production during the Byzantine time was the cementation method which could have yielded brass with a maximum zinc content of c. 28%. (Craddock , 1978).

- Group 3: Coins minted at Nicomedia (coins No. 17 and 23)

These two coins were made of low tin leaded bronze. The two coins have a similar chemical composition which indicates that they were made at the same mint using the same metal alloy. The chemical compositions of these two coins conform to the metal composition of coins made in Nicomedia in the sixth and seventh century AD. Studies have shown (Padfield, 1972, King et al, 1992) that Nicomedia was one of the Eastern Byzantine minting centres in addition to Pentanummia of Constantinople, and Carthage that struck coins made of bronze with various amounts of added lead. The lead content in these two coins is quite high but not extraordinary as such percentages or even higher were detected in Byzantine copper coins from different mints (Gierson, 1982). High percentages of lead imposed considerable technical constraints and difficulties for the striking process, which means that lead was not added for technical reasons. The most likely reasons for adding high percentages of lead are economic. Lead may have been used as a cheap diluent of the more expensive bronze in the time of economic difficulties. Based on these facts the coins in this group can be considered as passing the chemical composition test. However, final verdict on their authenticity requires further investigation.

- Group 4: A coin minted at Carthage (Coin No. 10)

This is the only coin in the collection that was presumably minted at the North African mint of Carthage. The coin contains 11.5% of tin which is unusually high for bronze used for coinage at this mint which was usually under 5%. This finding put serious doubt on the authenticity of this coin. The suspicion becomes almost certain when a comparison between the trace elements pattern is done. Copper-based coins minted at Carthage presents a rather consistent pattern of high zinc, low nickel, and high silver and moderate arsenic (Padfield, 1972) while the coin has low percentages of zinc, silver, and arsenic and high percentages of nickel and iron. The big discrepancy in the trace elements is another indicator that the coin is a forgery.

5. CONCLUSIONS

The results obtained in this study demonstrate that spotting the fakes and forgeries of ancient copper based coins can be easy and straightforward in some cases and difficult and complicated in other cases. It all depends on the method employed for imitating ancient coins and on the skills of the forgers. Crude forgeries can be easily detected using simple methods and tools such as stylistic investigation using a magnifying lens, or measurement of the diameter and weight of the coin using a calliper and a scale. Examples on this are coins No. 2, 7, 9, and 16 which can be declared as forgeries based on significant differences between these coins' weight and diameters and the weight and diameter of their respective authentic denominations. Another type of easily detectable non-professional method used by forgers to imitate ancient coins is casting. Casting usually leaves marks and signatures that can be easily spotted under the microscope such as a seam around the edge where the two sides of the mould join together, and pits and pumps caused by air bubbles. Five coins (Coins No. 1, 2, 7, 11, and 15) among the collection showed these signs under the microscope and therefore were classified as forgeries. The rest of the coins in the collection (17 out of 23 coins) respect the weight, diameter, and style and therefore passed the first series of tests. All these coins except two (coins No. 17, and 23) failed to pass the chemical composition test and therefore declared as forgeries. Chemical analyses show that these coins were made with metal alloys that do not conform to the metal production technology of the period and/or to the well-established compositional patterns of Byzantine copper coins of the various Eastern mints. Only two out of twenty-three coins passed all the tests conducted in this study. The final verdict on the authenticity of these two coins requires further investigation.

It should be emphasized at this point that the proposed systematic approach is highly effective for the detection of faked coins. Although passing all the proposed tests by a certain coin can be considered as a good sign of its authenticity rather than a final verdict. Further investigations should always be considered before the coin coming from unknown or suspicious sources is finally labelled as authentic. The proposed testing protocol can help in making forgery a very costly process for the forgers and almost impossible for forged coins to find their way into museums' collections.

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