A Study of the Metalworking Techniques Manifested in the Gold Buckle from Seogam-ri Tomb No. 9

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Introduction

The gold buckle (National Treasure No. 89) excavated from Seogam-ri Tomb No. 9, the oldest gold artifact crafted using the granulation technique to be discovered to date on the Korean Peninsula, is estimated to have been produced during the first or second century. Found at the waist level of the body interred in the tomb (indicating that it formed as part of a belt), this gold buckle stands out for its sumptuous decoration and fine crafting.

Both archaeological and art historical research on the buckle have been conducted through the collection of morphological information based on naked-eye inspection and comparison with similar items excavated and preserved in China and other countries. However, the exact provenance of the buckle remains unknown. It has been suggested that it was made on the Korean Peninsula in a place such as the Nangnang (alternatively, Lelang) Commandery, under the influence of central China and the Xiongnu (also known as the Hunnu) or other northern nomadic peoples from what is now Mongolia.

Identifying the buckle's region of production is a matter of importance since it could provide clues about the origins of the granulation technique in Korea and the state of foreign relations at the time it was made. To this end, scientific analysis of the materials and techniques used to create the buckle is a key, and a scientific investigation was carried out to determine the metalworking techniques used in the production of the gold buckle from the Seogam-ri tomb.

First, X-ray fluorescence spectrometer (XRF) analysis was performed to confirm the material composition of the gold sheet, gold wires, gold granules, and inset materials. Next, the conditions in the buckle's interior and the manner of joining of the parts were examined through radiography, and the state of the buckle's surface and structural details were confirmed using a stereoscopic microscope. After this, scanning electron microscope-energy dispersive spectrometer (SEM-EDS) analysis was applied to investigate the finer details of the gold granules and how they were bonded. Based on the chemical composition for the gold buckle and the results of the analysis of its structural details obtained through this process, a further integrated study of the buckle was accomplished.

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Method of Analysis

XRF Analysis

Using an X-ray fluorescence spectrometer, the material composition of the gold sheet, gold wires, gold granules, and inset minerals used to create the gold buckle were analyzed in a non-destructive manner. The analysis conditions are shown in Table 1 below.

Equipment	Analysis Conditions			
	Voltage	Current	Time	Collimator
Portable μXRF Spectrometer, ArtTAX, Röntec, Germany	50kV	600μA	200s	200㎛

Table 1. XRF analysis conditions

To confirm the purity of the gold, standard certified reference materials (CRM) produced by Bruker AXS Korea—Gold 1 (Au 84.71 wt%, Ag 10.30 wt%, Cu 4.99 wt%), Gold 2 (Au 89.80 wt%, Ag 9.13 wt%, Cu 1.07 wt%), and Gold 3 (Au 76.83 wt%, Ag 20.25 wt%, Cu 2.92 wt%)—were used. The calibration curve of each element was drawn and normalized to 100%. The CRM analysis results are listed in Table 2.

Reference Material		Chemical Composition		
		Au	Ag	Cu
Gold1	1	84.67	10.17	5.17
	2	84.60	10.29	5.11
	3	84.93	9.90	5.18
Average		84.73	10.12	5.15
Gold2	1	90.09	8.75	1.16
	2	90.04	8.78	1.18
	3	89.97	8.79	1.24
Average		90.03	8.77	1.19
Gold3	1	77.19	20.22	2.59
	2	77.11	20.22	2.66
	3	77.03	20.27	2.71
Average		77.11	20.24	2.65

Table 2. Results of XRF analysis of gold by standard certified reference materials (unit: wt%)

Radiography

Radiography (EX-300GH-3, Toshiba, Japan) was performed to investigate the state of the buckle's interior and the joining of the parts. The imaging conditions are shown in Table 3.

Voltage (kv)	Current (mA)	Time (mim.)	Fucus Film Distance (mm)	Film
130	5	4	100	Agfa D7

Table 3. Radiography conditions

Stereoscopic Microscope Analysis

The state of the gold buckle's surface and structural details were analyzed using a stereoscopic microscope (M205-A, Leica, Germany). This type of device allows the sample to be enlarged from 5 to 100 times and is thus useful for the examination of parts that cannot be easily scrutinized with the naked eye. The analysis was carried out by varying the magnification according to the area of investigation.

SEM-EDS Analysis

To study the bonding points of the gold granules and their finer details, SEM-EDS analysis was conducted under the conditions shown in Table 4. To confirm the purity of the gold, standard certified reference materials (CRM) produced by European Reference Materials—EB506 (Au 58.56 wt%, Ag 3.90 wt%, Cu 35.65 wt%, Zn 1.89 wt%), EB507 (Au 75.10 wt%, Ag 3.02 wt%, Cu 14.69 wt%, Ni 4.99 wt%, Zn 2.11 wt%), and EB508 (Au 75.12 wt%, Ag 24.90 wt%)—were used. The calibration curve of each element was drawn and normalized to 100%. The CRM analysis results are listed in Table 5.

Equipment	Analysis Conditions		
	Voltage	Current	Time
S-3500N, Hitachi, Japan/ X-max^N, Horiba, Japan	20kV	60–70μA	100s

Table 4. SEM-EDS analysis conditions

Chemical Composition						
Reference material		Au	Ag	Cu	Ni	Zn
EB506	1	59.65	3.81	34.39	-	2.16
	2	59.76	4.10	34.11	-	2.03
	3	59.79	3.56	34.32	-	2.33
Average		59.73	3.82	34.27	-	2.17
EB507	1	76.40	2.77	13.70	4.89	2.24
	2	75.14	3.58	14.01	4.63	2.64
	3	75.92	3.63	13.90	4.81	1.74
Average		75.82	3.33	13.87	4.78	2.21
EB508	1	74.91	25.09	-	-	-
	2	74.87	25.13	-	-	-
	3	74.48	25.52	-	-	-
Average		74.75	25.25	-	-	-

Table 5. Results of SEM-EDS analysis of gold standard certified reference materials (unit: wt%)

Analysis Results

Composition of the Gold Buckle

The analysis positions for the composition analysis of the gold sheet, gold granules, gold wires, and blue minerals used to produce the gold buckle are shown in Fig. 1, and the results for each position are listed in Table 6. The gold sheet had an average composition of Au 94.87 wt%, Ag 5.08 wt% with a purity of around 22.8K. The extra gold sheet appended to some parts had an average composition of Au 99.31 wt%, Ag 0.60 wt%, with a slightly higher purity at 23.8K. Using radiography and stereoscopic microscopy (as described in Metalworking Techniques), it was confirmed that an additional gold sheet of higher purity has been applied in some areas. The average composition for the gold granules was Au 99.32 wt%, Ag 0.55 wt%, and Au 99.31 wt%, Ag 0.60 wt% for the gold wires, and both the granules and wires had a similar purity at around 23.8K. The thin, flat gold wires surrounding the inset blue minerals proved to have a similar gold composition to the granules and other wire. The purity of the clasp is around 22.8K, and the purity of the wire holding the clasp in place is around 23.6K. The purity of the gold clasp is similar to that of the gold sheets, which indicates that the material is different from that used to form the granules and gold wires. The major composition detected in the blue mineral inset in the foreheads and bodies of the dragons decorating the surface of the buckle were Cu, Al, P, Zn, and Fe, which indicates that the mineral is likely to be turquoise $[CuAl_6(PO_4)_4(OH)_8 \cdot 5H_2O]$.

Chemical Composition					
Analysis position		Au	Ag	Cu	Purity
Gold granules	1	99.27	0.61	0.12	23.8K
	2	99.33	0.50	0.17	23.8K
	3	99.22	0.70	0.08	23.8K
	4	99.44	0.39	0.18	23.9K
Average		99.32	0.55	0.14	23.8K
Gold wires	5	99.35	0.54	0.12	23.8K
	6	99.16	0.62	0.23	23.8K
	7	99.36	0.60	0.03	23.8K
	8	99.26	0.65	0.08	23.8K
	9	99.32	0.52	0.17	23.8K
	10	99.29	0.64	0.08	23.8K
Average		99.28	0.60	0.12	23.8K
Thin, flat gold wires	11	99.51	0.45	0.04	23.9K
	12	99.32	0.64	0.03	23.8K
Average		99.42	0.55	0.04	23.9K
Gold sheet	13	95.17	4.78	0.05	22.8K
	14	95.45	4.52	0.03	22.9K
	15	94.32	5.61	0.07	22.6K
	16	94.53	5.41	0.06	22.7K
Average		94.87	5.08	0.05	22.8K
Added gold sheet	17	99.23	0.63	0.15	23.8K
Clasp	18	95.10	4.71	0.18	22.8K
Wire fixture for clasp	19	98.46	1.37	0.17	23.6K
Blue mineral	20	Cu, Al, P, Zn, Fe			

Table 6. Composition of the gold buckle (unit: wt%)

As analysis of the minute details on the dragons is not possible with XRF, the purity of the gold wires forming the nose was analyzed using SEM-EDS (Fig. 2, Table 7). The results showed that the gold wires used to express the noses on the seven dragons had an average gold composition of Au 97.18 wt%, Ag 2.37 wt%, and a purity slightly lower than that of the gold wires applied in other areas on the buckle.

Chemical Composition					
Analysis position		Au	Ag	Cu	Purity
Gold wires	1	96.85	3.15	0.00	23.2K
	2	96.59	3.37	0.03	23.2K
	3	96.88	3.12	0.00	23.3K
	4	97.45	2.55	0.00	23.4K
	5	97.04	2.96	0.00	23.3K
	6	97.71	2.29	0.00	23.5K
	7	97.77	2.17	0.05	23.5K
Average		97.18	2.37	0.02	23.3K

Table 7. Composition of the gold wires used for the dragons' noses (unit: wt%)

Fig. 1. Analysis positions

Fig. 2. Analysis positions of the gold wires used to express the dragons' noses

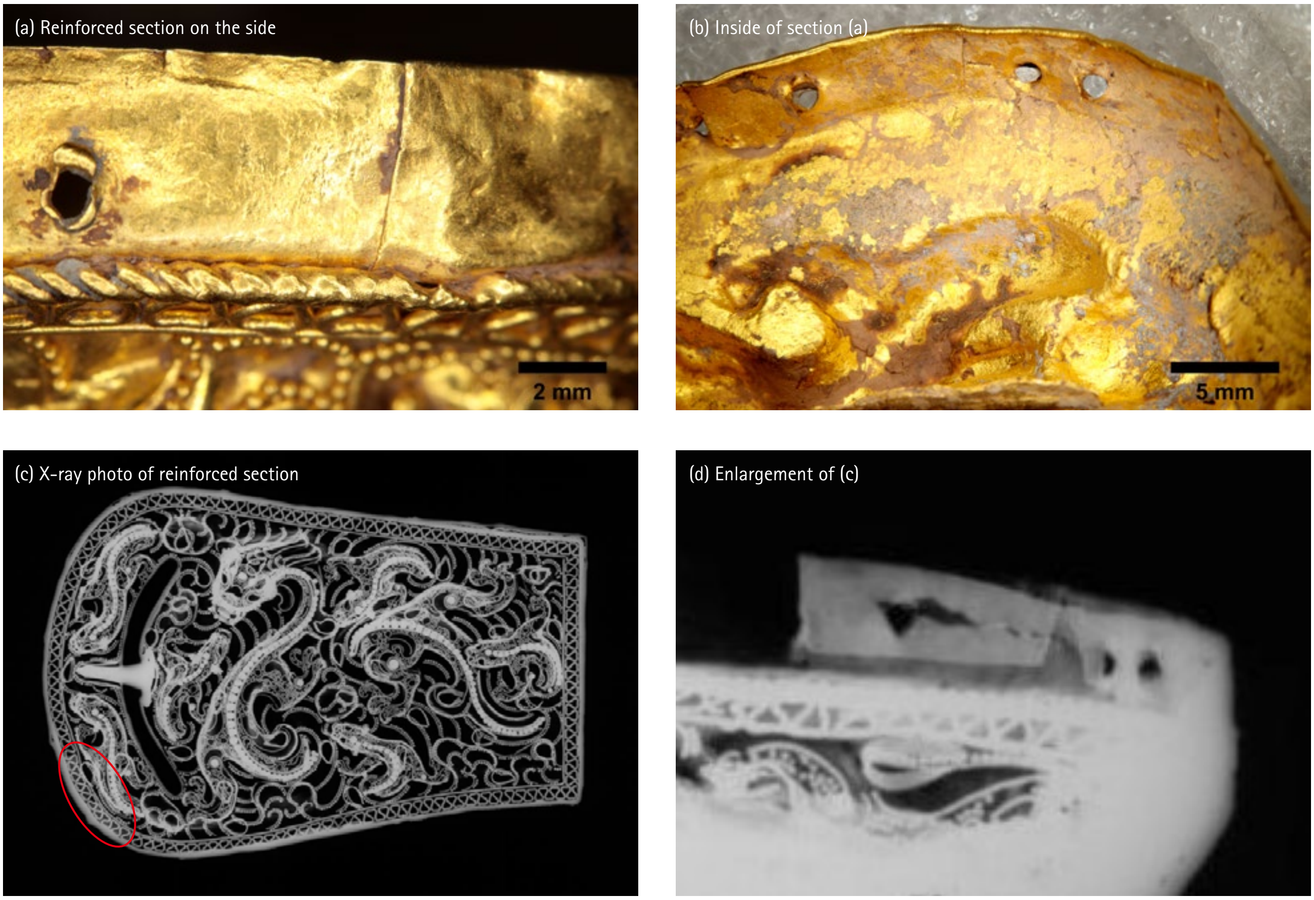

Fig. 3. Reinforced section

Metalworking Techniques Observed in the Gold Buckle

Gold sheet

The analysis performed indicated the gold sheet to be 0.3–0.7 millimeters thick and to possess a purity of 22.8K. The large dragon and the six smaller dragons surrounding it on the surface of the buckle were formed using the repoussé technique, which involves hammering a metal sheet from the reverse side. The bodies of the dragons, their outlines, and the edges of the buckle are decorated with gold granules and gold wires.

Repoussé is a metalworking technique in which a gold, silver, bronze, or other type of metal sheet is hammered from the reverse side in order to cause the surface to bulge outwards and produce a design in low relief. In East Asia, repoussé gold and silver artifacts have been excavated on rare occasions from Inner Mongolia and the Xinjiang Uyghur region, which were inhabited by nomadic peoples from the fourth century BCE to the third century BCE.

Using a microscope and radiography, the addition of a supplemental gold sheet to a section of the side of the buckle could be confirmed (Fig. 3). This added gold sheet (analysis position 17) has a purity of 23.8K. As the reinforced section is surrounded by decorative gold wire, it is presumed that the additional sheet was applied to address a defect that occurred during the production process. However, the possibility that the defect occurred at some other point cannot be ruled out.

Gold Wires

The three-section border around the entire buckle, the bodies of the dragons, and other surface decoration are expressed in gold wires. The outermost part of the border is made from two wires twisted together that are discontinuous at one point (Fig. 4). The central section of the border is decorated with a pattern of regular triangles created using a total of five strands of gold wire (Fig. 5). The inner side of the triangle design is finished with a border made with two strands of gold wire (Fig. 6).

Fig. 4. Discontinuous point in the gold wire of the outermost border

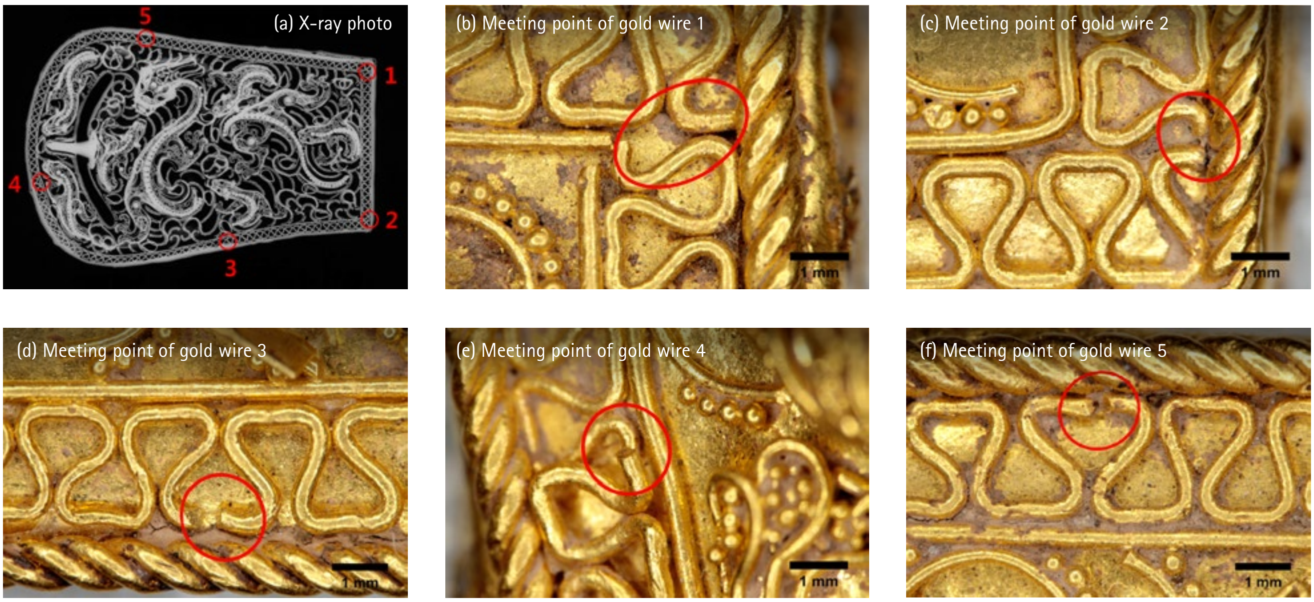

Fig. 5. Parts of the central border design where the gold wires meet

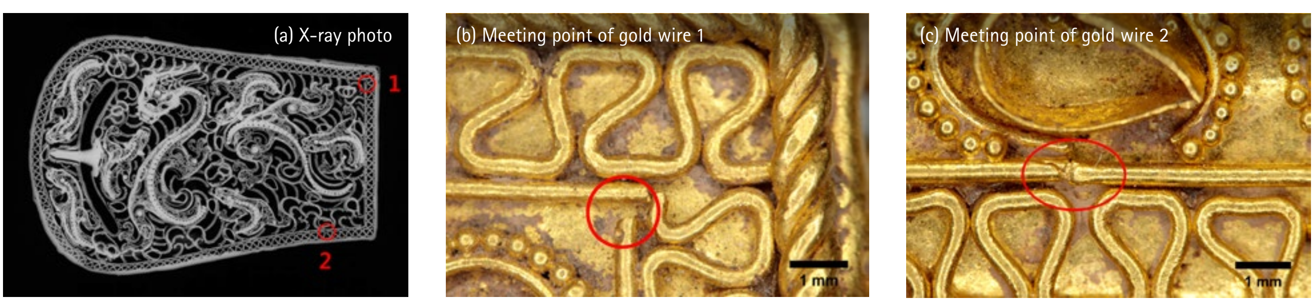

Fig. 6. Parts of the innermost border where the gold wires meet

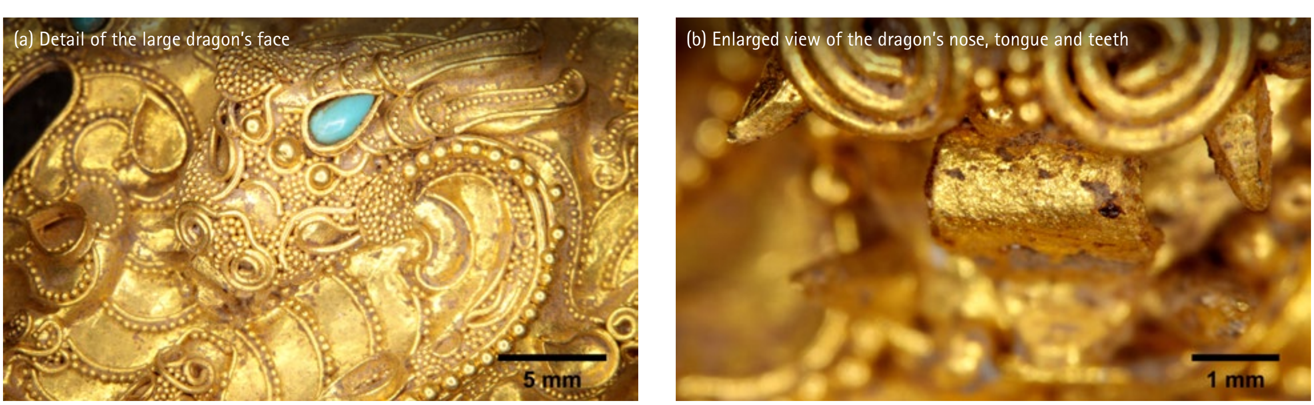

Fig. 7. Gold wires used to decorate the large dragon's nose, horns, teeth and tongue

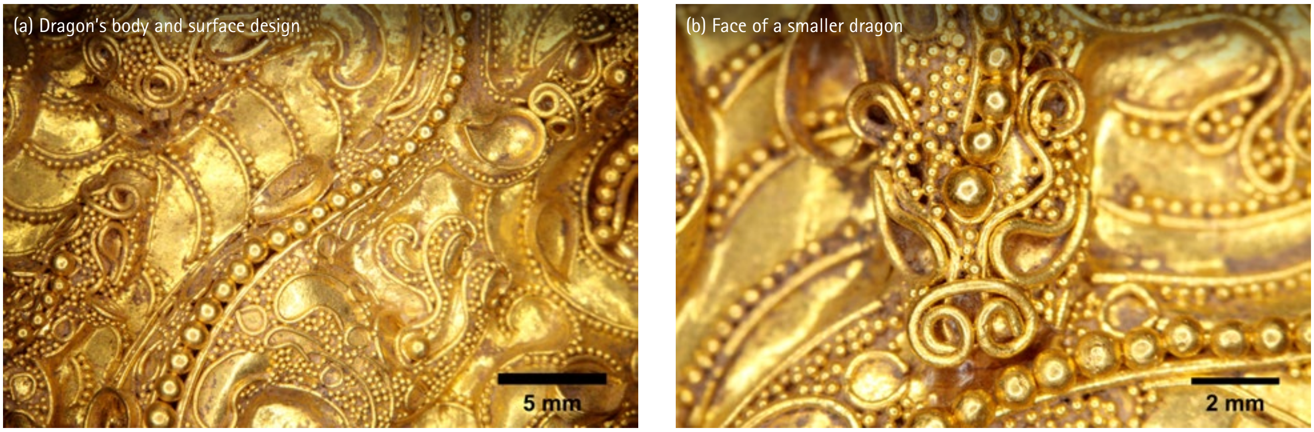

Fig. 8. Gold wires used in dragon's body and surface design, and faces of smaller dragons

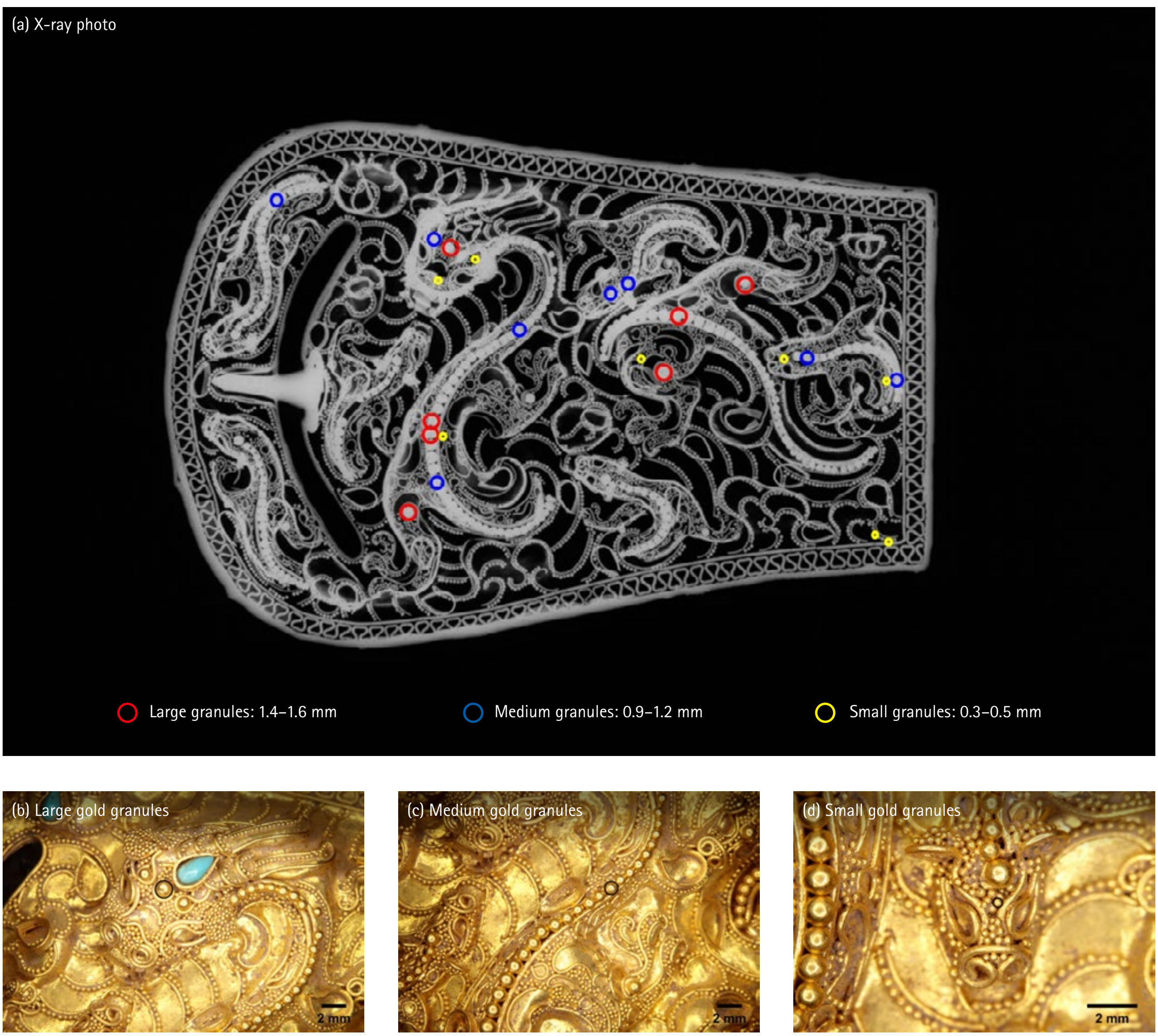

Fig. 9. Sizes of the gold granules

The gold wires used to form the noses of the dragons (Fig. 7 (a)) has an average purity (23.3K), slightly lower than that of the wires used in other parts of the buckle (23.8K). According to experiments regarding the hardness of gold according to its purity, the hardness of 24K gold is 30Hv while that of 22K gold is 52Hv. A reduction in purity of 2K results in more than a 70 percent increase in hardness. This means that the dragons' noses were made with harder wire than that used on other parts of the buckle.

The bodies of the dragons and the wave design on the surface of the buckle are made with 23.8K gold wires (Fig. 8). The horns, teeth and tongue of the large dragon in the center are formed from thick and thin gold wires (Fig. 7 (b)), but these features were omitted from the six smaller dragons (Fig. 8 (b)).

Production and Bonding of the Gold Granules

Measurements taken of the granules on the gold buckle indicated that they can be classified into three groups: small, medium, and large. The largest granules measured 1.4–1.6 millimeters in diameter and served to decorate the top of the largest dragon's head, body, and feet. The medium-sized granules, measuring 0.9–1.2 millimeters in diameter, were applied as decoration for the bodies of both the large dragon and the smaller ones. The small granules, measuring 0.3–0.5 millimeters in diameter, ornament the dragons' ears and bodies and the surface of the buckle (Fig. 9).

Known methods of bonding gold granules include soldering, copper diffusion, and welding. An analysis of the bonding points of the granules and traces of exfoliation on the fine details using SEM-EDS was performed to identify the composition of the bonding points and confirm the bonding methods used (Fig. 10, Table 8). When a bonding point was compared with the base gold, little difference in the composition of Au and Ag was noted but the Cu content was found to be

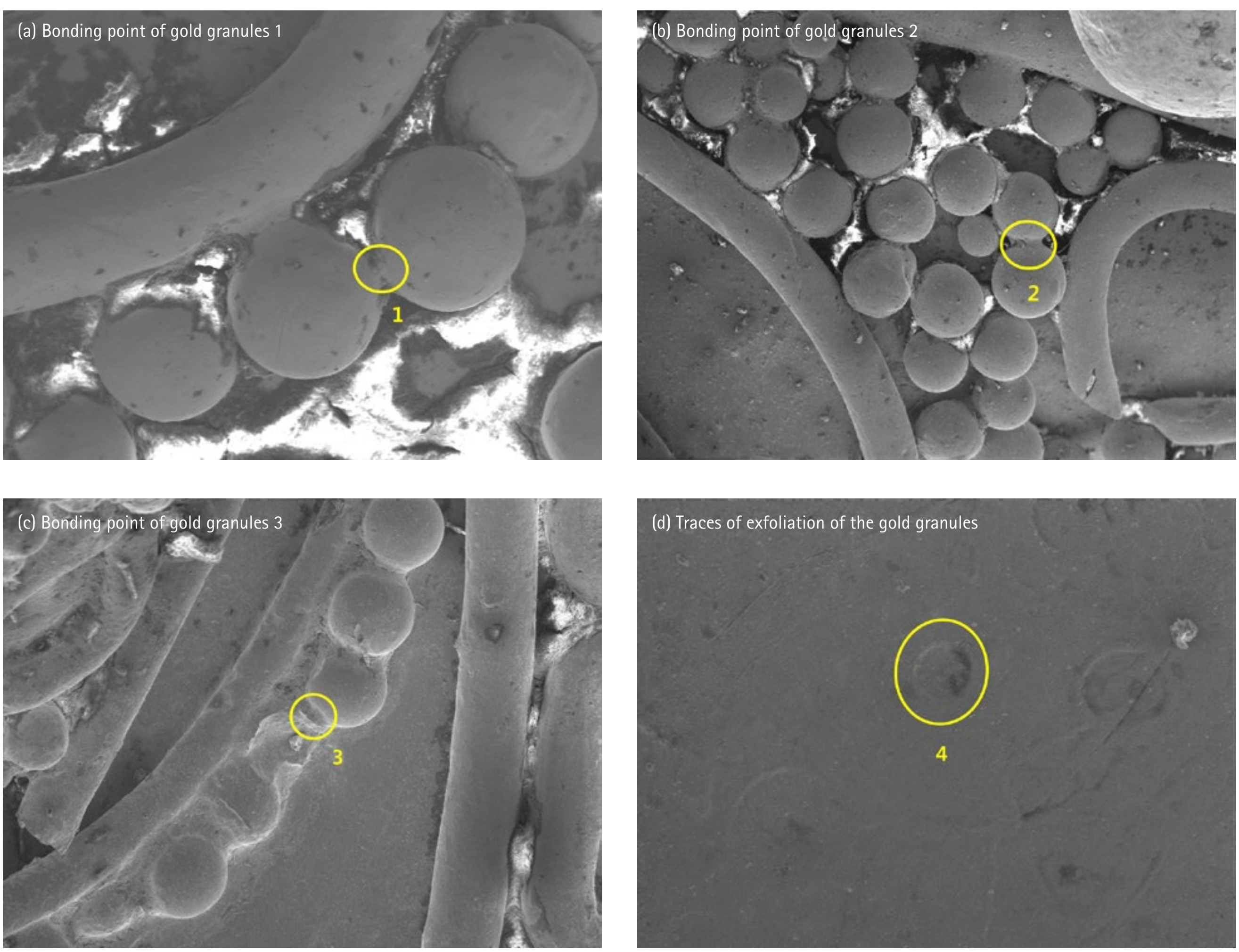

Fig. 10. SEM images of bonding between gold granules

0.43–1.51 wt%, higher than the corresponding figure in the gold sheet, gold granules, and gold wires. In addition, traces of reinforcement were detected, meaning in sum that it is highly probable that copper diffusion was used to bond the granules to the gold buckle.

Chemical Composition				
Analysis Position		Au	Ag	Cu
1	Bonding point (join between gold granule-gold granule)	99.05	0.52	0.43
2	Bonding point (join between gold granule-gold granule)	99.18	0.05	0.77
3	Bonding point (join between gold granule-gold granule)	98.35	0.14	1.51
4	Signs of exfoliation (join between gold granule-gold sheet)	93.72	5.14	1.14

Table 8. Results of EDS analysis of bonding between granules (unit: wt%)

Most of the gold items with granulated decoration excavated to date on the Korean Peninsula were made using soldering as the bonding method. Some examples are the Gold Earrings with Large Rings (National Treasure No. 90) discovered in Bubuchong (Tomb of Husband and Wife) in Bomun-dong in Gyeongju, the Gold Earrings with Small Rings and Gold Earrings with Large Rings (Treasure No. 557) in the collection of Leeum, Samsung Museum of Art, and the Gold Wind Chime that was found at the bottom of the inner sarira reliquary of the Eastern Three-Story Stone Pagoda at the site of Gameumsa Temple from the Unified Silla period. Aside from these granulated works, the Gold Necklace excavated from the Tomb of King Muryeong in Gongju was soldered using an alloy of gold, silver, and copper, and the Gold Cone-shaped Filigree Ornament discovered at a temple site in Neungsan-ri, Buyeo is known to have been soldered with an alloy of gold and copper. No report has yet been made of a gold granulated item found on the Korean Peninsula bonded using the copper diffusion method with a copper compound. However, the use of this copper diffusion technique has been identified in some gold ornaments from the tombs at Duurlig Nars in Mongolia.

Red Pigment Inset

Traces of a red pigment were detected around the eyes of the seven dragons decorating the gold buckle (Fig. 11). Most of it has flaked off and become difficult to identify with the naked eye, but these traces suggest that all of the dragons' eyes were once tinted red. It was already known that red pigment remained in the eye area of the large dragon and the small dragon immediately below it, but this study confirmed that red pigment had been applied to the eyes of all seven dragons. XRF analysis of the pigment detected Hg and S, indicating the pigment involved to be cinnabar/vermillion (HgS).

In Korea, inset red pigment has mainly been found in items related to royalty, as in the case of the king's earrings (Fig. 12), sword, dagger, and crown ornaments excavated from the Tomb of King Muryeong in Gongju. Cinnabar/vermillion pigment was also applied on the sarira enshrinement record written on the gold plate and the gold cap-shaped ornaments for curved jade pieces discovered at the Mireuksa Temple site in Iksan. On these gold cap-shaped ornaments, green and blue copper pigment was used along with cinnabar/vermillion, reflecting an expansion and diversification of the use of color. Moreover, it was confirmed that a gold ornament excavated from Seobongchong Tomb (Tomb of the Auspicious Phoenix) in Gyeongju dating to the Silla Kingdom features inset cinnabar/vermillion and black pigments.

Conclusion

Through an analysis of the composition of the gold buckle excavated from Seogam-ri Tomb No. 9 and the metalworking techniques used in its creation, it was possible to reach the following conclusions.

Filigree Technique (Wirework and Granulation)

All but the gold sheet used to make the buckle were found to have a purity level of 22.8K. The seven dragons were formed by hammering out their design in low relief using the repoussé technique, and their bodies, outlines and the buckle border were decorated with gold wires and gold granules. A portion of the buckle at the side was reinforced with an added 22K gold sheet.

The gold wires used to decorate the border, bodies and outlines of the dragons was found to be highly pure at around 23.8K and was applied either as a single strand or as two strands twined together. The wires used to form the dragons' noses was found to have a slightly lower level of purity than that of the wires used in other parts of the buckle, and consequently increased hardness. This harder wire was presumably applied as a means to ensure that the wire spirals forming the noses of the dragons maintained their shape over time.

The gold granules used to decorate the bodies of the

Fig. 11. Traces of red material

Fig. 12. Earrings from the Tomb of King Muryeong

Fig. 13. Gold ornament from Seobongchong Tomb in Gyeongju

dragons and the buckle's surface can be divided into small, medium and large groups. They were found to possess a high purity level at 23.8K. The elevated Cu content detected in the gold at the bonding point indicates that the copper diffusion method of bonding was used to attach the granules to each other and the surface.

Characteristics of the Decoration Techniques

Aside from filigree wire and granulation work, inset gemstones and pigments were applied to decorate the gold buckle. Blue turquoise stones were inset in the forehead and bodies of the dragons and cinnabar/vermillion pigment was inset in the eyes of all seven dragons.

The other gold items discovered on the Korean Peninsula featuring inset red pigment have mainly been excavated from sites related to Baekje royalty. Further research into this point could produce informative results.

The results of this study are significant in two aspects. First, it provided basic information central to identifying the provenance of the gold buckle, which has still not been categorically determined. With the accumulation of research materials on metalworking techniques in the region where it is hypothesized the gold buckle was created and further scientific analysis of buckles of similar types, it is anticipated that the place of production of the Seogam-ri gold buckle can eventually be clearly identified.

Second, it has been confirmed that the copper diffusion method was used for bonding the gold granules on the gold buckle. The same method has been found in gold ornaments excavated in Mongolia, which can be applied as objective material for investigating where the gold buckle was made.

Translated by Cho Yoonjung

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