A systematic procedure for the forensic examination of questioned coins with a face value of fifty New Taiwan Dollars

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ABSTRACT

Two NT$ coins with a face value of fifty dollars confiscated by local police were forensically examined. Dimensional, morphological, elemental and statistical analyses of genuine and questioned coins were carried out. The main instrument used was scanning electron microscope/energy dispersive X-ray analyzer (SEM/EDX).

The differences of color, weights, and dimensions between genuine and questioned coins were minor. Morphological analyses revealed that small details of stamped markings were blurred or absent on both questioned coins, but were clear and definite on genuine coins. In addition, there were visible concentric circular tool marks observed on one questioned coin. Tool marks produced by cutting procedures could also be observed on the lateral side of both questioned coins. There were no visible tool marks left on any genuine coins.

The major elements detected in the outer ring of both genuine and questioned coins were Cu and Ni. Statistical analyses indicated that compositional difference between questioned and genuine coins were significant. Thus questioned coins could be easily differentiated from genuine ones. Elements detected in the inner disc of genuine and questioned coins were (Cu, Al, and Ni), and (Cu and Zn), respectively. This significant difference in elemental composition of inner discs further differentiated questioned coins from genuine coins. Characteristic lead particles randomly distributed in a Cu-Zn alloy were detected in the inner discs of questioned coins. Based on these results, questioned coins were determined as counterfeit coins.

Keywords: Forensic science, Counterfeit coins, New Taiwan Dollars coins, Elemental analysis, Scanning electron microscopy/energy dispersive X-ray analysis (SEM/EDX)

Introduction

Since the advent of the new coin with a face value of fifty dollars (50 NT$), a compound coin composed of a brass-colored inner disc and a silver-colored outer ring, crime cases involving counterfeiting and use of false coins have drastically increased in Taiwan. Although the value of a 50 NT$ coin is less than that of most NT$ banknotes, the ease and low cost of counterfeiting a coin make 50 NT$ coins an alternative target for less skilled counterfeiters. In Taiwan, 50 NT$ coins are widely used in purchasing small goods through vending machines, outdoor markets, and small food stands. Nearly all kinds of ticket-selling machines accept coins as well. Coins are also used as change in all kinds of small goods trading. The prevalence of counterfeit coins affects more people than false banknotes do.

Counterfeit coins are usually produced by casting and show morphological details with less precision than those on genuine coins. The raw materials used for the production of counterfeit coins are similar to or different from those of genuine coins. Thus, the confirmation of counterfeit coins is best achieved by a comparative quantitative or semi-quantitative elemental analysis. A number of instrumental analysis methods are capable of quantitatively analyzing coins. However, most of them require the sacrifice of a detectable part of the coin. One exception is scanning electron microscopy/energy dispersive X-ray analysis (SEM/EDX) which is a widely used nondestructive elemental analysis method. [1–14] In addition, SEM/EDX can identify the morphological difference between questioned and genuine coins using secondary electron images. Furthermore, the X-ray mapping and backscattered electron image modes of SEM/EDX are powerful tools to display the two-dimensional distribution of analyzed elements.

In this work, definite results were achieved using
SEM/EDX and statistical analysis in a case concerning forensic analysis of questioned 50 NT$ coins confiscated by local police. Simultaneously acquired morphological and elemental characteristics were proven to be critical in the forensic examination of questioned coins.

### Experimental

#### Instruments and Materials

1. JSM-5410LV Scanning Electron Microscope (SEM), Jeol, Japan.
   - Accelerating voltage: 20KV.
   - Tilt of sample: 0˚.
   - Working distance: 15mm.
   - Images observed: Secondary electron and backscattered electron images.

2. LINK ISIS energy dispersive X-ray analyzer (EDX), Oxford, UK.
   - X-ray signals were collected from 0 to 20KeV, 10eV per channel.
   - Peak identification: manually and automatically.

5. Stereo microscope, SZ11, Olympus, Japan.
6. Coin samples: Eighteen genuine NT$ coins with different face values and two questioned 50 NT$ coins were collected from a local bank and confiscated evidence, respectively. Details of these samples are shown in Table 1.

#### Methods

1. Measurements of weight and dimension
   - The weight of each 50NT$ coin was measured to sub-milligram using an electronic balance. The mean and standard deviation of weights were calculated.
   - The diameter of each 50NT$ coin was measured twice employing a vernier caliper. The measured locations were specified by its clock face orientation: one from 3 to 9 o’clock and the other from 6 to 12 o’clock. The mean of these two measurements was regarded as the diameter of the coin. The mean and standard deviation of diameters were calculated.
   - Rim thickness of each 50NT$ coin was measured using a vernier caliper at six positions around the coin, which were: 2, 4, 6, 8, 10, and 12 o’clock. The mean was regarded as the rim thickness of the coin. The mean and standard deviation were calculated.

2. Observation of morphological details
   - Coin samples were observed using a stereomicroscope at low magnification. Concentric circular tool marks were discovered on both sides of a questioned coin that was labeled as sample F1. The other questioned coin was labeled as sample F2. The morphological details of F1, F2, and genuine coins were compared with each other and recorded using SEM.

3. Scanning electron microscopic/energy dispersive X-ray analysis
   - Three genuine 50 NT$ coins where one was made in 1997 and the others in 1998, questioned coins F1 and F2, and one coin each of obsolete editions of 1 NT$ coins and 5 NT$ coins were brushed and ultrasonically cleaned for 15 min in a detergent solution. The coins were then sequentially rinsed with distilled water, de-ionized water, and acetone.
   - Each cleaned coin was mounted on a SEM sample stub using double-sided carbon adhesive tape. The samples were then subjected to morphological observation and elemental analysis via scanning electron microscopy/energy dispersive X-ray analysis (SEM/EDX) without any coatings. The working distances and magnification powers were varied while conducting secondary image observation and photographing. A fixed working distance of 15mm and 200 times magnification were employed during energy dispersive X-ray analysis with a live time of 300 seconds. Three smooth areas each of the surface of the 5 NT$ coin, 1 NT$ coin, and the outer ring and inner disc of every 50 NT$ coin were randomly selected for X-ray analysis. Backscattered electron image and X-ray mapping modes were employed when required to obtain the data concerning two-dimensional distribution of detected elements.

### Results and Discussion

#### Measurements of weights and dimensions

The weights and dimensions results are shown in Table 2. The mean weight of sixteen genuine coins was
9.975g with a standard deviation of 0.073g and a coefficient of variation of 0.7%. The weight of F1 and F2 questioned coins was 9.915g and 10.227g, respectively. The differences of weight between genuine and questioned coins were so minor that they could only be differentiated using a precise analytical balance. This explained why most counterfeit coins were accepted by vending and ticket-selling machines.

The mean diameter of sixteen genuine coins was 27.96 mm with a standard deviation of 0.01 mm and a coefficient of variation of 0.04%. The diameter of F1 and F2 questioned coins was 27.93 mm and 27.87 mm, respectively, which was so close to the mean diameter of genuine coins that their differences could only be detected using a vernier caliper.

Because of the elevated stamp markings on both sides of a coin, it was not easy to define a suitable area for the measuring of coin thickness. Thus, rim thickness instead of coin thickness was measured for comparison purposes in this work. However, it should be noted that the protruded rim of a coin was thicker than its central area. Since the rim thickness was not constant throughout the whole ring, it was measured at six specific locations and the average of these measurements was regarded as rim thickness of the coin. The mean rim thickness and standard deviation of sixteen genuine coins was 2.17 ± 0.02 mm. And those of F1 and F2 questioned coins were 2.03 ± 0.02 mm and 2.06 ± 0.03 mm, respectively, which are smaller than that of genuine coins. The t test results indicated that the rim thickness of both F1 and F2 questioned coins were significantly different from those of genuine coins.

**Observation of morphological details**

The color and shape of questioned coins so closely resembled those of genuine coins that they could not be distinguished from genuine coins by the naked eye. The sounds generated by questioned coins were clearer and crisper than those of genuine coins when the coins were dropped onto a hard solid surface from a height of about 5cm. The small details of stamped markings were blurred or absent on both questioned coins, but were clear and definite on genuine coins. Typical examples of the clarity difference of stamped markings between questioned and genuine coins are shown in Fig.1 to Fig. 6. The stairs on the main entrance of the presidential hall and the year of minting are illustrated. In addition, there were visible concentric circular tool marks observed on both sides of the F1 coin. The concentric circular tool marks on the

<table>
<thead>
<tr>
<th>Sample name</th>
<th>Weight</th>
<th>Diameter</th>
<th>Rim thickness</th>
</tr>
</thead>
<tbody>
<tr>
<td>Genuine 50 NT$ coins&lt;sup&gt;a&lt;/sup&gt;</td>
<td>9.975 ± 0.073g</td>
<td>27.96 ± 0.01 mm</td>
<td>2.17 ± 0.02 mm</td>
</tr>
<tr>
<td>F1</td>
<td>9.915g</td>
<td>27.93 mm</td>
<td>2.03 ± 0.02 mm</td>
</tr>
<tr>
<td>F2</td>
<td>10.227g</td>
<td>27.87 mm</td>
<td>2.06 ± 0.03 mm</td>
</tr>
</tbody>
</table>

<sup>a</sup>Sixteen genuine coins were measured.

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**Fig. 1** Clear small details of presidential hall on inner disc of genuine 50NT$ coin.

**Fig. 2** Blurred markings of presidential hall and concentric circular tool marks on inner disc of F1 coin.

**Fig. 3** Blurred markings of presidential hall on inner disc of F2 coin.
inner disc and outer ring of the coin are shown in Fig. 2 and Fig. 5, respectively. Since coins were cast by steel molds, tool marks left on the molds during manufacturing procedures could be transferred to the surfaces of coins while casting the coins. This explained the formation of concentric circular tool marks on the F1 coin. The image of 200 times magnified tool marks shown in Fig. 7 revealed their class characteristics and reproducibility which could be employed to differentiate questioned coins cast by different molds or identify coins cast by the same mold. The blurring of stamped markings could also be attributed to imprecisely manufactured molds. There were no circular tool marks observed on the F2 coin, thus F1 and F2 were cast by different molds.

There were five groups of parallel protruded lines intermittently arranged along the lateral side of a 50NT$ coin. Each group contained fourteen lines parallel to the axis of the coin. These lines were cast onto the lateral side of genuine coins with the same procedure as casting the stamped markings[15]. However, they were cut into the lateral side of questioned coins by a cutter rather than cast by a mold. Tool marks produced by cutting procedures could be observed on both F1 and F2 coins as shown in Fig. 8. The tool marks on F1 were perpendicular to the protruding lines and those on F2 were parallel to the protruding lines. The distance between groups of lines on both questioned coins was shorter than that of genuine coins.

Fig. 4 Clear and sharp edges of year of make on outer ring of genuine 50NT$ coin.

Fig. 5 Blurred edges of year of make and concentric circular tool marks on outer ring of F1 coin.

Fig. 6 Blurred edges of year of make on outer ring of F2 coin.

Fig. 7 Magnified (× 200) image of concentric circular tool marks on outer ring of F1 coin.

Fig. 8 Tool marks on lateral sides of F1 (the 3rd from top) and F2 (bottom) coins, top two are genuine coins with no tool marks.
Scanning electron microscopic/energy dispersive X-ray analysis

After energy dispersive X-ray spectra were obtained for each coin sample, all detected elements were identified. Because the sensitivity of energy dispersive X-ray analysis was relatively low, trace elements could not be detected. The X-ray peaks of some minor elements were barely higher than noise levels. Typical energy dispersive X-ray spectra of coin samples are shown in Figs 9 to 14. The SEMQUANT software in LINK ISIS energy dispersive X-ray analyzer was used to calculate the weight percentage of detected elements. Data of default standard and detected peak intensity of selected sample element were used to calculate apparent concentration using equation (1).

Apparent concentration of A = \( \frac{I_{A \text{ spl}}}{I_{A \text{ std}}} \times \text{wt}\% A_{\text{std}} \) (1)

Where \( I_{A \text{ spl}}, I_{A \text{ std}}, \) and \( \text{wt}\% A_{\text{std}} \) are detected intensity of element A in a sample, default intensity of element A in the standard, and default weight percentage of element A in the standard, respectively. The apparent concentration was then subjected to intensity correction to give the weight percentage of each element. Finally, the total percentage of these selected elements was adjusted to 100% to give a normalized result. Since coin materials are a homogeneous metal alloy where composed elements are evenly distributed throughout the whole sample, surface analysis results obtained by SEM/EDX would faithfully reflect the composition of the bulk of coin material. A small area of surface material of both F1 and F2 coins was removed and reanalyzed; results confirmed that questioned coins were also made of homogeneous material. Results of elemental analysis are shown in Table 3.

The major elements detected in the silver colored

![Fig. 9 Energy dispersive X-ray spectra of outer ring of genuine 50NTS coin.](image)

![Fig. 10 Energy dispersive X-ray spectra of outer ring of questioned coin.](image)

![Fig. 11 Energy dispersive X-ray spectra of obsolete 5 NTS coin.](image)

![Fig. 12 Energy dispersive X-ray spectra of obsolete 1 NTS coin.](image)

![Fig. 13 Energy dispersive X-ray spectra of inner disc of genuine 50NTS coin.](image)

![Fig. 14 Energy dispersive X-ray spectra of inner disc of questioned coin.](image)
outer ring of both genuine and questioned 50 NT$ coins were Cu and Ni. The concentration ratio of Cu/Ni in both kinds of samples was roughly 3 to 1. A minor element Fe was detected in the F1 outer ring sample. The major elements detected in the silver colored obsolete 5 NT$ coin were Cu and Ni, and the Cu/Ni ratio was roughly 3 to 1 as well. The major elements detected in the silver colored obsolete 1 NT$ coin were Cu, Ni, and Zn, which were significantly different from the other silver colored coin samples. In order to differentiate the elemental composition between genuine and questioned coins, a statistical analysis using the concentration ratio of Cu/Ni was employed. The average of the elemental ratio of each sample, except for the 1 NT$ coin, was sequentially compared with that of the other samples. A t test was used to establish the significance of differences between the elemental ratios of compared sample pairs; a confidence level of 99% ($\alpha = 0.01$) was chosen for the test. The p values of t test results are shown in Table 4. The high p value of (F1, F2), i.e. 0.606, indicated that there was no significant difference of Cu/Ni between the outer rings of F1 and F2. The possibility that their raw materials were from the same source was high. The compositional difference between both questioned and genuine 50 NT$ coins were significant as indicated by the relatively low p values of 0.00205 and 0.0130, respectively. Thus questioned coins could be easily differentiated from genuine ones and could be determined to be counterfeit. A criminal investigation clue implied that the raw material of counterfeit coins possibly originated from scrapped obsolete coins. Elemental analysis results excluded the possibility of 1 NT$ coin being the source of raw material. The p values of t test result concerning (5 NT$, F1) and (5 NT$, F2) sample pairs were 0.00205 and 0.0130, respectively. Since the former was slightly smaller and the latter was slightly bigger than the $\alpha$ value 0.01, the results were ambiguous. Thus the most appropriate interpretation of these results would be: If the investigative clue was correct, obsolete 5 NT$ coins rather than 1 NT$ coins would be the source of raw material of counterfeit coins. Elements detected in the inner disc of genuine 50 NT$ coin were Cu, Al, and Ni, while the inner disc of F1 and F2 contained different elemental compositions of Cu and Zn. The inner disc of questioned coins could therefore be easily differentiated from that of genuine coins based on their significant differences in elemental composition. The concentration ratio of Cu and Zn of both F1 and F2 were about 6 to 4. In addition to Cu and Zn, a minor amount of lead was detected in the inner disc of both F1 and F2 coins. When a backscattered electron image was observed, bright particles were found randomly distributing in the matrix of the Cu-Zn alloy as shown on Fig. 15. These particles were irregular in shape and ranged from 0.5 to 10 µm in diameter. These bright particles were further analyzed using the spot analysis mode of EDX and were verified to be lead particles. A typical energy dispersive X-ray spectrum is shown in Fig. 16. Results of X-ray mapping analyses confirmed that Cu and Zn were evenly blended with each other as an alloy where lead existed as isolated particles in the Cu-Zn alloy rather than a component of the alloy. The X-ray

<table>
<thead>
<tr>
<th>Sample</th>
<th>Elements detected</th>
<th>Weight percentage and standard deviation of major detected elements</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outer ring of genuine 50 NT$ coins</td>
<td>Cu, Ni</td>
<td>Cu: 74.28% ± 0.65%, Ni: 25.72% ± 0.65%, n=9</td>
</tr>
<tr>
<td>Outer ring of F1 questioned coin</td>
<td>Cu, Ni, Fe</td>
<td>Cu: 76.35% ± 0.27%, Ni: 23.65% ± 0.27%, n=3</td>
</tr>
<tr>
<td>Outer ring of F2 questioned coin</td>
<td>Cu, Ni</td>
<td>Cu: 76.61% ± 0.85%, Ni: 23.39% ± 0.85%, n=3</td>
</tr>
<tr>
<td>Obsolete genuine 5 NT$ coin</td>
<td>Cu, Ni</td>
<td>Cu: 74.08% ± 0.50%, Ni: 25.92% ± 0.50%, n=3</td>
</tr>
<tr>
<td>Obsolete genuine 1 NT$ coin</td>
<td>Cu, Ni, Zn</td>
<td>Cu: 64.58% ± 1.78%, Ni: 19.72% ± 0.36%, Zn: 15.70% ± 1.77%, n=3</td>
</tr>
<tr>
<td>Inner disc of genuine 50 NT$ coins</td>
<td>Cu, Al, Ni</td>
<td>Cu: 92.71% ± 0.54%, Al: 4.97% ± 0.57%, Ni: 2.32% ± 0.12%, n=9</td>
</tr>
<tr>
<td>Inner disc of F1 questioned coin</td>
<td>Cu, Zn, Pb, Fe</td>
<td>Cu: 58.00% ± 0.33%, Zn: 42.00% ± 0.33%, n=3</td>
</tr>
<tr>
<td>Inner disc of F2 questioned coin</td>
<td>Cu, Zn, Pb, Fe</td>
<td>Cu: 59.94% ± 0.43%, Zn: 40.06% ± 0.43%, n=3</td>
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Table 3 Results of EDX analysis

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</tbody>
</table>

Table 4 The p values of t test of the mean of Cu/Ni for each silver colored sample

<table>
<thead>
<tr>
<th>Sample</th>
<th>F1 outer ring</th>
<th>F2 outer ring</th>
<th>Genuine 50 NT$ outer ring</th>
</tr>
</thead>
<tbody>
<tr>
<td>Genuine 5 NT$</td>
<td>0.00205</td>
<td>0.0130</td>
<td>0.594</td>
</tr>
<tr>
<td>Genuine 50 NT$ outer ring</td>
<td>0.000246</td>
<td>0.000403</td>
<td></td>
</tr>
<tr>
<td>F2 outer ring</td>
<td>0.606</td>
<td></td>
<td></td>
</tr>
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</table>
mapping results are shown in Fig. 17. Furthermore, spherical particles were observed on the surface of elevated stamped markings of the F2 inner disc. Diameters of these spherical particles ranged between 0.2 µm and 5 µm as shown in Fig. 18. Energy dispersive X-ray analysis results indicated that they were lead particles. The presence of micro spherical lead particles indicated that the inner disc of F2 had been subjected to high temperature treatment during the manufacturing process. It is possible that the raw materials used for counterfeit coins were from metal scraps and were contaminated by lead during the recycling process.

**Conclusions**

The color, dimensions, and weights of examined questioned coins were too close to genuine coins to be differentiated from genuine coins by the naked eye or vending machines. The blurred small details and unusual tool marks present on questioned coins suggested that they might be counterfeit coins. Elemental analysis using SEM/EDX and statistical analysis confirmed this. The preliminary results indicated that SEM/EDX analysis combined with statistical analysis possessed powerful potential in the forensic examination of questioned coins. Since only two questioned coins from one criminal case were examined, the analysis of more real case samples would be required to confirm the common applicability of this method.

**Acknowledgments**

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