

Method for cleaning epiphytes on stone monuments

Masayuki Morii * and Wataru Kawanobe

Abstract

Epiphytes are not only a factor for pollution but also for deterioration of the surface of stone monuments. These have been removed by surface cleaning which includes physical removal with a bamboo stick or a brush, steam cleaning or killing of epiphytes by chemicals. However, each method requires the skills of an experienced restorer because of the great possibility of damage by such attempts. Thus, cleaning epiphytes from stone monuments with UV-C irradiation was developed as a safer method than the usual physical cleaning. In this report, two cases of UV-C irradiation method will be introduced.

First, an attempt was made to remove moss that covered a Buddhist image carved on tuff cliff. At the Usuki Stone Buddha, moss covered the weak-welded layer in particular. It was confirmed that most of the moss (*Gymnostomum aeruginosum* Sm. and *Weissia longidens* Card.) were killed by UV-C and easily removed. But with bryophytes (*Conocephalum conicum* (L.) Dumort.), only those on the surface layer were killed at one trial, and repeated irradiation and removal were required. It was also confirmed that coating the surface with silicon-based water repellent

after cleaning was effective in order to control epiphytes.

Second, an attempt was made to remove lichens (*Chrysothrix candelaris* (L.) J. R. Laudon and others) at the Kumano Stone Buddha. Observation showed that lichens were damaged by UV-C irradiation and could be easily removed with an airbrush.

Introduction

The growth of epiphytes, including bryophytes and lichen, is one of the main factors of deterioration of stone cultural properties along with salt weathering and frost damage. In addition, it can also become a factor that obstructs appreciation because of the conspicuous color of epiphytes. For this reason, in normal work of conservation epiphytes are removed as a part of the process of cleaning.

Conventionally, epiphytes are removed physically by using a bamboo stick or a brush. However, since such a physical removal involves the risk of damaging the surface of the treated sculpture, great care is required as well as a tremendous amount of time. Thus, the authors considered a method for physically removing epiphytes by irradiating UV-C

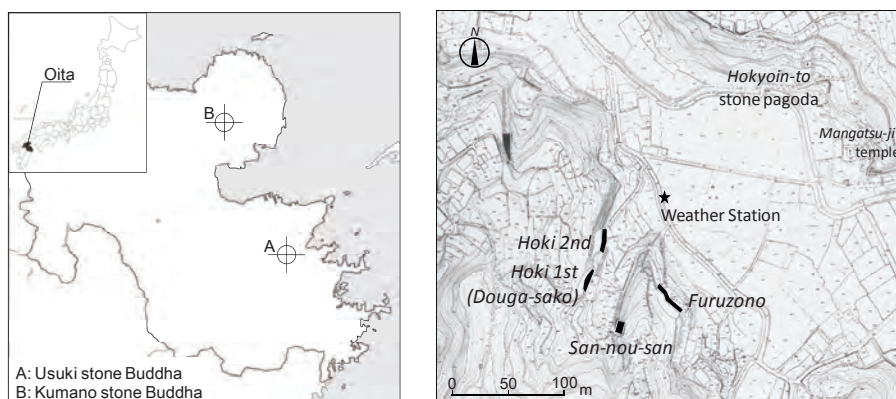


Fig.1 Location of Usuki Stone Buddha and Kumano Stone Buddha

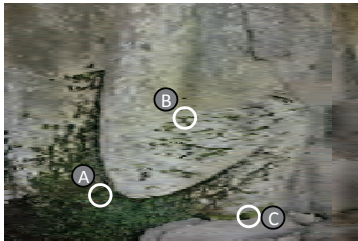
National Research Institute for Cultural Properties, Tokyo

* Corresponding author

Center for Conservation Science and Restoration Techniques, National Research Institute for Cultural Properties, Tokyo
13-43 Ueno-park, Taito-ku, Tokyo, 110-8713, Japan,

E-mail: morii@tobunken.go.jp, Tel: +81-3-3823-4922, Fax: +81-3-3823-4835

Table 1 Identification of bryophytes on the surface of Dainichi Nyorai Zazo

Sampling point	Analysis result
	A) <i>Conovephalum conicum</i> (L.) Dumort. (Liverwort, Conocephalaceae)
	B) <i>Gymnostomum aeruginosum</i> Sm. (Moss, Pottiaceae)
	C) <i>Weissia longidens</i> Card. (Moss, Pottiaceae)

with wave length of approximately 254nm in order to control their growth or to dry and kill them. They then confirmed the effectiveness of this method by testing on a foundation that was added in a past conservation (Kawanobe et al. 2001).

Based on the results of on-site testing, UV-C was irradiated on areas around Dainichi Nyorai Zazo in the Furuzono cluster of Usuki Stone Buddha (Fig. 1 (A)), on whose weak-welded layer was a significant growth of bryophytes, and on the right shoulder of the Dainichi Nyorai image of Kumano Stone Buddha (Fig. 1 (B)) where inhibition of appreciation due to the growth of what appeared to be golden lichen was an issue. At Usuki, bryophytes were removed after UV-C irradiation (Morii et al. 2009; 2010).

In this paper, an outline of the treatment and the

results of observation following treatment will be presented.

Condition of stone monuments before cleaning

Usuki Stone Buddha

The condition of the Usuki Stone Buddha has become better compared with that previously as a result of two sessions of conservation work in the past (Usuki City Education board 1997). However, growth of epiphytes can still be confirmed on the upper portion of the foundation of the Buddha images in the Furuzono cluster (Fig. 2 right, darkened part). Investigation made during conservation work revealed that the ground layer of the upper part of the foundation

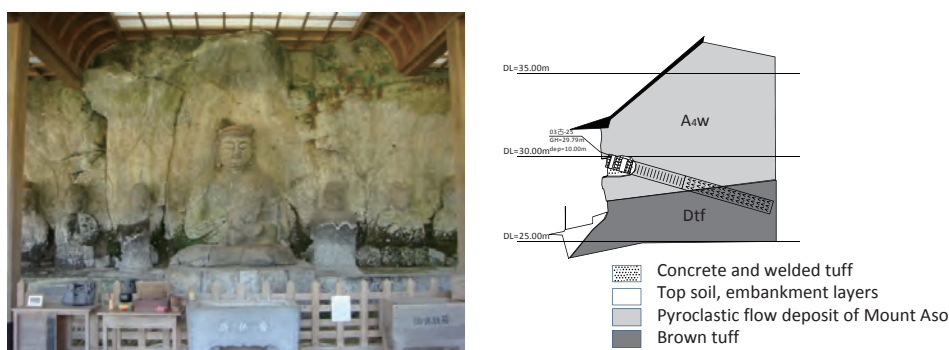


Fig.2 Dainichi Nyorai Zazo of Usuki Stone Buddha and its geological section



Fig.3 Identified moss: a) *Conocephalum conicum* (L.) Dum.; b) *Gymnostomum aeruginosum*; c) *Weissia longidens* Card.

Table 2 Identification of lichens at the Kumano Stone Buddha

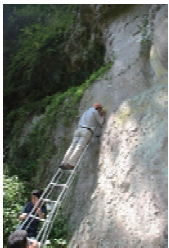
Sampling point	Lichens identified in survey area
Right shoulder of Dainichi-nyorai (Kumano stone Buddha)   Field survey image	<i>Agonimia tristicula</i> (Nyl.) Zahlbr. <i>Bacidia hakonensis</i> (Müll.Arg.) Yasuda <i>Chrysothrix candelaris</i> (L.) J.R.Laudon <i>Cladonia caespiticia</i> (Pers.) Flörke <i>Cladonia humilis</i> (With.) J.R.Laundon <i>Cladonia ochrochlora</i> Flörke <i>Cladonia ramulosa</i> (With.) J.R.Laundon <i>Cladonia scabriuscula</i> (Delise) Leight. <i>Cladonia subcariosa</i> Nyl. <i>Endocarpon petrolepideum</i> (Nyl.) Hue <i>Lepraria</i> sp. <i>Myelochroa irrugans</i> (Nyl.) Elix & Hale <i>Myelochroa leucotyiza</i> (Nyl.) Elix & Hale <i>Pertusaria commutata</i> Mull.Arg. <i>Phaeophyscia hispidula</i> (Ach.) Essl. <i>Physciella melanchra</i> (Hue) Essl. <i>Porpidia albocaerulescens</i> (Wulfen) Hertel & Knoph <i>Pyxine endochrysin</i> Nyl. <i>Ramalina kurokawae</i> Kashiw. <i>Ramalina yasudae</i> Räsänen



Fig.4 Dainichi Nyorai image of the Kumano Stone Buddha in 2007

is brown tuff and that it containing clay and that its water content is comparatively high. Therefore, it is considered that epiphytes grow much on damp brown tuff.

Furthermore, among the epiphytes around Dainichi Nyorai Zazo, bryophytes were identified by visual and microscopic observations (specimen identification by Masanobu Higuchi). The results of identification are provided on Table 1 and Figure 3. During sampling, growth of epiphytes, possibly moss, was observed under the bryophytes that had been sampled.

Kumano Stone Buddha

From 1976 to 79, synthetic resins were used to reinforce the stone at Kumano Stone Buddha. Since the surrounding environmental condition was good,

the condition of conservation of the stone Buddha images was thought to be good even today, 30 years after the treatment (Fujimoto 2006). However, dark yellow epiphytes had grown over a large area extending from the head to the chest of the Dainichi Nyorai image. These had raised problems in appreciating the images, causing complaints from visitors (Fig. 4).

The yellow epiphytes observed on the Dainichi Nyorai image was thought to be lichens and sampled from areas around the right shoulder for identification (specimen identification by Hiroyuki Kashiwadani). For identification of the components of the lichens, microchemistry, thin-layer chromatography and high-speed liquid chromatography were used. To observe the inner structure and outer configuration of lichens, a microscope was used.

Results of identification are shown on Table 2. It was found that the golden lichens covering the Dainichi Nyorai image are *Chrysothrix candelaris* (L.) J. R. Laudon. Moreover, areas where *Chrysothrix candelaris* alone were found were very few. It was found that in many places they were found together with *Legraria* sp. *Physciella melanchra*, *Ramalina kurokawae*, *R. yasudae* and other lichens.

Cleaning epiphytes

Growth of bryophytes and lichens were confirmed mainly on the brown tuff of each cluster of



Fig.5 UV-C irradiating system

Usuki Stone Buddha. The environment inside the shelter of each cluster was comparatively stable, and the conditions made it easy for epiphytes to grow (Morii 2006). Although bryophytes and grasses were observed on the lower portion of the Buddha images, most were lichens such as golden lichen. Not only were these epiphytes that covered the stone images a cause for hindering appreciation but there was also a great possibility that many of the epiphytes might damage the surface of the images. For these reasons, it is desirable to remove them regularly. However, roots of living epiphytes are very difficult to pull out and there is a great risk of damaging the stone surface when a bamboo stick or a brush or a pair of tweezers was used to physically remove them.

Thus, the authors considered irradiating UV ray with wavelength of approximately 254nm, which will cause great damage to the epiphytes, in order to dry

them and to remove them in that condition. For this purpose, the authors developed a UV-C irradiating system (Fig. 5). Safety measures, such as limiting the hours of irradiation and installing a cover around each irradiation device, were also taken so that visitors would not directly look at the UV lamp.

Then the UV-C irradiating system was installed around the Dainichi Nyorai Zazo in the Furuzono cluster of Usuki Stone Buddha and the Dainichi Nyorai image of Kumano Stone Buddha in order to remove epiphytes. However, since the targeted epiphytes and the method of their removal differed at the two places, each case will be discussed separately in the following section.

Usuki Stone Buddha

On the Dainichi Nyorai Zazo at the Furuzono cluster of Usuki Stone Buddha, UV-C was irradiated and the dried epiphytes, such as bryophytes and blue-green algae, were removed in two sessions (Table 3). Care was taken in actually irradiating UV-C so as not to have the device come in direct contact with parts of the image where there are traces of remaining pigments. Irradiation was conducted after visiting hours, between 17:00 and 7:00 of the following morning, in consideration of the safety of the visitors. In addition, since the surface bryophytes are in a multi-layer with bryophytes growing on the back of moss, irradiation was conducted over several days before removing the dried bryophytes on the surface; this process was repeated (Yamaji 2008).

A brush, a pair of tweezers and other tools were

Table 3 Outline of cleaning epiphytes at Usuki Stone Buddha

	Duration	Irradiation area	Description
First treatment	2008.1.8-16	Left and right part of the statue 	UV-C lighting system × 2 (40W Germicidal light × 47) 2008. 1. 15 midterm cleaning
Second treatment	2008.5.26-6.4	Arms, back, both sides of the statue 	UV-C lighting system (40W Germicidal light × 13) 2008. 5. 28, 30 midterm cleaning



Fig.6 Tools for cleaning epiphytes

used to remove the dried epiphytes (Fig. 6). It was quite easy to brush off the moss, lichens and blue-green algae. However, since bryophytes like *Conocephalum conicum* were attached very firmly to the wall surface, a pair of tweezers was used to pick the fronds so as not to damage the stone surface and rhizoids were cut off with a pair of scissors.

After completing irradiation, removal of epiphytes and cleaning, silicon-based water repellent (Shin'etsu Bio-water Guard M) was applied in order to control future growth of epiphytes (Hayakawa and Kawanobe 2001; 2008).

Kumano Stone Buddha

Unlike the epiphytes at Usuki Stone Buddha, those at Kumano Stone Buddha are mainly dark yellow lichens. They grow over an extensive area, from the head to the chest, and physical removal by a conservator without preparing a full-size scaffold would be quite difficult. In such a case, if a UV-C

irradiating system is used, it would be possible to remove the epiphytes even from high places quite easily without only a simple scaffold and using tools. So at Kumano Stone Buddha, an on-site test was conducted on the right shoulder of the Dainichi Nyorai image before removing the lichens in the following manner.

Duration: August – December 2009

Place: Dainichi Nyorai image and the lower portion of the Fudomyo-o image

In this conservation work, a scaffold was installed, UV-C was irradiated, epiphytes were removed, measures were taken to prevent future growth (water-repellent treatment), and the scaffold was disassembled.

Since the Dainichi Nyorai image is extremely large, it being 6.8m high, and is located within a historic site, care was taken in installing the scaffold so that it would not fall on the side of the image; stakes were not used for digging (Fig. 8). Investigation was made after installing the scaffold and it was decided that only the removal of epiphytes and water-repellent treatment to prevent future growth would be conducted once UV-C had been irradiated.

Monitoring after cleaning

Usuki Stone Buddha

Following UV-C irradiation and removal of epiphytes from the left and right sides of the Dainichi Nyorai Zazo in the Furuzono cluster (January 8-16, 2008), the condition of the stone surface was monitored visually and by photographing (Table 4).

	Aug.	Sep.	Oct.	Nov.	Dec.
Electric work	—				
Scaffolding construction		—	—	—	—
Condition check	—				
Germicidal lamp irradiation		—	—	—	
Cleaning				—	
Water repellency treatment				—	
Deconstruction and removal					—

Fig.7 Work schedule



Fig.8 Scaffold at Kumano Stone Buddha

At the beginning, intensity of UV-C irradiation was raised in order to effectively dry the epiphytes; irradiation was continued for about a week. However, it was found that after treatment only the uppermost layer of *Conocephalum conicum* that had been growing had dried and that the layers underneath had received very little effect of UV-C. Thus, the portions that had been dried by irradiation were removed (intermediate removal) and UV-C was irradiated again. As a result, the dark brown tuff became exposed and the work of removal was completed.

However, a month after removal, growth of moss was found again at places that had been treated, and in about 3 months it had increased further. The reason for this is thought to have been the fact that since the weather at the time of removal was not good, the brown tuff was more damp than usual and some of the moss had not been removed completely. Another reason is that water-repellent was not applied after the removal of epiphytes.

From May 26 to June 4, 2008, UV-C was irradiated again on the epiphytes that had grown on both sides of the Dainichi Nyorai Zazo after the previous removal. Irradiation was conducted also on the chest and hip portions. *Conocephalum conicum* were removed on May 28 and 30 and water-repellent was applied on the exposed brown tuff after irradiation and removal. The results of monitoring, visually and by photographing, are shown on Table 4, to the right. This time, it was possible to remove the bryophytes effectively because of two sessions of intermediate removal. Furthermore, the blue-green algae observed on the left arm before irradiation could not be found after irradiation.

In the process of observation after the second

Table 4 Monitoring after cleaning – Usuki Stone Buddha

	First treatment	Second treatment
Before irradiation		
Before midterm cleaning		
After midterm cleaning		
After irradiation		
1 month after irradiation		
3 months after irradiation		

Table 5 Results of color change

		Before irradiation	After cleaning	After 1 month	After 2 months
A	L*	21.67	28.8	23.29	21.67
	a*	-6.56	-0.73	-1.23	0.83
	b*	17.44	4.38	5.19	7.45
B	L*	40.77	47.69	42.25	36.28
	a*	-1.88	-0.51	0.04	1.36
	b*	13.23	7.45	8.15	12.8
C	L*	55.97	57.68	56.08	59.89
	a*	0.94	1.88	2.15	1.37
	b*	12.24	15.71	13.03	12.27



Fig.9 Monitoring points for color change

treatment, a color spectrometer (MINOLTA CG-400) was used in addition to visual inspection and photographing (Measuring points: Fig. 9; Results: Table 5 and Fig. 10). At point A where there was a growth of *Conocephalum conicum*, there was no large

change in a* or b* value after removal; the values also confirmed that the growth of moss had been controlled. At point B, which had appeared yellowish green before irradiation because of the growth of blue-green algae, the color had become lighter with irradiation; it was confirmed that the yellowish green color would return with time. At point C, where there was some cream color remaining, UV-C was irradiated indirectly but there was no change in the measured value; it was confirmed that UV-C irradiation had no effect on the pigments, as had been shown in a laboratory test (Kuchitsu 2001).

Kumano Stone Buddha

As an on-site testing, UV-C was irradiated from July 7 to 15, 2008 on the right shoulder of the Dainichi Nyorai image (Fig. 11). After that, monitoring was conducted visually, by photographing and with a color spectrometer (MINOLTA CM-2600d). In the

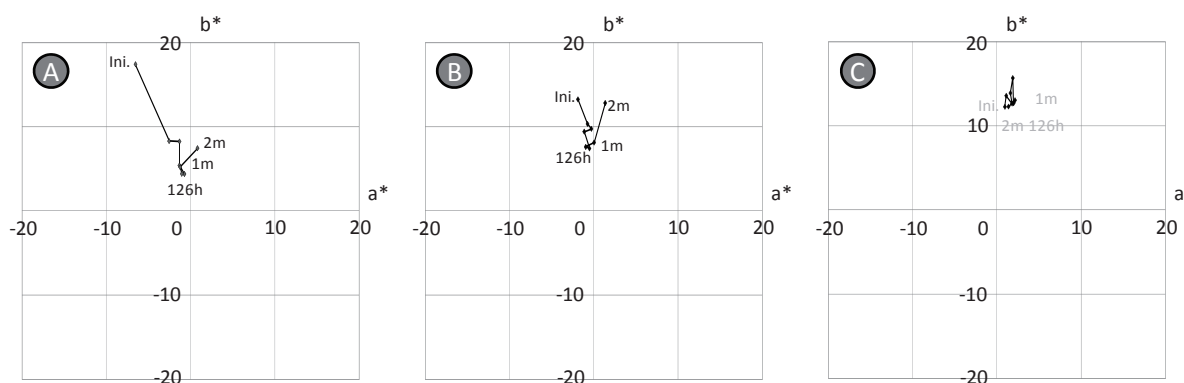


Fig.10 Results of color change (Ini.: before, 126h: after, 1m; 1 month, 2m: 2 months)



Fig.11 On-site testing of UV-C irradiation at Kumano Stone Buddha)



Fig.12 Surface after cleaning



Fig.13 Surface after 2 months

first on-site testing, golden lichens were found remaining (Fig. 12), but at the end of September 2007, 2 months after irradiation, the dark yellow color had disappeared from the irradiated area and the rock surface could be confirmed (Fig. 13). At this point, it

was assumed that unlike the bryophytes that dry immediately after irradiation and become grey, the effect became apparent sometime after irradiation. In the on-site testing that followed, 5 places were chosen for measuring, based on the shape of the irradiating

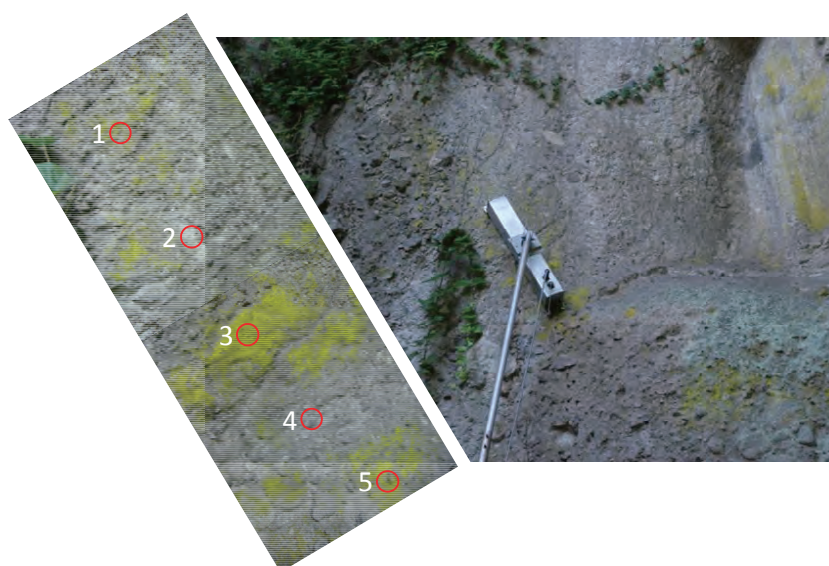


Fig.14 Monitoring points for color change – Kumano Stone Buddha

device; for point 2 only, measurement was done on the part where the rock surface had become exposed (Fig. 14).

Figure 15 shows the results of color measurement. The horizontal axis shows the change in a^* value ($-5 < a^* < 5$), while the vertical axis shows the change in b^* value ($-50 < b^* < 50$). Of the measuring points, at point 1 and point 3 where golden lichens were growing most, b^* value had decreased greatly even a month after irradiation (point 1: $36.12 \rightarrow 11.42$; point 3: $46.94 \rightarrow 15.2$). Visual observation showed that although yellow color could still be seen, it had certainly decreased. At other points, too, b^* value also decreased. Monitoring will be continued, but the yellow color had certainly become lighter a month after irradiation of UV-C on the golden lichens, showing the effectiveness of cleaning.

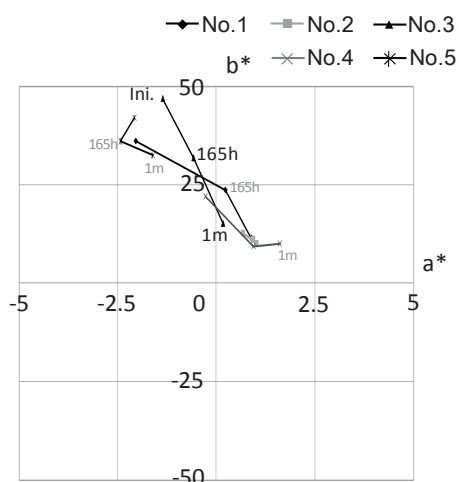


Fig.15 Results of color change at Kumano Stone Buddha

As a result of on-site testing, cleaning was done in 2009 as a part of conservation work. Since Kumano Stone Buddha today is in an outdoor environment, a waterproof UV-C irradiating system (Ginza Sakura Co. Ltd., Fig. 16) was used. It is possible to install 5 standard 40W UV germicidal lamps with 19.8W UV output. UV-C irradiation intensity 30cm away from a lamp is 0.38mW/cm^2 . Moreover, since the surface of the Dainichi Nyorai image is deeply carved, the irradiation device was adjusted so that it would move along the curving surface (Fig. 17).

As for the number of irradiating devices and the irradiating schedule, approximately 10 devices were installed and irradiating was conducted over a period of about one week, taking into consideration the load



Fig.16 UV-C irradiating system for Kumano Stone Buddha

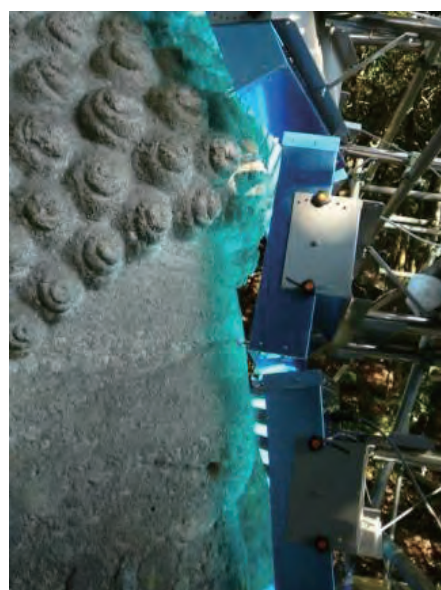


Fig.17 UV-C irradiation to the face of Dainichi Nyorai image

on the scaffold and the restriction of electric output. Irradiating points were changed and the entire Dainichi Nyorai image and the lower portion of the Fudomyo-o image were irradiated in approximately 9 weeks. Furthermore, within that time, the condition of the golden lichens after UV-C irradiation was observed visually (Figs. 18 and 19).

Visual observation was conducted a month after irradiation, when irradiation had been completed (Moon et al 2008). As has already been mentioned, the dark yellow color did not disappear immediately after irradiation. However, visual observation showed that in places like the face, irradiation was successful and that lichens had been killed. Nevertheless, in places like the border between the image and the cliff surface or between spirals, lichens still remained. Thus, the angle of the devices was changed and irradiation was done again.



Fig.18 Observation of epiphytes at Kumano Stone Buddha



Fig.21 Cleaning epiphytes



Fig.19 Golden lichens on the spirals



Fig.22 Before cleaning epiphytes



Fig.20 Applying water repellent



Fig.23 After cleaning epiphytes

Immediately after irradiation of the Dainichi Nyorai image and of the lower portion of the Fudomyo-o image was completed, epiphytes were removed from the images and water-repellent treatment using Shin'estu Bio-water Guard M was conducted in order to prevent future growth of

epiphytes (Fig. 20).

Since epiphytes, especially golden lichens, had dried and become pulverized after UV-C irradiation, they were removed with a brush. At the same time, a very mild wind was sent from an air compressor to remove the epiphytes that had collected on the gaps

of the stone surface. As a result, it was possible to completely remove the golden lichens (Figs. 21 and 22).

Results

UV-C irradiation with wavelength of approximately 254nm was proposed as an effective and safe method for removing epiphytes from the surface of stone Buddhas and this method was tested at Usuki Stone Buddha and Kumano Stone Buddha.

At Usuki Stone Buddha, bryophytes like *Conocephalum conicum* and *Weissia longidens* Card. growing on the brown tuff layer of the lower portion of the images at Furuzono cluster were irradiated with UV-C and dried, and then removed in a mass. It was not only confirmed that bryophytes can be removed safely and effectively by irradiation but also that, when bryophytes grow in layers, they can be removed for certain by re-irradiating UV-C after having first removed part of them following several days of irradiation.

However, since a new growth of bryophytes was seen a month after treatment, a silicon-based water repellent was applied to the treated surface (particularly the brown tuff with high moisture content). As a result of observation, it was found that there was no new growth of bryophytes, proving that application of silicon-based water repellent together with UV-C irradiation is effective in extending the time span between treatments.

At Kumano Stone Buddha, golden lichens covering the surface of the Dainichi Nyorai image were removed by UV-C irradiation. Visual observation and inspection with a color spectrometer showed that the yellow color gradually became lighter and thus that UV-C irradiation is effective with golden lichens. In the conservation project of Kumano Stone Buddha, it was also found that in the case of sculptures that are deeply carved, like the Dainichi Nyorai image, it is necessary to adjust the irradiation device in such a way that UV-C will reach all points of the sculpture, including the crevices. Furthermore, the fact that the lichens could be removed with a brush and very mild blow of air once they had been dried and become pulverized provided some information about the mechanism by which golden lichens disappear after UV-C irradiation.

Now, based on the results of treatment at Usuki Stone Buddha and Kumano Stone Buddha removal of epiphytes from other stone cultural properties, such as stone pagodas and wall paintings, with UV-C irradiation is being applied. As of now, no serious problems have been reported. However, no matter what method is employed, monitoring after treatment is important, and post-restoration observation will continue with this method as well.

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