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Research Article

Conservation Status Diagnosis of Mural Painting in Geungnakjeon Hall of Daewonsa Temple, Boseong: Avalokitesvara Bodhisattva Mural and Buddhist Monk Bodhidharma Mural

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ABSTRACT Investigation of conservation status, optical survey, infrared thermography, and ultrasonic examination were performed on Avalokitesvara Bodhisattva mural and Buddhist Monk Bodhidharma mural to determine the conservation status and physical properties. As a result of investigation of conservation status, the types of damage are largely divided into the wall and finishing layer damage, painting layer degradation, damage due to restoration materials, stains and contamination, and biological damage. As a result of the optical survey, drawing, stains, and repainted site were confirmed. Result of the infrared thermography, the delamination of the finishing layer was confirmed, and some locations and shapes of the wooden lath inside the wall were identified. The result of the 3D scanning, the deviation, and the separation of the wall was confirmed. As a result of ultrasonic examination, it was confirmed that the physical properties of the mural were identified and the ultrasonic speed was relatively low due to physical damage such as delamination and exfoliation of the finishing layer and cracking. Ultrasonic speed values were also high in some wall cracks or delamination, and it was confirmed by the infrared thermography results that the wooden lath inside the wall was located in those parts. It was possible to understand that the wooden lath inside the walls affects the ultrasonic speed during the ultrasonic examination. Therefore, management through periodic inspection of the relevant elements is necessary, and a countermeasure for damage that may occur in the future should be prepared along with intensive monitoring of the major damage identified in this diagnosis result.

Key Words Buddhist mural painting, Conservation status, Non-destructive diagnosis, Investigation, Preservation

1. INTRODUCTION

Buddhist murals in Korea are constantly damaged due to environmental factors, limitations of the materials, and structural factors of the wooden structures (Lee, 2012). Especially the murals painted on earthen walls suffer from various types of damage compared to damage on other relics, therefore it is necessary to continuously record and observe the damage.

Research related to the conservation of the Buddhist murals in Korea has been widely conducted since the 2000s and in addition to theoretical studies such as damage factors and conservation methodology, research applicable to conservation treatment, preliminary investigation and diagnosis, and restoration materials treated in the past, research results were published. As an example of mural diagnosis research conducted in Korea, there is a study on the status of damage to the murals on the inner wall of Geungnakjeon Hall of Muwisa Temple in Gangjin (Institute of Conservation of Paintings, Konkuk University *et al.*, 2006) and overseas, there is a diagnostic study on the mural in Phaya-Thone-Zu Temple in Bagan, Myanmar (Korea Cultural

Heritage Foundation *et al*., 2018).

The Avalokitesvara Bodhisattva mural and the Buddhist Monk Bodhidharma mural in Geungnakjeon Hall of Daewonsa Temple in Boseong are on the east and west walls inside of Geungnakjeon Hall. The two murals, said to have been made in the mid-18th century, were designated as treasures in 2015 and conserved for their cultural value (Figure 1). It is estimated that the murals were repaired at the time of repair of Geungnakjeon Hall and Dancheong in 1983 and reported that conservation treatment was made in 2012 by universities in Korea and Japan (Kim, 2018).

The wooden structure of the Avalokitesvara Bodhisattva mural and the Buddhist Monk Bodhidharma mural of Geungnakjeon Hall of Daewonsa Temple in Boseong is formed between the Jongryang (floorboard) at the top and the Changbang (lintel) in the center, with the central Goju (high column) of the two rows of left and right side walls of the Geungnakjeon Hall building. In the center of the mural, a two-row vertical Jungbangjae (windowsill) prevention is located. The Avalokitesvara Bodhisattva mural and the Buddhist Monk Bodhidharma mural are painted on the earthen wall and Jungbangjae (windowsill), and represent the style for making Buddhist murals in the Joseon Dynasty.

For the wall, wooden lath was weaved with twine to prepare a frame, and then the first layer, middle layer, and finishing layer were made with pugging mixed with sand, red clay, and fibers. For the painting layer, green earth was used to form a ground layer, and then pigments such as lead white, white clay, atacamite, copper green, smalt, cinnabar, hematite, and minium were used(Bosung-gun *et al.*, 2021).

As part of the mural conservation treatment project in 2021, a investigation on the conservation status of the murals was conducted, and damage such as cracks and exfoliation of the wall, deterioration of the painting layer, contamination, and damage due to restoration materials, and it was confirmed that conservation treatment was necessary (Bosung-gun *et al.*, 2021).

Scientific diagnosis and investigation of the murals can record the degree of damage and reveal the cause and suggest a more reliable and effective conservation methodology (Lee *et al.*, 2018). Therefore, in this study, various scientific diagnostic methods were applied to the Avalokitesvara Bodhisattva mural and the Buddhist Monk Bodhidharma mural in Daewonsa Temple, and the physical properties of the murals were identified, and the overall conservation status was evaluated by comparing and analyzing the results of the

Figure 1. 3D scanning image and scale for current status (A: Avalokitesvara Bodhisattva mural, B: Buddhist Monk Bodhidharma mural).

conservation status investigation.

2. RESEARCH METHOD

2.1. Investigation of Conservation Status

To understand the type and degree of damage to the murals, the status of conservation was investigated based on the visual investigation. A digital camera (G-15, Canon, Japan; TG-3, Olympus, Japan) was used to record the damage. The damage was divided into the wall and painting layer and subdivided by the main type (Table 1). To create damage mappings for murals, we used digital image analysis program PicMan (WaferMasters, Inc., USA) and the image editing program Photoshop (Adobe, USA). The conservation status was evaluated by creating a damage mapping based on the color information of the mural's digital image and comparing it with the damage status investigation result.

2.2. Optical Survey

Infrared and ultraviolet photography was carried out to identify matters such as the presence of drawings, which are difficult to visually confirm, and traces of past conservation treatments such as repainting. Infrared photography was used by installing a 912 filter on an IR lamp and infrared camera (EF-X8, Fujifilm, Japan). The ultraviolet photograph was performed using a UV lamp and DSLR camera (EOS 800D, Canon, Japan).

2.3. Infrared Thermography

A high-resolution thermal imaging camera (Testo 882, Testo, Germany) and interlocking software were used to diagnose the surface cracks and delamination of the murals. Since the investigation environment is indoors, an active method of applying heat using a halogen lamp was used.

2.4. Ultrasonic Examination

To identify the distribution of the surface properties of the murals, ultrasonic measurement (Ultracon-170, MKC Korea, Korea) using a needle rod type probe was performed. Measurement was carried out by an indirect method, and the measurement conditions were set as P wave, voltage of 1200 V, and a frequency of 5 Hz. The distance between the probes was 150 mm, and the ultrasonic speed was measured at 276 points for the Avalokitesvara Bodhisattva mural and 262 points for the Buddhist Monk Bodhidharma mural, and then an image distribution map was created based on the average value.

2.5. 3D Scanning

3D-scanning (Faro X330 3D Laser Scanner, Faro Technologies Inc., USA) was performed to evaluate the wall spacing and wall surface smoothness. Since the murals are placed high on the left and right walls of the building, a wideband scan was performed to obtain 3-dimensional shape coordinates.

Table 1. Classification according to the type of damage and used color information

Classification	Color Information used in the PicMan			
	H	S	V	
Crack of Wall	4-114	30.6-53.3	1.2-27.8	
Delamination of Finishing Layer	-	-	-	
Exfoliation of Finishing Layer	16-55	49.8-76.5	15.3-42.0	
Delamination of Painting Layer	-	-	-	
Exfoliation of Painting Layer	27-52	24.7-51.4	66.7-85.5	
Contamination	20-45	27.5-46.3	72.9-87.8	
Restoration Material	4-72	37.6-87.8	27.8-78.0	
Damage of Wooden Structure	4-58	24.7-71.0	2.4-32.9	
Biological Damage	28-68	2.7-21.6	53.3-64.3	

3. RESULTS

3.1. Investigation of Conservation Status

The main damage to the wall is cracks. In the case of the Avalokitesvara Bodhisattva mural, cracks are found throughout the mural, and it is concentrated in the center and the right part (Figure 2A). In the case of the Buddhist Monk Bodhidharma mural, cracks were observed in Buddha's face (Figure 3A), and the cracks were worsened in the lower left part of the mural.

For damage to the finishing layer, exfoliation and delamination damage are mainly observed in the Avalokitesvara Bodhisattva mural at the point where the edge and the Junggit meet (Figure 2B). Buddhist Monk Bodhidharma mural, like Avalokitesvara Bodhisattva mural, was also mainly found to have damage to the finishing layer in the area in contact with the edge and Junggit of the mural (Figure 3B).

In both murals, the painting layer painted on the earthen wall was mostly in good condition, but delamination and exfoliation damage mainly occurred in the painting layer on the surface of the Junggit. Regarding the Avalokitesvara Bodhisattva mural, delamination and exfoliation are mainly observed in the green painting layer painted on the Junggit, and another painting layer is found under the exfoliated painting layer in the turquoise color of mudra and the lower part of the Yeonhwamun (louts pattern) (Figure 2C). In the Buddhist Monk Bodhidharma mural, delamination and exfoliation are observed mainly in the orange painting layer painted over the Junggit (Figure 3C).

Damage to the area restoration material during the past repair is confirmed in both murals. In the Avalokitesvara Bodhisattva mural, the restoration material area is roughly treated, therefore it feels different from the surrounding mural surface, and cracks or separation from the surrounding mural are observed (Figure 2D). The restoration material areas of the Buddhist Monk Bodhidharma mural also show damage similar to those of the Avalokitesvara Bodhisattva mural (Figure 3D).

In case of the surface stains and contamination of murals, the Avalokitesvara Bodhisattva mural shows them mainly on the parts painted in skin colors such as Buddha's face and Samdo (the three lines of Buddha's neck) and mudra. In addition, the substance presumed to be the fixative from the past treatment forms spots around the cracks, and white contamination are observed in the painting layer of the Junggit (Figure 2E). In the Buddhist Monk Bodhidharma mural, white contamination is observed on the orange painting layer of the Buddha's face, skin-colored parts, and Junggit (Figure 3E).

The biological damage is mainly caused by insects, presumed to be arachnids, and the damage is found both in the Avalokitesvara Bodhisattva mural and the Buddhist Monk

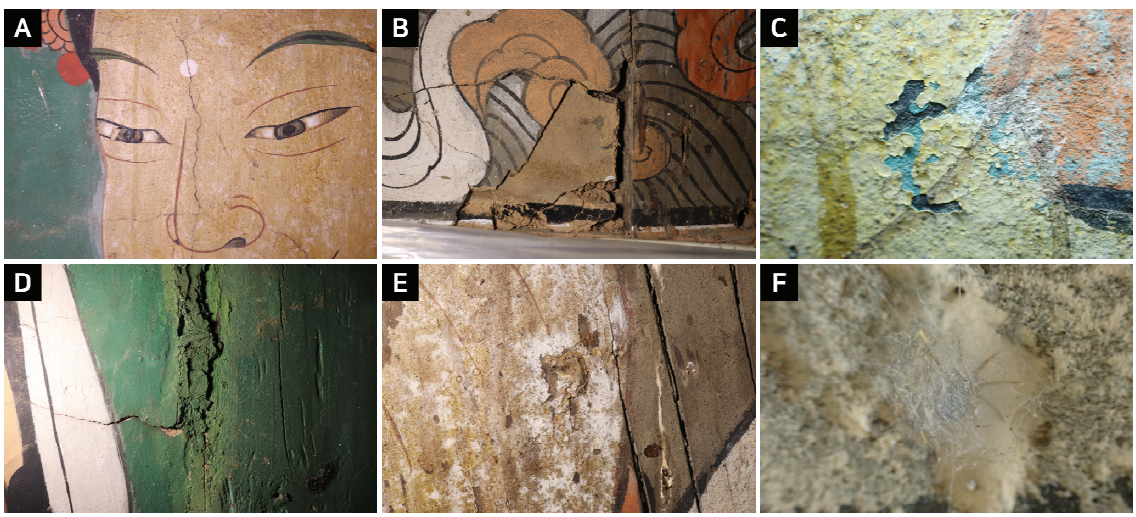

Figure 2. Type of damages of Avalokitesvara Bodhisattva mural (A: Crack of finishing layer, B: Exfoliation of finishing layer, C: Exfoliation & Delamination of painting layer, D: Restoration material, E: Contamination, F: Biological damage).

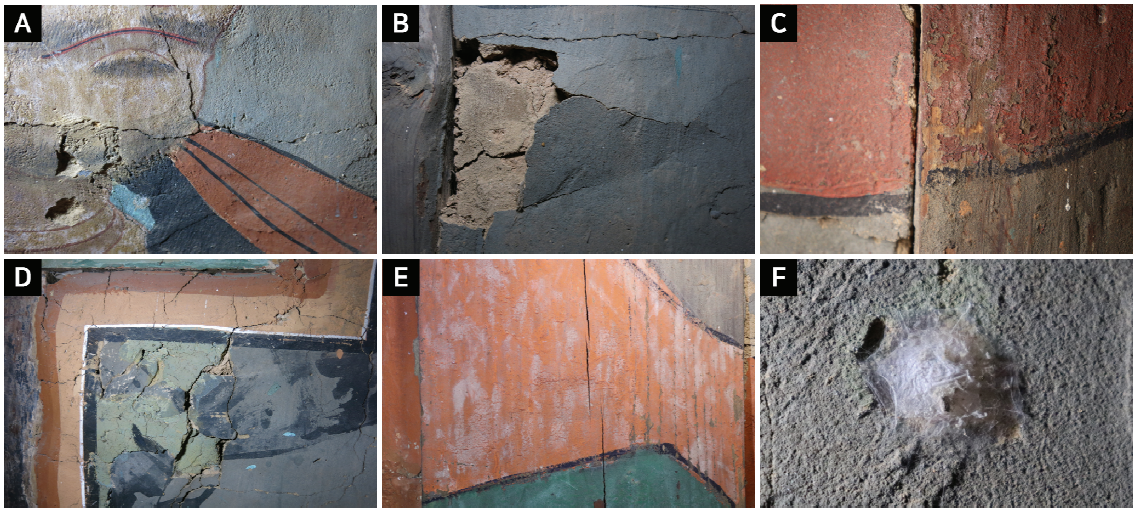

Figure 3. Type of damages of the Buddhist Monk Bodhidharma mural (A: Crack of finishing layer, B: Exfoliation of finishing layer, C: Exfoliation of painting layer, D: Restoration material, E: Contamination, F: Biological damage).

Bodhidharma mural. In particular, webs of spiders inhabiting the surface of the murals are observed, and the concentration tends to be high in the lower part of the murals (Figure 2F, Figure 3F).

Summarizing the damage caused of the Avalokitesvara Bodhisattva Mural, it was confirmed in the order of contamination (7.30%)> restoration material (6.26%)> crack (1.65%)> exfoliation of finishing layer (1.01%)> delamination & exfoliation of painting layer (0.58%)> delamination of finishing layer (0.27%). In addition, damage of wooden

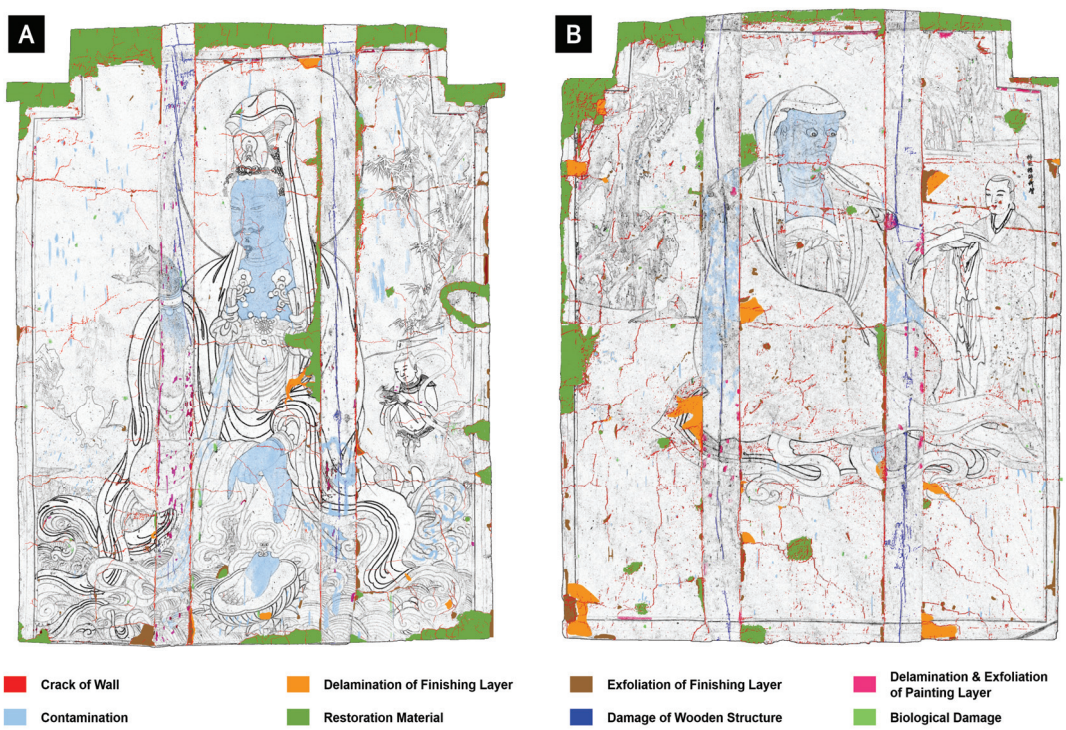

Figure 4. Damage mapping image (A: Avalokitesvara Bodhisattva mural, B: Buddhist Monk Bodhidharma mural).

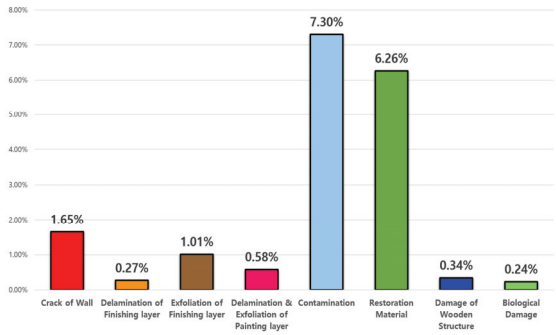

Figure 5. Graph of area by damage type of Avalokitesvara Bodhisattva mural.

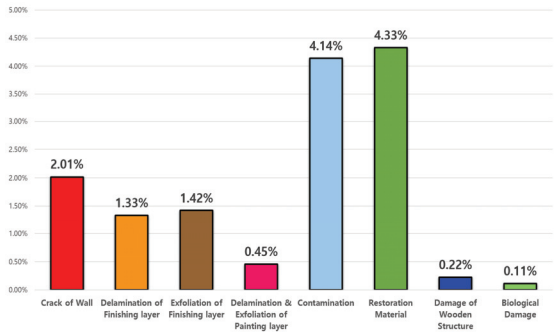

Figure 6. Graph of area by damage type of Buddhist Monk Bodhidharma mural.

structure was 0.34%, and biological damage was 0.24% (Figure 5). In the case of the Buddhist Monk Bodhidharma Mural, it was confirmed in the order of restoration material (4.33%)> contamination (4.14%)> crack (2.01%)> exfoliation of finishing layer (1.42%)> delamination of finishing layer (1.33%)> delamination & exfoliation of painting layer (0.45%). In addition, damage of wooden structure was 0.22%, and biological damage was 0.11% (Figure 4, Figure 6).

3.2. Optical Survey

As a result of infrared photography, drawing under the painting layer, which is difficult to visually identify (Figure 7A, 7B), was confirmed, and damage such as exfoliation or contamination of the painting layer was identified. As a result of UV photography, restoration material and contaminated parts were detected in both murals.

In the case of the Avalokitesvara Bodhisattva mural, the

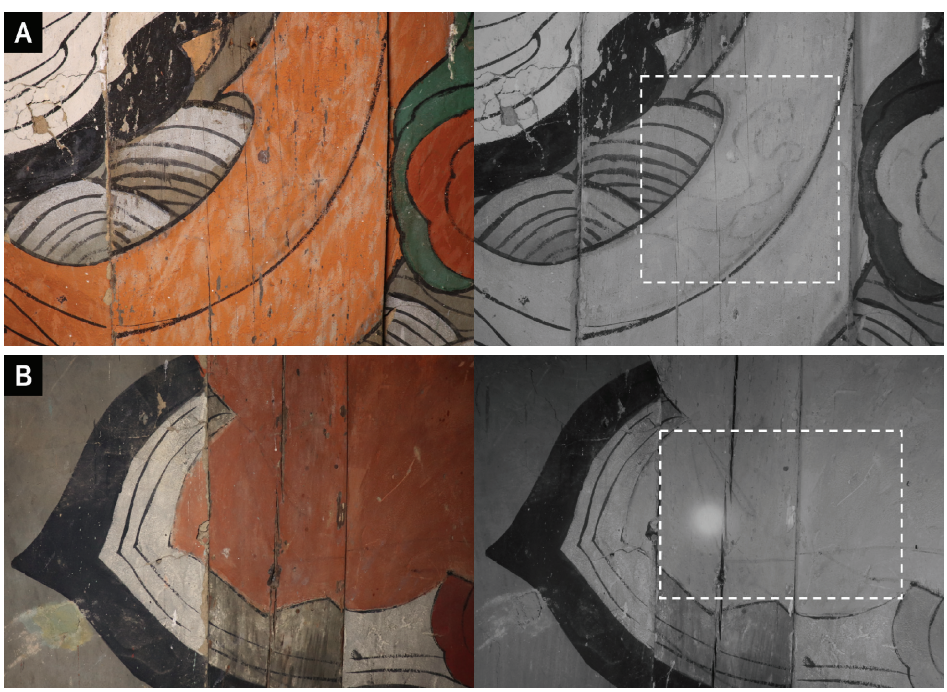

Figure 7. Result of the infrared survey (A: Detection of drawings under the painting layer in Avalokitesvara Bodhisattva mural, B: Detection of drawings under the painting layer in Buddhist Monk Bodhidharma mural).

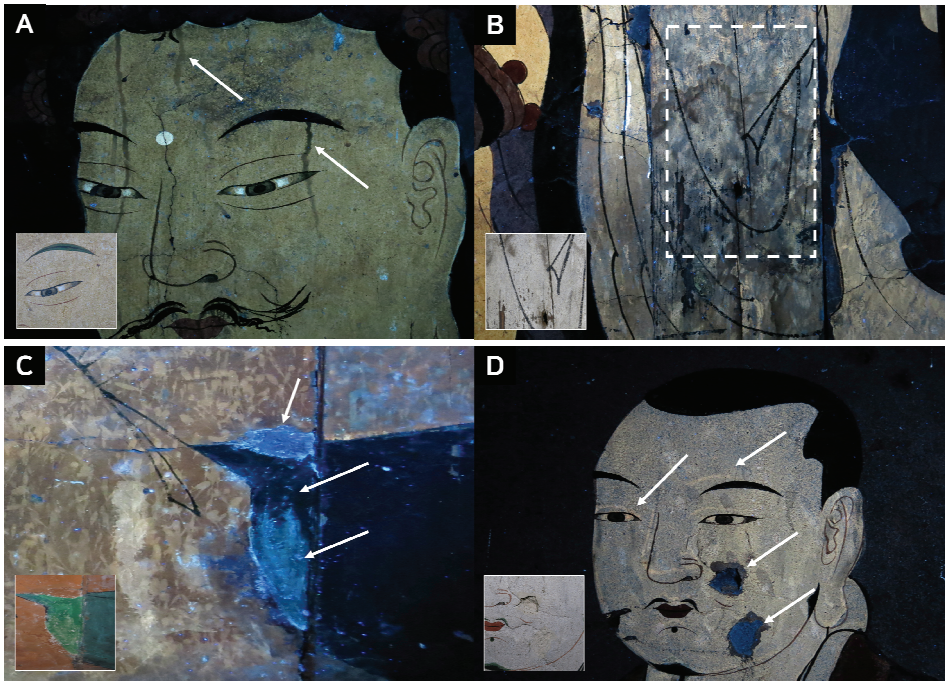

Figure 8. Result of uv survey (A: Detection of presumed to be a fixative, B: Detection of stains, C: Damage detection through uv light, D: Detection of repainted site and drawing in Huike Duanbei).

form of a material that was presumed to be a fixative from past treatment in the Buddha's face was identified by UV fluorescence reaction (Figure 8A). In the part of the white clothes above the Junggit (Figure 8B), stains that are not identified in the visible light area cause a fluorescence reaction to UV light, and a similar reaction was observed in

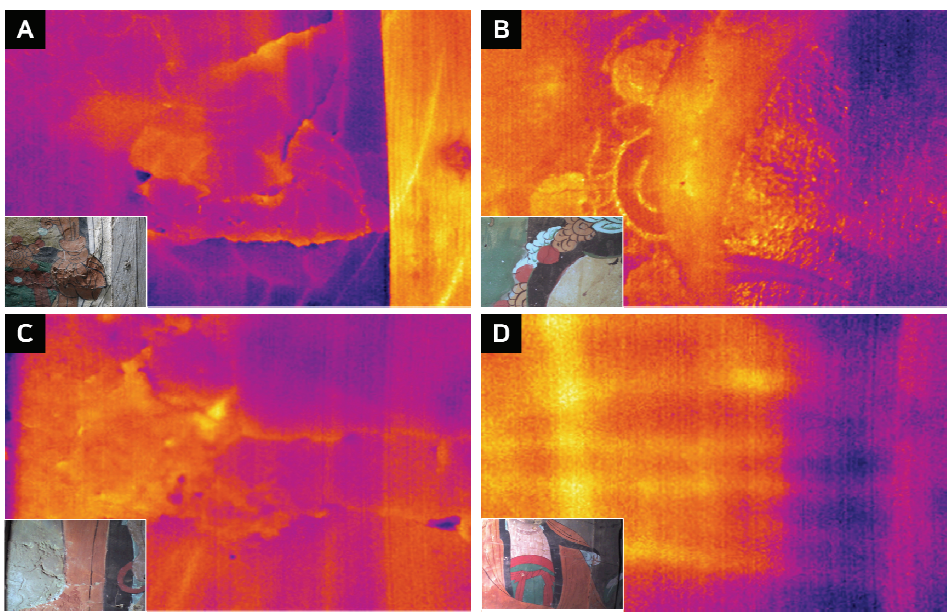

Figure 9. Result of the infrared thermography (A: Delamination of finishing layer, B: Contamination of mural's surface, C: Restoration material, D: Detection of wooden lath in wall).

various parts such as the skin color of the Sudhana Kumāra.

In the Buddhist Monk Bodhidharma mural, it was investigated that the part of the Buddha's beard, the right shoulder, and the green repainted wall adjacent to the Junggit showed UV fluorescence reaction (Figure 8C). In addition, ultraviolet fluorescence reactions were detected in areas repainted on Huike Dianbei, and drawing such as eyebrows, eyes, and nose was identified (Figure 8D).

And in both murals, biological damage such as spider webs that occurred throughout the murals reacted strongly to UV light.

3.3. Infrared Thermography

Infrared thermography was used to identify the range of physical damage to the murals. In the case of the Avalokitesvara Bodhisattva mural, there was a difference in the temperature distribution due to the delamination of the finishing layer that occurred around some wall cracks (Figure 9A). The temperature distribution on the face and chest was shown in a grid shape, and the location and shape of the wooden lath inside the wall were identified. Also, on the Buddha's face, there was a difference in the temperature distribution of the part presumed to be the fixative used in the past conservation treatment (Figure 9B). In the Buddhist Monk Bodhidharma mural, the range of the restoration material around the edge and the Junggit was identified (Figure 9C), and the shape of the wooden lath of the inner wall was confirmed from the chest (Figure 9D).

3.4. Ultrasonic Examination

With the ultrasonic speed value, it was possible to grasp the relative physical properties of each mural. The average ultrasonic speed of the wall of the Avalokitesvara Bodhisattva

Table 2. The results of the ultrasonic examination (m/s)

	Avalokitesvara Bodhisattva		Buddhist Monk Bodhidharma	
	Wall	**Junggit**	**Wall**	**Junggit**
Average	382.0	699.5	415.6	581.7
Minimum	79.5	204.0	166.0	244.0
Maximum	802.0	1277.0	872.5	1178.0

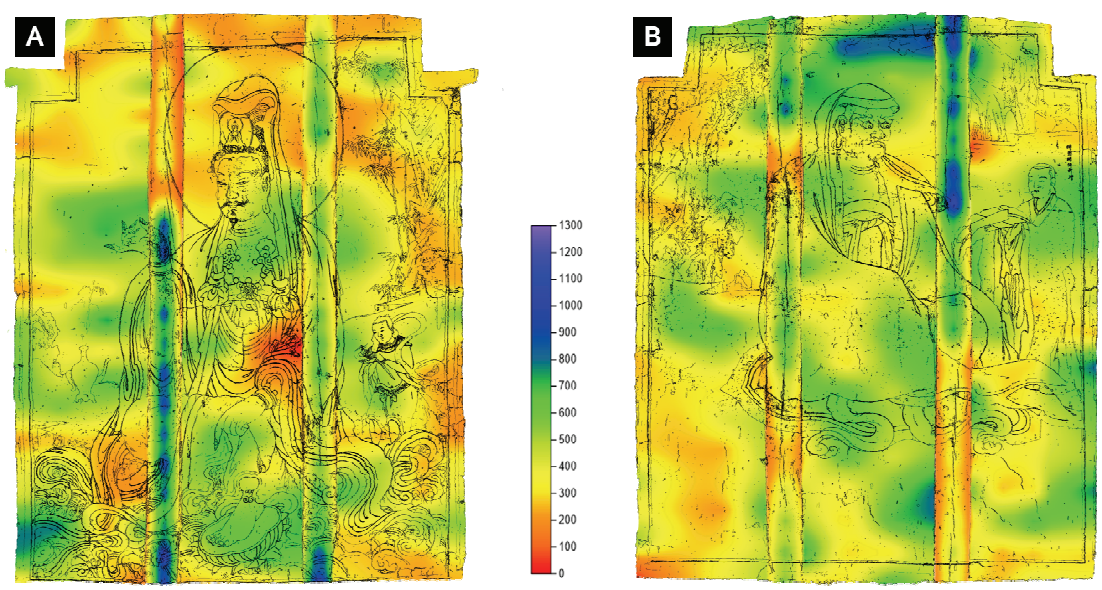

Figure 10. Ultrasonic examination mapping image (A: Avalokitesvara Bodhisattva mural, B: Buddhist Monk Bodhidharma mural).

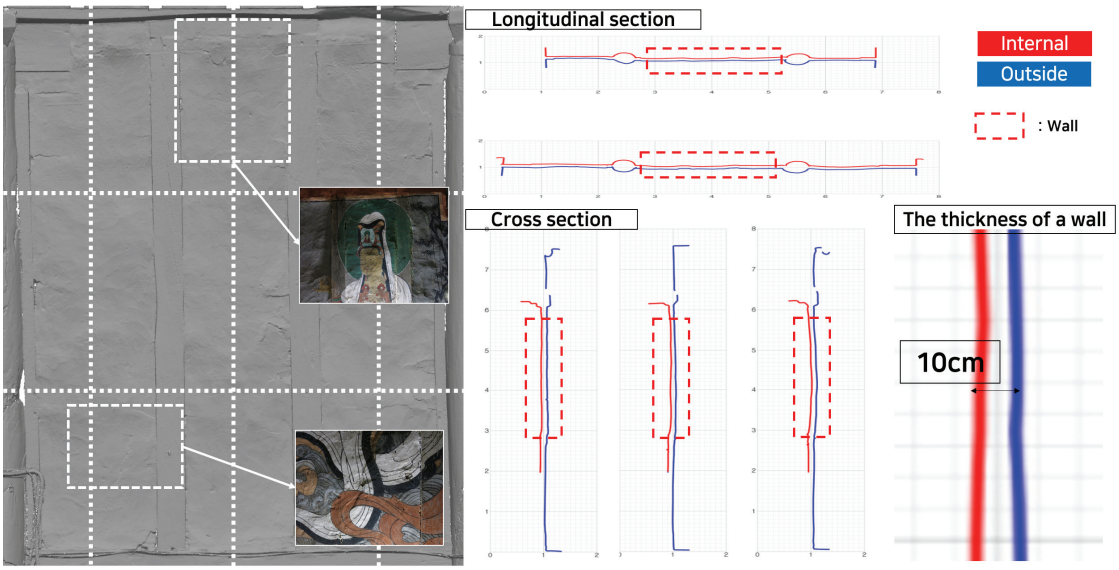

Figure 11. The result of displacement in wall.

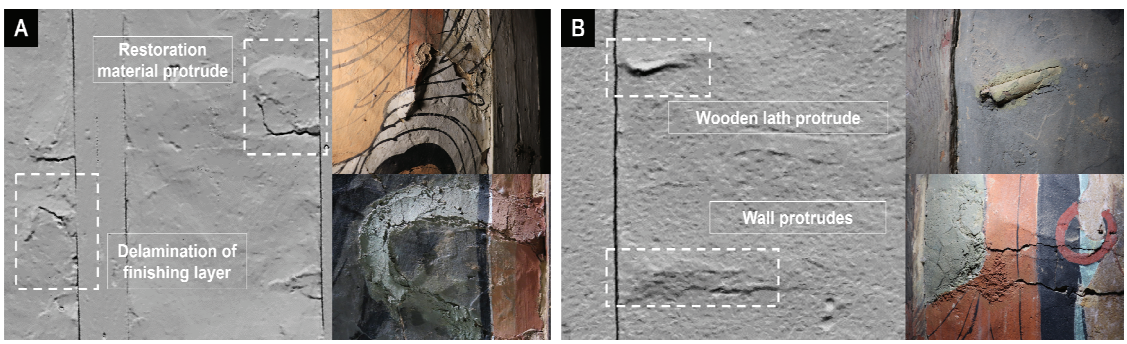

Figure 12. Detection of wall protruded to 3D scanning (A: Avalokitesvara Bodhisattva mural, B: Buddhist Monk Bodhidharma mural).

mural was about 382.0 m/s, the minimum was 79.5 m/s and the maximum was 802.0 m/s. In the case of the Junggit, the average ultrasonic speed was measured to be approx. 699.5 m/s, the minimum of 204.0 m/s, and the maximum of 1277.0 m/s. The average ultrasonic speed of the wall of the Buddhist Monk Bodhidharma mural was approx. 415.6 m/s, the minimum 166.0 m/s, and the maximum 872.5 m/s, and the ultrasonic speed of the Junggit was measured to be approx. 581.7 m/s, the minimum 244.0 m/s, and the maximum 1178.0 m/s (Table 2, Figure 10).

3.5. 3D Scanning

As a result of the 3D scanning, it was possible to estimate the degree of wall deformation of the murals (Figure 11). It was confirmed that the average thickness of the walls was about 100 mm from the results of the cross-sectional and longitudinal scan images of the walls. In the case of the Avalokitesvara Bodhisattva mural, it seems that the left center of the wall protrudes about 35 mm, and some restoration materials are separated from the wall (Figure 12A). The Buddhist Monk Bodhidharma mural also showed that the left center of the wall protruded about 32 mm, and some restoration materials were separated (Figure 12B).

4. DISCUSSION

As a result of the investigation of conservation status of

the Avalokitesvara Bodhisattva mural and the Buddhist Monk Bodhidharma mural in Geungnakjeon Hall of Daewonsa Temple, the types of damage are largely divided into the wall and finishing layer damage, painting layer damage, damage due to restoration materials, stains and contamination, and biological damage and the damage types are similar in both murals.

The cracks in the walls of the Avalokitesvara Bodhisattva mural and the Buddhist Monk Bodhidharma mural are mainly found in the location adjacent to the north side of the building. Damage to the finishing layer was mainly found in the area where the Junggit and the wall meet, and it was confirmed by the 3D scanning result that part of the finishing layer was separated around the Junggit. In a wooden architecture heritage, the load on the roof is large and the structural members tend to be deformed due to the anisotropy and corroding nature of the wood itself, and such changes worsen the damage such as cracks and exfoliation of the wall (Lee *et al*., 2015).

The geographical condition of Geungnakjeon Hall, around which there are mountains and a lake (Juam Lake), can accelerate physical changes in the structure of the building and the walls. Also, considering that the two murals are large, the micro-movement and deformation of structural members due to the self-load and the surrounding environment are factors that can cause cracks in the walls and damage to the finishing layers.

Damages such as wall cracks and exfoliation of the finishing layers found in various parts of the murals can also be related to the influence of the wooden lath, which is the wall structure, and as a result of infrared thermography, the temperature distribution image in the form of a grid was confirmed for both murals.

This is considered to be due to the result that the murals of Geungnakjeon Hall in Daewonsa Temple were made with the wooden lath adjacent to the finishing layer compared to other Buddhist murals. The ultrasonic measurement results of both murals were found to be somewhat higher than those of the existing Buddhist murals of the Joseon Dynasty (Chun *et al*., 2009; Kim *et al*., 2014; Lee *et al*., 2018).

This is due to the influence of the wooden lath, which has a higher ultrasonic speed than the wall and it is assumed that the wooden lath is close to the wall surface therefore the average speed is measured high. Ultrasonic speed values were also high in some wall cracks or delamination sites, and it was confirmed by the infrared thermal imaging results that the wooden lath inside the wall was located in those parts (Figure 13D, 13E, 13F).

If structural deformation of the murals occurs under the condition that the wooden lath is adjacent to the surface of the mural, cracks in the wall or exfoliation of the finishing layer may be developed faster, and additional damage may occur in the current conservation status. Therefore, it is necessary to observe the physical change in the murals through periodic monitoring and to respond promptly when a change occurs.

Another factor that affects wall damage is the wall restoration material used in the past repair. Through various diagnostic techniques, damage to the wall caused by the restoration material or damage caused to itself was confirmed. The difference in physical properties between the wall and the restoration material was identified through infrared thermography and ultrasonic examination (Figure 13A, 13B), and as a result of the 3D scanning, deviation or separation from the original wall was confirmed (Figure 13C). Since the difference in the physical properties of the wall and the restoration material and the physical change of the wall can indicate continuous damage, reinforcement using materials with similar properties to the wall as a supplement for a weak element or a wall reinforcement should be considered.

In addition to the examination of the diagnosis results, it was possible to understand that the structure inside the walls affects the ultrasonic speed during the ultrasonic examination (Figure 13E). Since the ultrasonic examination result is not an absolute value indicating the physical properties of the murals, this study suggests that it is necessary to use it along with a technique such as infrared thermography in order to increase the reliability of the physical property diagnosis result.

In the case of painting layer damage, exfoliation and delamination were observed mainly in the painted area of the Junggit. It seems that the coefficient of contraction and expansion of wood is larger than that of the wall, and the decay status of wood also affects it. The main factor in the exfoliation of the painting layer is a decrease in adhesion due to the decomposition of the medium, but it may also occur due to the different physical properties of the painting layer

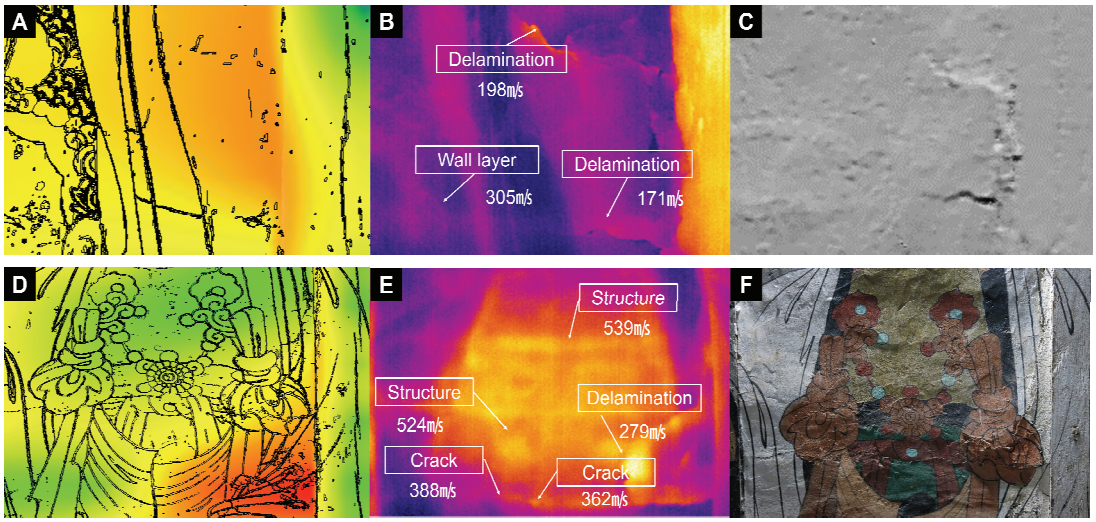

Figure 13. The result of non-destructive diagnosis in the Avalokitesvara Bodhisattva mural (A: Detection the ultrasonic speed difference between the wall and the restoration material, B: Delamination of wall detection by an infrared thermograph, C: 3D scanning image of deviation site, D: High values of ultrasonic speed in some wall cracks or delamination sites, E: Wall interior wooden lath detection by an infrared thermograph, F: A real image of E).

and the support layer. Therefore, it can be said that a fixing treatment is necessary for the deteriorated painting layer to increase the bonding force between the pigments and the adhesion with the support layer.

As a result of the optical survey, the conservation status of various types of painting layers was identified through ultraviolet fluorescence reaction. There are two aspects of staining, the first aspect seems to be the effect of the presumed fixative used in the past conservation treatment, and the second aspect is the influence caused by a specific action taken at the time the mural was painted or after the mural was painted.

In some cases, the conservation status is good where a stain caused by a presumed fixative is found, but there are parts where the painting layer has deteriorated (Figure 14B). It seems that measures such as fixation treatment are necessary for areas where the painting layer is cracked or exfoliation or delamination off due to the change in the presumed fixative. Also, areas showing luster and stains while the presumed fixative forms a film of paint on the surface of the painting layer may show damage due to deformation or discoloration in the future, therefore a methodology for periodic inspection and stabilization should be prepared (Figure 14A, 14C).

Another type of stain is the irregular stains seen in many painting layers. It is found mainly in the orange robes of the Buddhist Monk Bodhidharma mural, and this is also confirmed in some cases in the UV fluorescence response to other Buddhist murals. It can be said that a detailed investigation of the cause is needed through additional

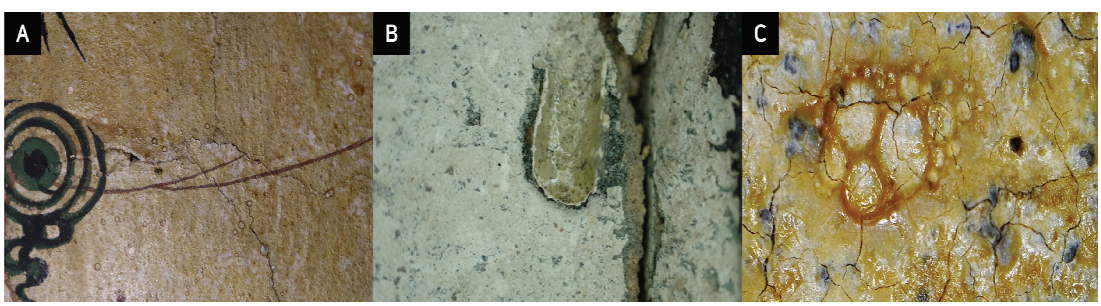

Figure 14. Damage caused by presumed to be the fixative (A: Crack, B: Delamination, C: Gloss).

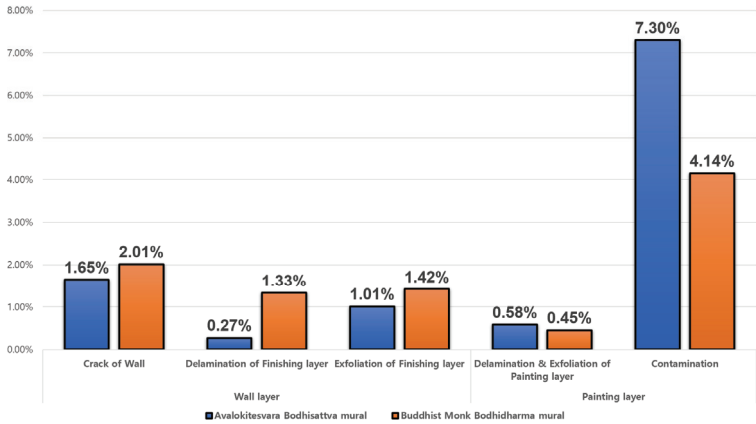

Figure 15. Comparison of damage to murals.

research.

And UV fluorescence reaction different from the surrounding color was confirmed in the parts that were repainted on restoration material in the past repair. It is necessary to periodically observe the change in color or restoration material area while maintaining the current condition for regions that do not show great heterogeneity in the visible light area.

As a result of comparing the area values of the two murals by type of damage, the Buddhist Monk Bodhidharma mural showed 1.84% higher damage to the wall and finishing layer than the Avalokitesvara Bodhisattva mural, and in particular, the damage to the delamination of finishing layer showed a greater difference. The damage to the painting layer is 3.29%, indicating that the Avalokitesvara Bodhisattva mural is more damaged than the Buddhist Monk Bodhidharma mural (Figure 15).

In addition to structural factors, damage to murals is caused by various factors such as the materials used, painting techniques, and the surrounding environment. Although the types of damage caused to the two murals are similar, the Avalokitesvara Bodhisattva mural was evaluated to have a relatively greater degree of damage compared to the Buddhist Monk Bodhidharma mural. Although the two murals were created inside the same building, as mentioned above, the degree of damage varies depending on the structural relationship where the murals are located in the building, the environmental conditions, the materials and painting techniques used to make the murals, and the restoration materials, methods and range. Therefore, management through periodic inspection of the relevant elements is necessary, and a countermeasure for damage that may occur in the future should be prepared along with intensive monitoring of the major damage identified in this diagnosis result.

5. CONCLUSIONS

A more accurate and objective judgment is needed because the conservation status diagnosis for murals can be used as important data for conservation treatment. Through such diagnosis, it was possible to identify the types and ranges of damage according to various conditions and characteristics, such as the structures and materials of the murals, and the restoration material sites. The diagnosis results obtained from the study were used as effective information to evaluate the conservation status of the murals, and by examining the causes of damage and conservation methodology, a conservation methodology for the Avalokitesvara Bodhisattva mural and the Buddhist Monk Bodhidharma mural in Geungnakjeon Hall of Daewonsa Temple was suggested. In the future, technical research on the diagnosis of murals should be continuously conducted, and effective conservation measures for the conservation of the murals should be suggested.

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