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Sakagami, Takahide
Mizokami, Yoshiaki
Shiozawa, Daiki
Hayashi, Masahiro
Takeguchi, Masahiro

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Application of infrared camera for steel bridge maintenance

Takahide Sakagami [a], Yoshiaki Mizokami [b], Daiki Shiozawa [a],
Masahiro Hayashi [b], Masahiro Takeguchi [b]

[a] Dept. of Mechanical Engineering, Kobe University,
1-1 Rokkodai-cho, Nada-ku, Kobe, Hyogo 657-8501 Japan
[b] Honshu-Shikoku Bridge Expressway Company Ltd,
4-1-22 Onoe-dori, Chuo-ku, Kobe, Hyogo 651-0088 Japan

ABSTRACT

Heavy-duty anticorrosion coating with multiple-layered paints is applied to long-span steel bridge members on the sea. By aging deterioration, the coating is worn from surface year by year. Appropriate repainting programs should be adopted for the maintenance of the bridges according to the evaluation of wear extent. In this study a new nondestructive evaluation technique using short wavelength infrared (SWIR) camera, that enables us to easily detect the wear loss of surface fluororesin coating layer, is developed based on the difference in spectral absorptance between surface fluororesin coating and inner-layer epoxy resin coating.

Keywords: Nondestructive evaluation, Spectral absorption characteristics, SWIR camera, Wear loss, Multiple-layered corrosion protection coating, Steel bridges

1. INTRODUCTION

"Fatigue" and "Corrosion" are two major primary factors of the aging deterioration of steel bridges. Planning and adopting appropriate maintenance program for "Fatigue" and "Corrosion" is essential for prolonging their life and guaranteeing safety in their service. For the maintenance of fatigue damage, the present authors have been developing new nondestructive evaluation techniques that can be applied through the life cycle of the steel bridges [1-3]. Corrosion protection coating has been applied as the preventive maintenance for corrosive damages. In general heavy-duty anticorrosion coating with multiple-layered paints is applied to long-span steel bridge members on the sea. An example of the structure of heavy-duty anticorrosion coating is shown in Fig. 1.

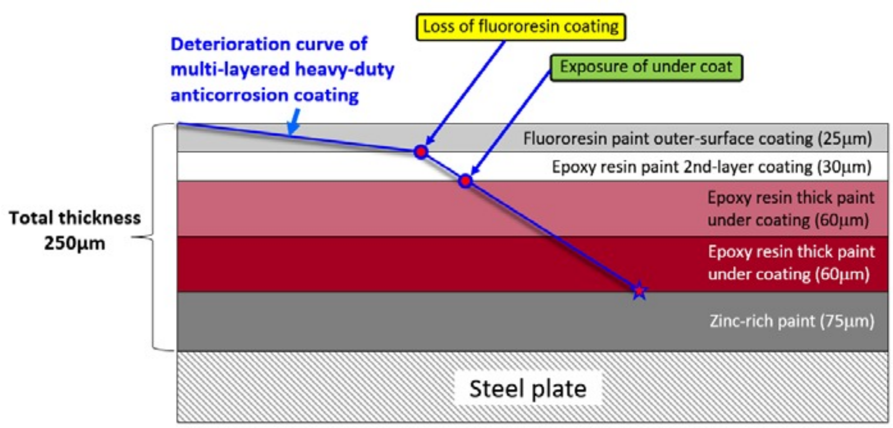

Fig. 1 Illustration of structure and deterioration curve of heavy-duty anticorrosion coating.

As shown in the figure, zinc-rich paint expecting electric anticorrosion effect is applied on steel surface. Epoxy resin layers for protecting the zinc-rich paint are painted next. Finally fluororesin coating with excellent weather resistance is applied

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on the outer surface. This kind of multi-layered coating is worn from surface year by year due to aging deterioration. The wear rate of the outer surface fluororesin coating is relatively small, however the wear rate of the epoxy resin paint is accelerated after the loss of the fluororesin coating. In the maintenance program of the heavy-duty anticorrosion coating, protection of the zinc-rich paint is very important since on-site fabrication of the zinc-rich paint coating is almost impossible. Therefore the appropriate timing for repainting maintenance should be set when the surface fluororesin coating is lost. However it is difficult to detect the loss of the surface coating by visual inspection, because the similar color paint is chosen for the second-layer epoxy resin paint for better appearance. Nondestructive testing technique that is suitable for early global inspection of wear of surface fluororesin coating has not been developed yet. In this study a new nondestructive evaluation technique that enables us to easily detect the loss of surface fluororesin coating layer is developed based on the difference in spectral absorptance between the surface fluororesin coating and the second-layered epoxy resin.

2. PRINCIPLE OF NONDESTRUCTIVE EVALUATION OF COATING DETERIORATION BASED ON SPECTRAL INFRARED ABSORPTANCE

Spectral infrared absorptance of materials shows characteristic distribution influenced by the material's molecular structure, and this enables identification of materials and analysis of chemical structures. As an example, spectral infrared absorptance measured for outer surface fluororesin coating and second-layer epoxy resin coating of the multi-layered heavy-duty anticorrosion coating is shown in Fig. 2. It is found from the figure that fluororesin coating and epoxy resin coating show almost same spectral infrared absorptance in the range of wavelength of 1500nm or over. In contrast, the fluororesin coating shows higher infrared absorption rate than that of epoxy resin coating in the range of wavelength of 1500nm or below.

When an infrared radiation is incident on an object, the relationship of reflectance ρ, absorptance α and transmittance τ obeys the conservation law of energy as follows.

$$\rho + \alpha + \tau = 1 \tag{1}$$

For opaque materials, the transmittance is assumed to be zero and this leads to the following equation.

$$\rho + \alpha = 1 \tag{2}$$

When surfaces of fluororesin coating and epoxy resin coating are observed by the SW infrared camera under broad band infrared illumination covering detectable wavelength of the camera, luminosities are almost same for fluororesin coating and epoxy resin coating over the wavelength of 1500nm; in contrast luminosity for fluororesin coating is lower than that for epoxy resin coating below the wavelength of 1500nm. This kind of infrared spectral luminosity change detected by the infrared camera with sharp-cut wavelength filtering can be utilized for the detection of exposure of the 2nd layer epoxy resin coating due to the wear of outer surface fluororesin coating.

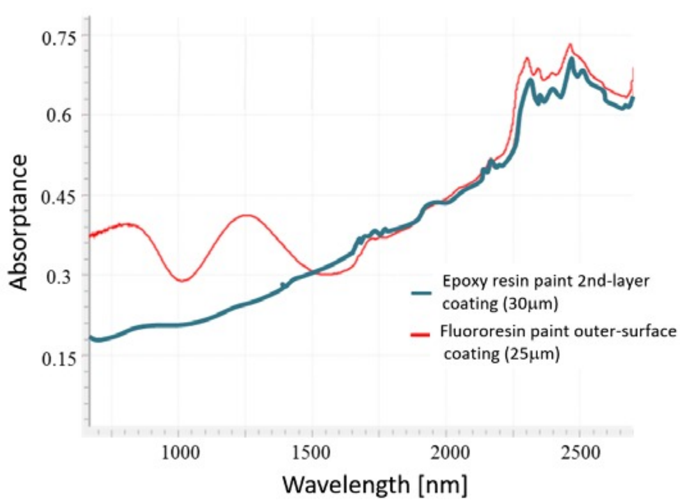


Fig. 2 Infrared spectral absorptance measured for fluororesin coating and epoxy resin coating.

3. EXPERIMENTAL RESULTS FOR LABORATORY SPECIMEN

A steel plate specimen with multiple-layered heavy-duty anticorrosion coating employed in this study is shown in Fig. 3. This specimen has the same coating structure shown in Fig. 1. The infrared spectral absorptance was measured by the FT-IR instrument and the result was shown in Fig. 2. The SWIR camera with InGaAs array detector was employed in this experimental study. Specifications of the SWIR camera are shown in Table 1. According to the infrared spectral absorptance obtained for fluororesin coating and epoxy resin coating, a sharp cut filter transmitting infrared light with a wavelength of 1400nm or over as well as a sharp cut filter transmitting infrared light with a wavelength of 1450nm or below were prepared. Measurements were conducted using the SWIR camera and the two filters under the conditions shown in Table 2. Sun light in fine weather and halogen lamps were employed as infrared illuminations.

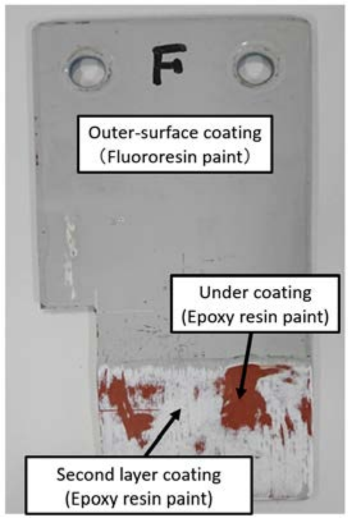


Fig. 3 Steel plate specimen with multiple layered heavy-duty anticorrosion coating employed in this study.

Table 1 Specifications and setting of employed infrared camera.

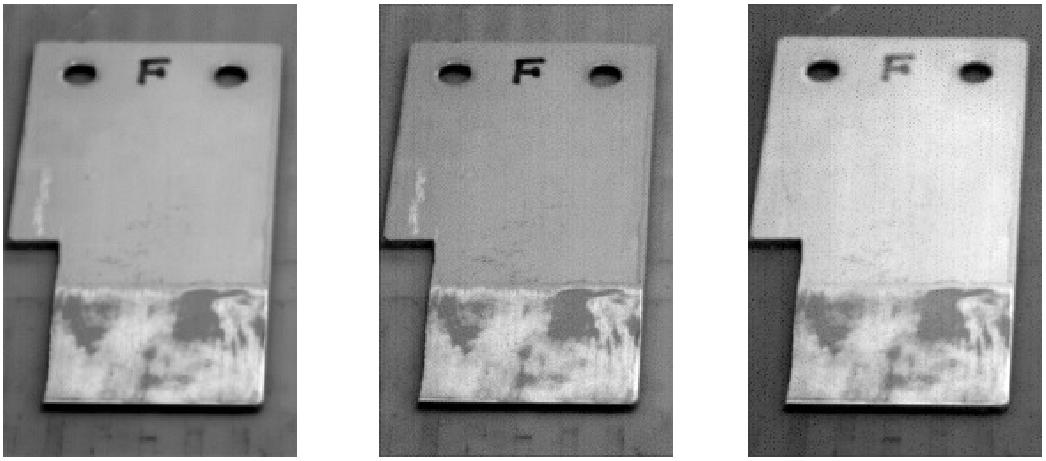
Infrared detector	InGaAs
Detectable wavelength	900–1700 nm
Number of detectors	320 × 256
Framing rate	340 Hz

Table 2 Measurement conditions.

Open	900～1700 nm
SP : Shortwave Pass	900～1450 nm
LP : Longwave Pass	1400～1700 nm

3.1 Experimental results under sun light illumination

The heavy-duty coating specimen and SWIR camera were set on the sunny day so that direct sun light was incident on the specimen surface. Infrared images taken under the three filtering conditions are shown in Fig. 4. It is found from the figure that infrared image with LP filter measured in the wavelength range from 1400nm to 1700nm shows similar luminosities for fluororesin coating and epoxy resin coating. In contrast infrared image with SP filter measured in the wavelength range from 900nm to 1450nm shows distinctively low luminosity on the region where the outer surface fluororesin coating is remaining.



(a) without filter (b) with SP filter (c) with LP filter

Fig. 4 Infrared images taken under sun light illumination for three filtering conditions for heavy-duty coating specimen.

3.2 Experimental results under halogen lamp illumination

Infrared measurements under artificial illumination using halogen lamps were conducted assuming night time inspections or inspections of bridge members when enough sun light illumination is not expected. Experimental set up with commercially available halogen light projectors and SWIR camera is shown in Fig. 5. Infrared images taken under the three filtering conditions are shown in Fig. 6. It is found from the figures that experimental results show the same tendency as those for sun light illumination measurement: infrared image with LP filter shows similar luminosities for fluororesin coating and epoxy resin coating; in contrast infrared image with SP filter shows low luminosity on the region where the outer surface fluororesin coating is remaining. For the both cases, the loss of the surface fluororesin coating can be clearly identified using SWIR camera with spectral transmittance filtering.

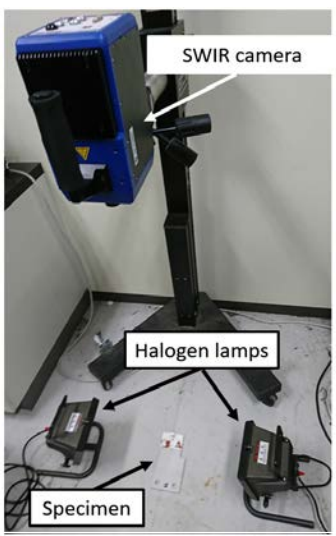


Fig. 5 Experimental set up for halogen lamp illumination.

(a) without filter (b) with SP filter (c) with LP filter

Fig. 6 Infrared images taken under halogen light illumination for three filtering conditions for heavy-duty coating specimen.

4. EXPERIMENTAL RESULTS FOR ACTUAL BRIDGE MEMBERS

Experimental investigation for remote nondestructive inspection for the deterioration of heavy-duty anticorrosion coating was conducted for a long-span suspension bridge on the sea that started in service in 1998. The outer surface layer coating of the bridge was repainted with fluororesin paint in 2001. Several deterioration areas, where loss of the outer surface fluororesin coating was detected, have been reported after the passage of 16 years. The structure of multi-layered coatings is similar as that shown in Fig. 1, however the infrared spectral absorptance has not been measured by FT-IR instrument.

Figure 7 is a photograph showing the situation of infrared measurement on the bridge. Visible image and infrared images taken under the three filtering conditions are shown in Fig. 8. The rectangular red and blue marks on the images indicate outer surface fluororesin coating and inner epoxy resin coating, respectively. The pixel values obtained in red and blue marks under the three filtering conditions are shown in Fig. 9.

Fig. 7 Photograph showing the situation of infrared measurement on the bridge.

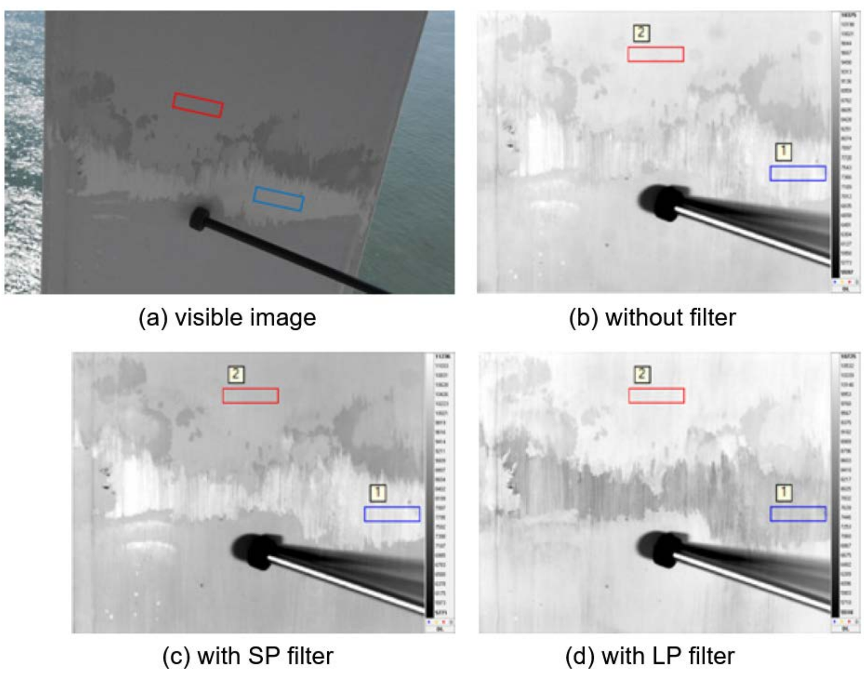


Fig. 8 Visible image and infrared images taken under three filtering conditions.

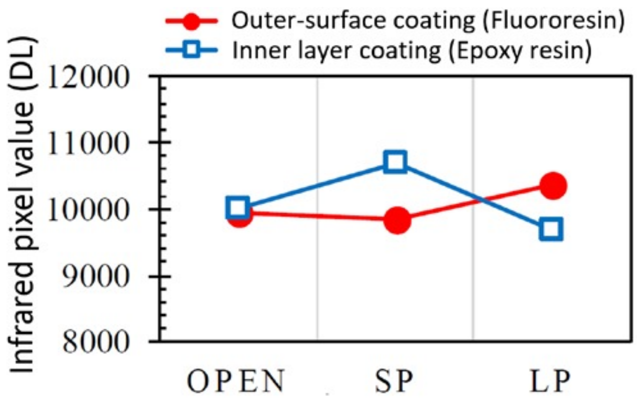


Fig. 9 Pixel values obtained for fluororesin coating and epoxy resin coating under three filtering conditions.

It is found from figures that the tendency of the infrared pixel values is partially different from that of the plate specimen shown in the foregoing paragraph. Figs. 8(b) and 9 show that measured infrared pixel values show similar values for fluororesin coating and epoxy resin coating in the case of without filtering. Figs. 8(c), 8(d) and 9 show that the infrared luminosity shows higher values in the inner layer epoxy coating with SP filter; on the other hand the infrared luminosity shows higher values in the outer surface fluororesin coating with LP filter. It can be estimated that the spectrum absorptance of the anticorrosion coatings fabricated on this bridge is partially different from that shown in Fig. 2; that is to say the tendency of spectrum absorptance of the outer surface fluororesin coating and the inner epoxy resin coating is reversed below and over the wavelength of 1500nm.

5. CONCLUSIONS

Heavy-duty anticorrosion coating with multiple-layered paints is applied to steel bridge members. The coating is worn from surface year by year due to aging deterioration. In this study a new nondestructive evaluation technique using SWIR camera for the wear loss of surface fluororesin coating was developed based on the difference in spectral absorptance between surface fluororesin coating and second-layer epoxy resin coating. It was found from experimental investigations that the loss of the surface fluororesin coating can be clearly identified using SWIR camera with spectral transmittance filtering.

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