

Material and Manufacturing Properties of Bracket Mural Paintings of Daeungjeon Hall in Gaeamsa Temple, Buan

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Received January 25, 2022

Revised February 4, 2022

Accepted February 8, 2022

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Journal of Conservation Science
2022;38(1):45-54

<https://doi.org/10.12654/JCS.2022.38.1.04>

eISSN: 1225-5459, pISSN: 2287-9781

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ABSTRACT This study examined the production technique of bracket murals in Daeungjeon Hall, Gaeamsa Temple by conducting a analysis of their wall structure, material characteristics, and painting layers. Wall was a single-branch structure with support layer, middle layer, finishing layer, and painting layer. The support layer, middle layer and finishing layer, were produced by mixing sand (quartz, feldspars etc.), and loess. The ratio of above medium sand to below fine sand was approximately 0.7 : 9.3 in the support layer, 4 : 6 in the middle layer and 6 : 4 in the finishing layer, which had a more percentage of above medium sand than the support layer. The analysis of the painting layer showed that natural soil pigment was used to establish a relatively ground layer of up to 50 μm , and pigments such as Lead sulfate, atacamite and mercury sulfide were painted on top of the layer. This study's results confirmed that the bracket mural paintings in Gaeamsa Temple are within the category of the production style of murals during the Joseon period. However, the points that the middle layer was formed several times, the significant difference in particle size distribution between the wall, and the absence of chopped straw in the support layer are a feature of bracket mural paintings in Gaeamsa Temple. These properties of murals as material and structure may be viewed for correlation with the degree of damage to wall structure of mural painting and would serve as an important reference to diagnosis the conservation conditions of murals or prepare conservation treatments.

Key Words Buddhist mural paintings, Earthen wall, Manufacturing technique, Material properties, Conservation

1. INTRODUCTION

Temple murals in Korea were painted on the mud wall of wooden buildings, and natural pigments and the vehicle were mixed to produce the painting layer after the wall was built with tree branches as its frames on top of wooden furniture and the soil as its major material (Lee, 2013). Murals, whose materials are mostly soft in nature, are reported to be vulnerable for conservation due to their material characteristics and the environmental factors in their locations (Lee *et al.*, 2018a). Furthermore, due to some treatments conducted on temple murals in early days of the conservation of temple murals in Korea when there was a lack of studies on mural materials and manufacturing

techniques, many murals have been damaged or made difficult for coneservation, which calls for a study on the manufacturing characteristics of murals. Hence, if materials and techniques used in the production of murals are identified accurately, it would make it possible to conduct a reliable study on the conservation of murals and suggest more systematic and effective conservation options (Lee, 2013).

Studies on the material characteristics and manufacturing techniques of temple murals in Korea include the first study in 2006 that scientifically demonstrated the traditional materials and manufacturing techniques of four-sided interior murals in Geungnakjeon Hall, Muwisa Temple, Gangjin (Chae *et al.*, 2006; Fine Art Conservation Institute, 2006) and a 2008 study conducted on manufacturing techniques based

on the material characteristics of Yeongsan Hoesang murals in Bongjeongsa Temple, Andong (Jeong and Han, 2008). Since then, there were studies comparing the characteristics of manufacturing techniques in temple murals, including murals at the back of the altar in Daeungjeon Hall, Heungguksa Temple, Yeosu, exterior murals in Mireukjeon Hall, Geumsansa Temple, Gimje, and murals at the back of the altar in Daeungjeon Hall, Seonunsa Temple, Gochang (Lee, 2016; Han, 2010). In particular, while studies in the past focused on scientific investigations about relatively important temple murals, studies are being conducted around 2020 by closely interpreting mural materials and production techniques and proposing conservation measures about bracket murals in Daeungjeon Hall, Jikjisa Temple (Lee *et al.*, 2018a) and bracket murals in Daeungbojeon Hall, Naesosa Temple (Lee *et al.*, 2018b).

Daeungjeon Hall, Gaeamsa Temple, Buan is currently designated as Treasure No. 292 and has 52 murals, including bracket murals painted on interior and exterior walls and murals at the top of Nemok-dori (Figure 1). While there are 32 interior bracket murals with 6 each on the east and west and 10 each on the south and north, 4 on the north have no painted image and 5 have been repainted relatively lately. The latest scientific investigation on bracket murals in Daeungjeon Hall, Gaeamsa Temple found that damage in the wall and damage due to the deteriorated painting layer had gotten worsen, which would require conservation treatment (Figure 2). Accordingly, a study identifying manufacturing conditions based on structures and materials, which constitute murals, would need to be conducted first to prepare stable

conservation options.

In this context, this study identified the manufacturing characteristics of bracket murals in Daeungjeon Hall, Gaeamsa Temple by closely analyzing the wall and painting layer consisting of the murals and wish to offer an effective reference for diagnosis the conservation conditions and preparing conservative treatment of murals in the future.

2. METHOD

2.1. Structure of mural painting

The structure of the mural painting was investigated by visually observing the damaged or broken wall of the mural and observing the cross-section with a microscope. Murals are basically divided into the wall and the painting layer, and categorized further into additional layers depending on their making process. To begin with, the structure of layers around damaged parts of the wall was investigated and the thickness of each layer was measured. For the painting layer, the cross-section of murals whose pigments were retrieved was examined to identify the painting layer thickness by color.

2.2. Analysis of material properties

With the structure of the murals, this study conducted a physical and chemical analysis on materials consisting of the wall and the painting layer to identify the characteristics of the materials. Samples which came off of the murals were used for analysis, and the following analyte and analytical



Figure 1. Inside the Daeungjeon hall of Gaeamsa Temple, Buan.



Figure 2. Example of conservation status of murals in Gaeamsa Temple, Buan.

Table 1. List of analysis objects

Sample name	Description	Location
S1	Support layer	South side 1 st mural
M1	Middle layer	North side 3 rd mural
F1	Finishing layer	East side 3 rd mural
G1	Ground layer	South side 4 th mural
P1	White color	West side 1 st mural
P2	Green color	West side 1 st mural
P3	Painting layer	West side 2 nd mural
	Red color	West side 2 nd mural
P4	Green color	West side 2 nd mural

Table 2. List of analysis object and analysis equipment for mural painting

Sample name	Classification	Analysis equipment	
S1, M1, F1	Investigation of naked eye	Digital camera	G15, Canon, Japan
	Microscopic analysis	Stereoscopic microscope	SMZ18, Nikon, Japan
	Microstructure chemical component	SEM-EDS	JSM-7610F, JEOL, Japan
	Crystal phase	XRD	Miniplex 600, Rigaku, Japan
	Particle size	PSA	Testing sieve, JIS Z 8801, Japan
G1, P1, P2 P3, P4	Wood and fiber identification	Digital microscope	G-scope, Genie Tech, Korea
	Investigation of naked eye	Digital camera	G15, Canon, Japan
	Microscopic analysis	Digital microscope	G-scope, Genie Tech, Korea
	Microstructure chemical component elemental mapping	SEM-EDS	JSM-7610F, JEOL, Japan

method were used (Tables 1 and 2): For the analysis of material characteristics, a basic investigation was conducted first with the stereo microscope (SMZ18, Nikon, JPN) and the digital microscope (G-scope, Genie Tech, KOR) and then microstructure and chemical composition analyses were conducted with the scanning electron microscope and the energy dispersive X-ray fluorescence spectrometer (JSM-7610F, JEOL, JPN). Furthermore, to analyze the characteristics of materials in the wall, the X-ray diffractometer (Miniplex 600, Rigaku, JPN) was used to identify the mineral crystal habit, while a wet sieve analysis based on the standard stainless sieves (JIS Z 8801, Okutani Ltd., JPN) was conducted to identify the distribution ratio of particle sizes in the wall. For the classification of particle sizes, their residual weight was measured in accordance with standards from the United States Department of Agriculture (USDA) and the International Union of Soil Sciences (IUSS)

and represented in cumulative percentages.

3. RESULTS

3.1. Properties of wall layer

3.1.1. Structure of wall

The walls of the bracket murals in Gaeamsa Temple were made with soil around the branches were tied with straw rope. On the top of the branches that serve as the frame of the wall, a support layer in the form of plastering a mixture of fine loess and sand is confirmed, and a layer of sand with large particles and various sizes is observed above it, and the corresponding layer has two layers. Separated from above. Bracket murals in Daeungjeon Hall, Gaeamsa Temple, Buan consisted of three layers: the support layer, middle layer, and finishing layer (Figure 3A). In some parts, traces confirmed that the middle layer was made more than once (Figure 3B).

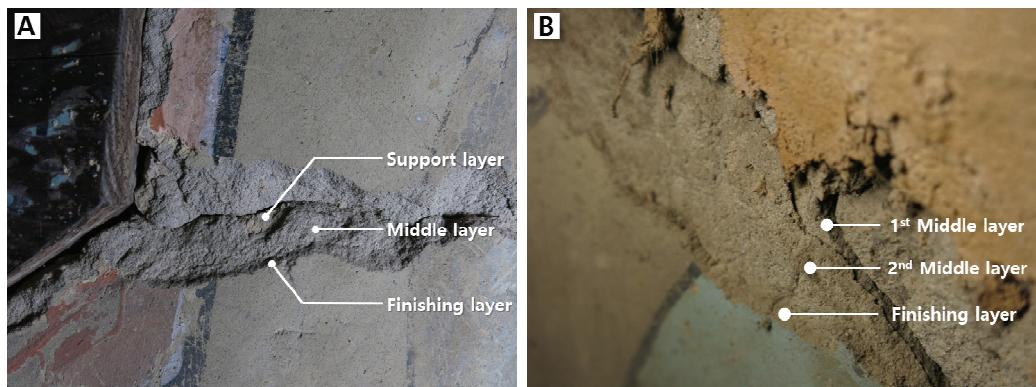


Figure 3. Types of wall layers (A: 3 Layers, ‘support layer - middle layer - finishing layer’, B: 4 Layers, ‘support layer - 1st middle layer - 2nd middle layer - finishing layer’).

It is found that the support layer has a thickness of about 50 mm from the branch, and traces of roughly and quickly plastering appear through the area where the mural has been exfoliated, and a mixed of wooden material and leaves is observed on some walls. The middle layer and finishing layer were applied relatively evenly with a high level of smoothness, the thickness of the middle layer was estimated to be about 7 mm, and the finishing layer to be 3 mm.

3.1.2. Material of Wall

Results of microscopic observation of wall samples of the braket mural painting of Daeungjeon Hall in Gaeamsa Temple (Figure 4), while samples from the support layer consisted of below silt particles rather than larger ones like gravel, samples from the middle layer and the finishing layer had a mixture of larger particles like sand grains and silt or like clay. In addition, fibers presumed to have been mixed during the wall manufacturing process were confirmed in all



Figure 4. Microscopic image of samples (A: Support layer, B: Middle layer, C: Finishing layer).



Figure 5. Digital microscope image of wood and fiber mixed in the wall (A: Wood piece in support layer, B: Wood piece in middle layer, C: Fiber in finishing layer).

samples of the support layer, the middle layer, and the finishing layer.

In the case of the support layer, fibers presumed to be wood or bark were mixed in the wall (Figure 5), and it was confirmed that the fibers of fine thickness were evenly mixed in the middle layer and the finishing layer. The microstructure analysis by the scanning electron microscope confirmed that soil particles such as sand and clay minerals formed aggregates in the support layer, and multiple materials suspected to be fibers were observed. Large and small soil particles were found to have a plate-like microstructure, which was believed to be an aggregate of clay minerals.

In the middle layer and the finishing layer, aggregates of soil particles resembling silt or clay minerals as large and small ones or in the form of plates were observed on the surface of large particles suspected to be quartz. The chemical composition analysis detected silicon (Si), aluminum oxide (Al), iron (Fe), potassium (K), magnesium (Mg), and sodium (Na) in the support layer, and in the middle layer and the finishing layer, atoms usually found in the soil such as iron (Fe), potassium (K), magnesium (Mg), and sodium (Na) were detected, including silicon (Si) and aluminum oxide (Al) like the support layer (Figure 6).

The analysis of the mineral crystal habit detected the mica group, such as muscovite and albite, and feldspars along with

quartz in the support layer. In the middle layer, feldspars such as quartz, microcline, and albite were identified, while the same minerals from the initial layer such as quartz, muscovite, and albite were found in the finishing layer. It is estimated that feldspars including quartz and minerals in the mica group were used in bracket murals (Figure 7).

The particle size analysis by the wet sieve (Table 3, Figure 8) found that in terms of distribution in the size of mineral particles used in the support layer of bracket murals, very coarse sand accounted for 3.79%, coarse sand 1.33%, medium sand 1.52%, fine sand 9.47%, very fine sand 15.15%, and below silt 68.75%. For the support layer of bracket murals in Gaeamsa Temple, below fine sand accounted for more than 93%, which led this author to believe that it was mixed with the soil of very fine particles. In terms of distribution in the size of mineral particles used in the middle layer, very coarse sand accounted for 3.40%, coarse sand 23.63%, medium sand 12.70%, fine sand 26.59%, very fine sand 13.59%, and below silt 20.09%. Below fine sand accounted for more than a half of the middle layer, and it had a higher percentage of sand than the support layer. Finally, in terms of distribution in the size of mineral particles used in the finishing layer, very coarse sand accounted for 13.33%, coarse sand 33.33%, medium sand 14.29%, fine sand 19.05%, very fine sand 8.57%, and below

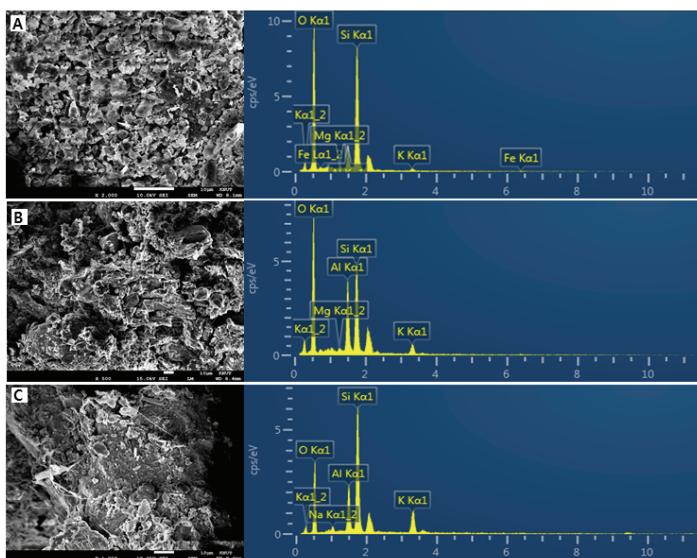


Figure 6. Results of SEM-EDS (A: Support layer, B: Middle layer, C: Finishing layer).

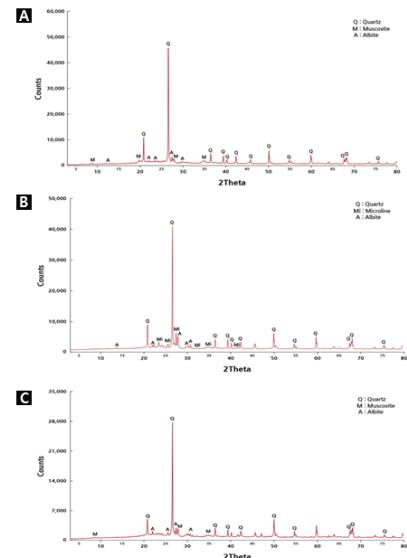
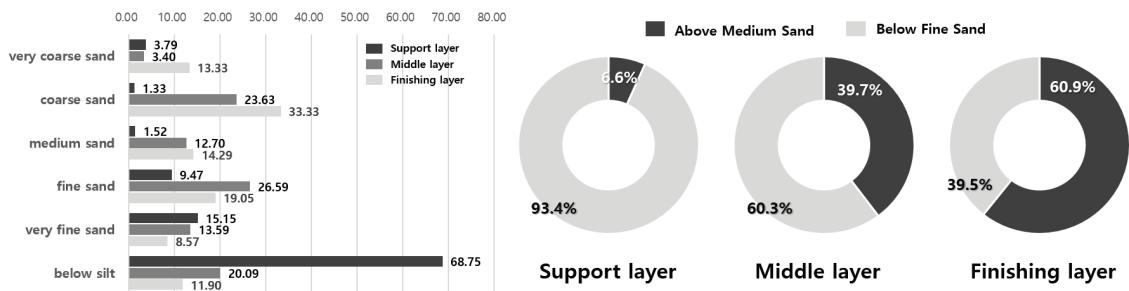


Figure 7. Results of XRD (A: Support layer, B: Middle layer, C: Finishing layer).

Table 3. Results of particle size analysis (unit: %)

	Very coarse sand	Coarse sand	Medium sand	Fine sand	Very fine sand	Below silt			
	Over 1.0 mm	1.0-0.5 mm	500-300 μm	300-212 μm	212-100 μm	100-75 μm	75-45 μm	45-25 μm	below 25 μm
S1	0.95	2.84	1.33	1.52	9.47	5.68	9.47	15.15	53.60
M1	0.44	2.95	23.63	12.70	26.59	5.47	8.12	10.78	9.31
F1	0.48	12.86	33.33	14.29	19.05	3.81	4.76	9.52	2.38

**Figure 8.** Results of particle size analysis.

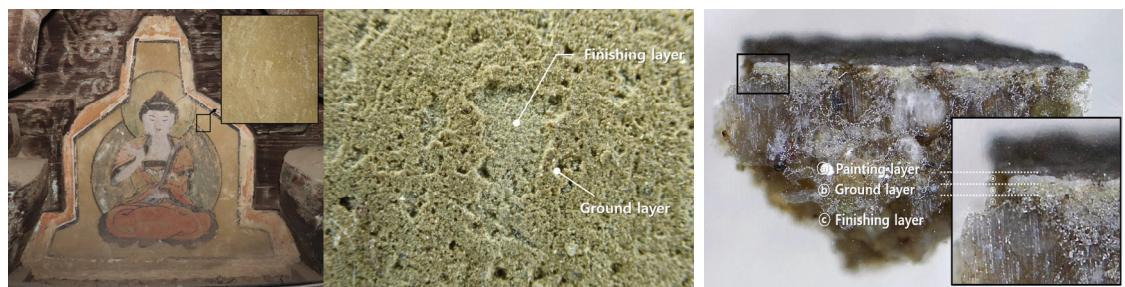
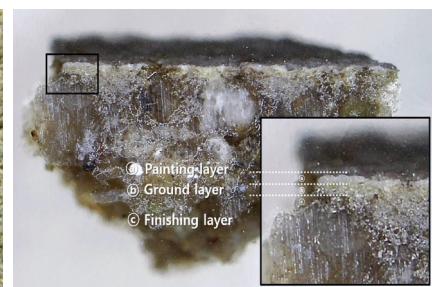
silt 11.90%. Above medium sand accounted for more than a half of the finishing layer of bracket murals, and it had a higher percentage of sand than other layers. When the particle size distribution was divided into above medium sand and below fine sand, the finishing layer had an opposite trend to the middle layer in terms of the particle size distribution.

3.2. Properties of painting layer

3.2.1. Structure of painting layer

Murals in Daeungjeon Hall, Gaeamsa Temple, Buan were painted in seven colors: white, black, grey, dark green, pale green, red, and flesh color. By examining the surface of the murals, this study identified the ground layer (Figure 9). The

retrieved samples were used to investigate the cross-section and showed some traces, confirming that the ground layer was made and painted on top of the finishing layer (Figure 10). The ground layer was pale ochre (off white) and had the thickness of 35 to 50 μm . The painting layer painted on the ground layer had the thickness of 22 to 80 μm . The painting layer in the white sample (P1) had thickness with 21.53 μm in thin parts and 38.3 μm in thick parts, while the painting layer in the green sample (P2) ranged from 45.77 μm to 79.38 μm in thickness. In addition, another green sample of P3 other than P2 ranged from 36.33 μm to 48.46 μm in thickness, which showed a difference of 2.69 μm to 43.05 μm from P3, albeit in the same color category. Lastly,

**Figure 9.** Coloring condition of mural painting.**Figure 10.** Structure of painting layer.

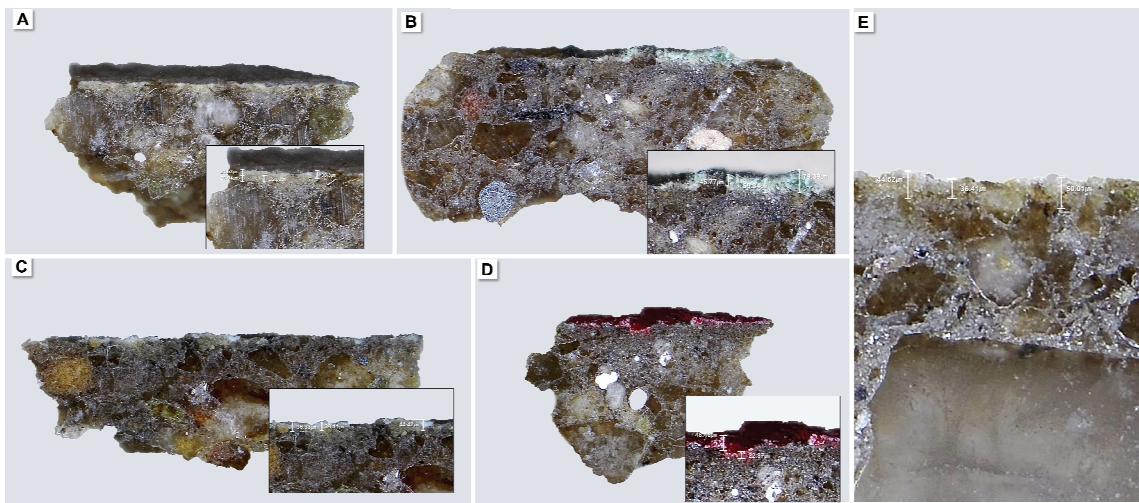


Figure 11. Thickness measurement results for painting layer through cross-section (A: Cross section of P1, B: Cross section of P2, C: Cross section of P4, D: Cross section of P3, E: Cross section of G1).

the red sample (P4) from $26.91 \mu\text{m}$ to $48.46 \mu\text{m}$ in thickness (Figure 11).

3.2.2. Material of painting layer

Based on the results of the cross-section investigation into the structure of painting layer, the results of chemical components analyzed from 4 samples from the ground layer and the painting layer are provided in Table 4 and Figure 12. G1 found in the ground layer mainly consisted of silicon (Si) and aluminum oxide (Al), along with calcium (Ca) and iron (Fe). To confirm whether there was the ground layer below the painting layer, samples from the painting layer were analyzed for parts suspected to be the ground layer through the microstructure, which showed the layer below the painting layer in P1 to P4 had the same chemical composition as G1. The white P1 was confirmed to contain lead (Pb) and sulfur (S), and the green mainly consisted of P2 copper (Cu) and chlorine (Cl), along with tin (Sn), lead (Pb), and sulfur (S). P3 had copper (Cu), tin (Sn), lead (Pb), and sulfur (S).

The red P4 mainly consisted of mercury (Hg) and sulfur (S).

4. DISCUSSION AND CONCLUSION

By conducting a scientific analysis on the structure and material of the bracket mural paintings inside the Daeungjeon Hall in Gaeamsa Temple, Buan, the characteristics of the walls and painting layer and the method of manufacturing the murals could be grasped. The study results are summarized as follows.

First, an investigation into the wall structure revealed that branches were tied with straw rope and mud plaster was applied three times to produce the earthen wall.

According to studies on the wall structure of buddhist mural paintings in the Joseon Dynasty, showed that the structure of buddhist murals produced across the Joseon period includes distinguished wall into the support layer, middle layer, and finishing layer. Also, most of the support layer and middle layer generally have chopped straw mixed.

Table 4. Results of SEM-EDS

Sample name	Description	Major elements
G1	Ground layer	Al, Si, Ca, Fe
P1	White color	Pb, S
P2	Painting layer	Cu, Cl, Sn, Pb, S
P3	Green color	Cu, Sn, Pb, S
P4	Red color	Hg, S

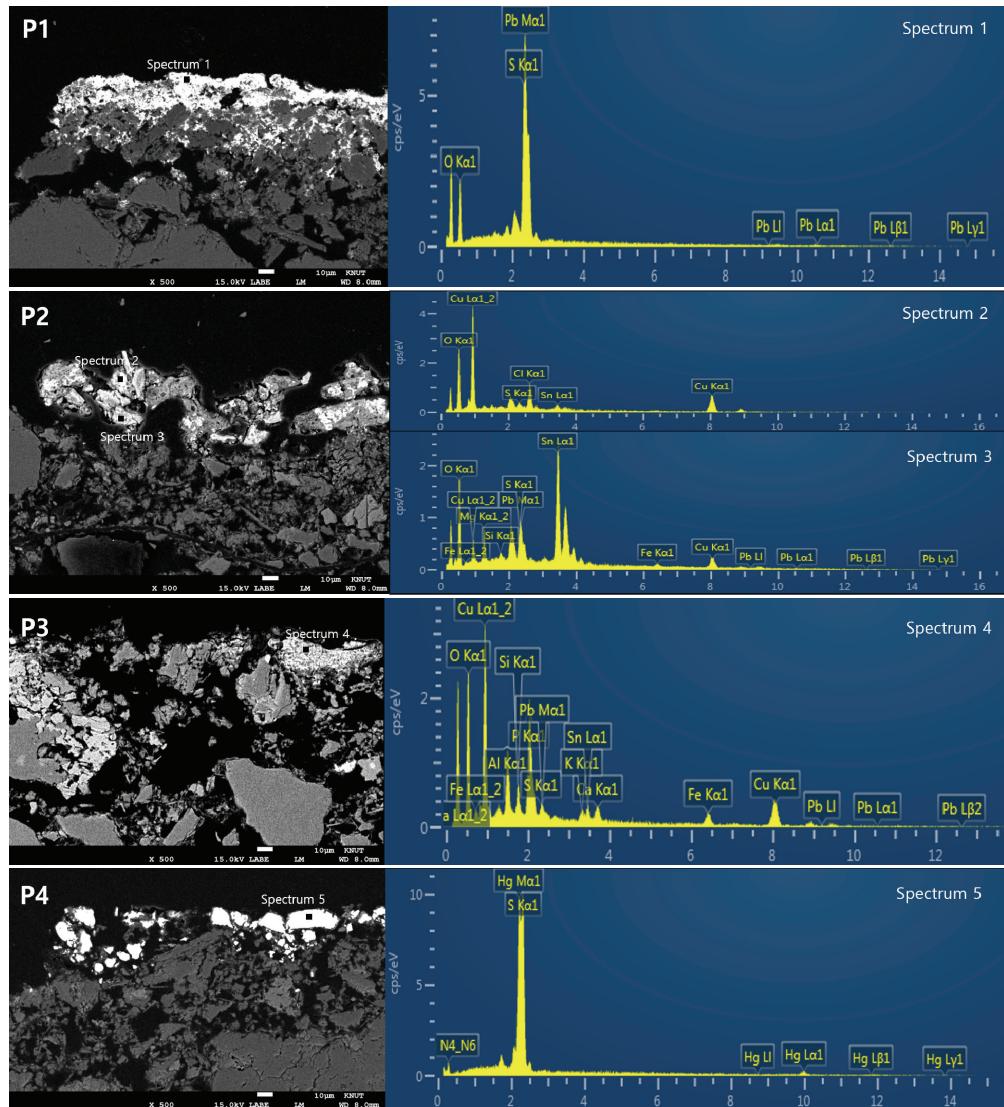


Figure 12. Results of SEM-EDS.

Like some murals at Naesosa Temple in Buan, these types in which the absence of the middle layer and wooden materials mixed, but this does not belong to the general manufacturing style of buddhist mural paintings (Lee *et al.*, 2018b).

Comparing the characteristics of the previously reported buddhist murals with the bracket murals of Daeungjeon Hall in Gaeamsa Temple, it can be that the murals at Daeungjeon at Gaeamsa belong to the category of general buddhist mural paintings. However, it is not a general tendency that the middle layer is applied more than once, that wood is mixed in the wall, and that materials presumed to be chopped straw

were rarely identified. The thickness of the bracket murals of Daeungjeon Hall in Gaeamsa Temple was investigated to be about 60 mm, and the thickness of the support layer was about 50 mm. This result is similar to the thickness of the general buddhist murals, but compared to the murals in which the middle and finishing layers are created one at a time with a thickness of about 10 mm, the bracket murals of Daeungjeon Hall in Gaeamsa Temple have two or more layers. It seems that the middle layer and finishing layers of Gaeamsa Temple's mural paintings have a thin thickness. Multiple applications of thin walls have the advantage of preventing cracks and allowing the walls to dry well (Hwang,

2008). While if it is manufactured without considering the particle size, the adhesive force between the layers may be lowered, thereby aggravating the damage caused by the separation between the layers. And since fiber reinforcements used in the wall, such as chopped straw, prevent cracks and dispersions due to the contraction of the wall (Han, 2003), the absence of such materials would serve as a vulnerability if physical damage to the wall occurs.

An analysis of the microstructure and chemical composition of particles consisting of each layer of bracket murals detected soil particles of various sizes or crystal aggregates in plates and chemical components usually found from soil materials such as silicon (Si) and aluminum oxide (Al). Furthermore, the mineral crystal habit such as quartz and feldspars was identified, demonstrating that the main materials of the wall layer and the finish layer were weathered soil and sand originating from rocks, which is consistent with the results of a previous study on the wall material characteristics of temple murals (Lee, 2016).

A particle size analysis found that the support layer had a high content of loess, while the middle layer and the finishing layer had a fairly high content of sand. In the support layer, above medium sand accounted for 7% and below fine sand 93%. And since the proportion of soil less than silt is 53.6% even in the soil of fine sand or less, it is estimated that the support layer is made by mixing soil of relatively even and fine soil materials to produce the murals. In the middle layer, above medium sand accounted for 40% and below fine sand 60%, showing that it had a higher fine sand content than the support layer. In the finishing layer, above medium sand accounted for 60% and below fine sand 40%, compared to other layers, the proportion of very coarse sand and coarse sand size soil is high, indicating that the content of large sand is high. The difference in the particle size distribution of the soil at each layer indicates the difference in the voids according to the arrangement of the soil particles, and the attractive force according to the particle gap affects the cracks or strength of the wall, which is directly related to the conservation of the mural. In particular if moisture were absorbed and released repeatedly in the wall, this condition would lead to changes in the volume fraction between wall layers, create a difference in stress over the long term, and cause physical damage such as cracks and separations between the layers

(Lee *et al.*, 2018b). As it can be seen that the pattern of damage confirmed in the current murals of Gaeamsa Temple reflects some of these structural and material characteristics, attention is required for the conservation of the murals.

An analysis of samples by the digital microscope found five colors: white, dark green, pale green, red as well as ochre in the ground layer. From the ochre ground layer, silicon (Si), aluminum oxide (Al), calcium (Ca), and iron (Fe) were detected as the main components, which suggest soil pigments such as loess or kaolinite may have been used. In the white color layer, lead (Pb) and sulfur (S) were the main components, and lead (II) sulfate seems to have been used. For green, copper (Cu) and chlorine (Cl) were observed as the main components, and atacamite may have been used. For red, mercury (Hg) and sulfur (S) were detected, showing that mercury sulfide pigments may have been used. The existence of the ground layer and the pigments used in the painting layers identified in the bracket mural paintings of Gaeamsa Temple belong to the category of the types of pigments applied to the buddhist murals of the Joseon Dynasty investigated so far, and their production methods are similar. It has been reported that the conservation condition of the painting layer is relatively good compared to the wall, and, judging from the pigment used or the composition of the painting layer, no factors directly affecting the damage have been identified so far. The structure and materials of the bracket mural paintings of Daeungjeon Hall in Gaeamsa Temple, Buan have a similar manufacturing style in terms of the earthen wall layer, pigments, and techniques, compared to the Buddhist mural paintings in the Joseon Dynasty studied so far. Such information can provide useful data for diagnosing the conservation status of the bracket mural painting in Gaeamsa Temple and is expected to provide effective information on materials and technologies for conservation treatment planning.

ACKNOWLEDGMENTS

This paper was written as part of Konkuk University's research support program for its faculty on sabbatical leave in 2021.

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