Quantification of rust colour distribution rate of galvanized steel wires

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1. Introduction

Preventive maintenance against corrosion and breakage of suspension bridge cables is essential. The main cables of a long-span suspension bridge have corrosion prevention measures by a cable dehumidification system, but effective measures for short/medium-span suspension bridge/cable-stayed bridge cables have not yet been established [1,2]. In particular, it is common to visually judge the soundness of cables. Therefore, the inspection and repair techniques need to be improved to reduce the possibility of cable failure. The purpose of this study is to quantify the rust colour distribution rate of high-strength galvanized steel wire used for suspension bridge cables by combining conventional visual inspection methods with an image analysis technology.

2. Corroded wire specimens

2.1 Galvanized steel wires

The galvanized steel wires with a diameter of 4.89 mm and tensile strength of 1,670 MPa were used. The amount of the zinc galvanized layer is 300 g/m^2 which corresponds to about 50 μm layer in thickness. Fig. 1a shows the appearance of un-corroded single wire specimen. This type of high-strength wires is mainly used for stay-cables and main cables of medium to long span bridges such as cable-stayed bridges and suspension bridges. The total number of specimens was 6 specimens, and the length of each specimen was 300 mm.

2.2 Accelerated corrosion method

The accelerated corrosion test was conducted by the salt spray test method. The corrosive environment at the time of implementation was always sprayed at a constant temperature of 35 °C and a sodium chloride concentration of 5 %. The corrosive environment at the main cable centre of the suspension bridge was assumed, so the salt spray test was conducted with the specimens were placed horizontally (Fig. 2, ITABASHI RIKAKOGYO Co., Ltd). For comparison of corrosion conditions, two corrosion levels (they were named level A and B) were set, and three specimens were set for each level (Test time; Level A: 1008 hours, Level B: 2520 hours). Figs. 1b and 1c show the appearance of representative corroded wire specimens obtained at two corrosion levels.

3. Rust colour distribution rate

3.1 Analysis method

After the corrosion acceleration test, the digital image colour analysis system Feelimage Analyzer (Viva computer Inc.) [3] is used to displayed and classified how much the target rust colour is distributed in the image of the corrosion wire appearance photograph taken with the digital camera. As for the shooting method, the digital camera (CANON Inc.) and the standard light source D65 (Luci Co., Ltd) defined by the International Commission on Illumination (CIE: Commission internationale de l'éclairage) [4] are set as shown in Fig. 3, and each specimens were photographed under the same conditions. By additionally developing a system that can set and classify the colour range to the existing Feelimage Analyzer, it is possible to perform analysis specialized in quantifying the rust colour distribution rate. In this

(a) Un-corroded wire

(b) Corroded wire: Corrosion level A (1008 hours)

(c) Corroded wire: Corrosion level B (2520 hours)

Fig.1 Un-corroded and corroded wire specimens

Fig.2 Accelerated corrosion method

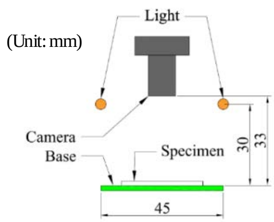
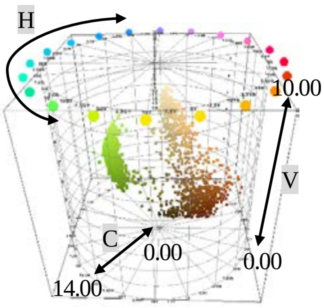
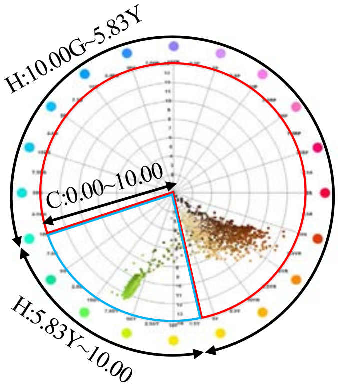


Fig.3 Shooting method

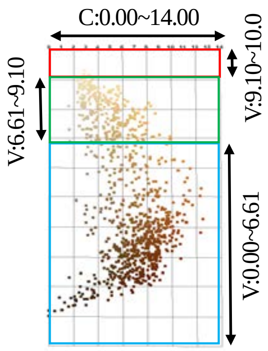
(a) Image example



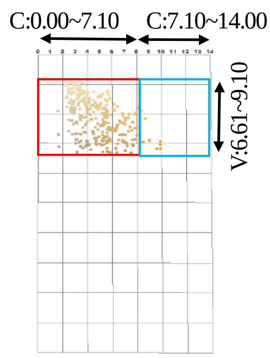
(b) Munsell colour system 3D display (H-V-C)



(c) Background and Specimen area 2D display (H-C)



(d) White and Red rust area 2D display (V-C)



(e) Mixed area 2D display (V-C)

Fig.4 Analysis example by digital image colour analysis system

Table 1. Setting range of H-V-C

Setting range	H	V	C
Background	5.83Y ~ 10.00G	0.00 ~ 10.00	0.00 ~ 14.00
White rust	10.00G ~ 5.83Y	9.10 ~ 10.00	0.00 ~ 14.00
Red rust	10.00G ~ 5.83Y	0.00 ~ 6.61	0.00 ~1 4.00
Mixed area (White)	10.00G ~ 5.83Y	9.10 ~ 10.00	0.00 ~ 7.10
Mixed area (Red)	10.00G ~ 5.83Y	0.00 ~ 6.61	7.10 ~ 14.00

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Table 2. Analysis results of corrosion level A and B

Corrosion level A			Corrosion level B		
A1-Front A1-Back		White: 76 % Red: 24 %	B1-Front B1-Back		White: 14 % Red: 86 %
A2-Front A2-Back		White: 74 % Red: 26 %	B2-Front B2-Back		White: 20 % Red: 80 %
A3-Front A3-Back		White: 68 % Red: 32 %	B3-Front B3-Back		White: 21 % Red: 79 %
Average	White rust: 73±3.4 %, Red rust: 27±3.4 %		Average	White rust: 18±3.1 %, Red rust: 82±3.1 %	

Note) The rate of red and white rust was shown as the average of the front and back.

analysis system, the three elements of the Munsell colour system, which is a system in which all pixels in an image quantitatively represent colours: the hue; H, the brightness; V and the saturation; C are displayed in three dimensions. The analysis method quantifies how much the target rust colour is included by setting a colour range consisting of three elements: hue: H, brightness: V, and saturation: C of the colours contained in the image and classify.

Hue: H indicates the hue, "Red (R)", "Yellow-Red (YR)", "Yellow (Y)", "Yellow-Green (YG)", "Green (G)", "Blue-Green (BG)", " Blue (B), Blue-Purple (PB), Purple (P), and Red-Purple (RP) are represented by 10 major hues. Each hue is subdivided into 0.01 to 10.00. Brightness: V indicates the degree of brightness of a colour. The higher the lightness, the brighter the colour, and the lower the lightness, the darker the colour. The lightness is represented by 0.00 to 10.00, with a lightness of 0.00 indicating pure black and a lightness of 10.00 indicating pure white. Saturation: C indicates the degree of vividness of a colour. The higher the saturation, the more vivid, and the lower the saturation, the more achromatic. Saturation is represented by 0.00 to 14.00. The target rust colours were classified into two types: white rust peculiar to zinc galvanization on the wire surface and red rust peculiar to iron.

In addition, when photographing the corroded wire, by setting a yellow-green background that contrasts with the above rust colour, it was easy to classify the rust colour and the background colour. Fig. 4 shows an example of analysis using the digital image colour analysis system. The analysis procedure is explained using an example of a corroded wire (specimen B1 front) image taken with a digital camera shown in Fig. 4a. When the target image is inserted into the system, it is displayed three-dimensionally as a group of pixels on Munsell as shown in Fig. 4b. Firstly, the background area is determined from the hue H and the saturation C projected on the two-dimensional display (Fig. 4c). The colour range of the background area was determined to be H: 5.83Y ~ 10.00G and C: 0.00 ~ 14.00 so as to include only the greenish hue that is the background colour. At this time, V is set to 0.00 ~ 10.00 for two-dimensional display with H and C. Then, the background area is excluded in order to classify the colours of the background area and the specimen area. This makes it possible to display only the white rust and red rust displayed on the specimen. Hue H and saturation C including the specimen region were set to the colour range other than the background region, and H: 10.00G ~ 5.83Y and C: 0.00 ~ 14.00 were determined. Secondly, in order to classify the white rust and red rust areas in the test piece area, each colour range is set. The white rust and red rust regions are classified from the brightness V and saturation C projected on the two- dimensional display (Figure 4d). Here, from the setting of the brightness V that indicates the degree of brightness, the white rust area is defined as the V: 9.10 to 10.00, the saturation C: 0.00 to 14.00, and the red rust area is defined as V: 0.00 ~ 6.61 and C: 0.00 ~ 14.00 were determined. However, in the above setting procedure, there is a problem that a mixed region of white and red rust is generated. For example, the area shown in Fig. 4e. Therefore, white rust and red rust were classified even in this mixed region. Firstly, in the white/red rust mixed region, from the setting of saturation C indicating the vividness of the colour, the white rust region is set to V: 6.61 to 9.10 and C: 0.00 to 7.10, the red rust region was determined to be V: 6.61 to 9.10 and C: 7.10 to 14.00. Table 1 shows the colour range settings for hue H, lightness V, and saturation C in the background, white rust, red rust, and mixed region.

3.2 Analysis results

The analysis results of corrosion level A and B are shown in Table 2. The white and red rust regions classified in the mixed region were classified into each targeted region. The rust colour distribution rate was calculated as white rust 73±3.4 % and red rust 27±3.4 % for the average of corrosion level A, and white rust 18±3.1 % and red rust 82±3.1 % for the average of corrosion level B. This made it possible to quantitatively grasp the corrosion level more than visual evaluation. In addition, no significant difference was observed between the test specimens at both corrosion levels, demonstrating that corrosion is promoted in the same environment.

4. Conclusion

The rate of zinc-specific white rust and iron-specific red rust, which characterizes the corrosion status of bridge wires, can be quantified by introducing the digital image colour analysis system. This suggests that the proposed system can be a useful tool to improve the corrosion criteria available for corroded bridge wires.

As a future study, in order to establish the corrosion evaluation criteria for the corroded wires, it is necessary to increase more corrosion levels and specimens. Furthermore, by clarifying correlation between the rust colour distribution rate, the corrosion surface roughness and fatigue strength, it will be possible to construct an investigation method that can evaluate the soundness of the cables.

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