PREDICTION METHOD OF REBAR CORROSION DEGREE IN REINFORCED CONCRETE BY THERMOGRAPHY

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Abstract: In this study, a new non-destructive testing method for the detailed estimation of the rebar corrosion in RC structure, is proposed using infrare thermography and electromagnetic heating. The corrosion product has insulation effectiveness by heat characteristic. Therefore, when the rebars are heated equally, the surface temperature of concrete in which rebar corroded is lower than that of the concrete in which rebar doesn't corroded. The result of our experiment shows that it is feasible to use the proposed method.

1 INTRODUCTION

In Japan, RC structures which had been constructed over 50 years ago are increasing. Owing to this, the early deterioration of RC structures become the social problem in recent years. Much more attention is paid to the rebar corrosion, because it cause the reduction of the structural performance by decreasing the cross section of rebar and the appearing corrosion crack. Thus, it is important to estimate rebar corrosion degree to make structure to live longly.

Recentlly, Half-cell potentials measurement and polarization resistance method are mainly used for testing of rebar corrosion in RC. However, those methods can't estimate quantitatively the rebar corrosion degree. In Addition, it is necessary to break concrete on rebar because of attaching electrode. Therefore, it is important to estimate quantitatively the degree of the rebar corrosion by non-destructive testing method.

For this reason, A new non-destructive testing method is propose, here. It is based on heat characteristics of corrosion product on rebar. In such way, rebar corrosion degree can be quantitatively estimated. (hereinafter referred to "*proposed method*").

Propose this paper, to make clear heat characteristics of corrosion product and heat diffsion behavior by heating rebar in concrete. Beside, to discuss applicability of *proposed method* for RC structure.

2 OUTLINE OF PROPOSED METHOD

The outline of *proposed method* is shown below: The heat is conducted from the rebar in RC structure by electromagnetic induction coil. The surface temperature of the concrete, which increase by the heat transmited from the rebar, is photographed by thermography camera. At that time, difference of surface temperature arise on reinforced concrete if corrosion

Table 1: Heat characteristic

Non-corroded rebar	Thermal conductivity	51.30 W/m℃
	Density	7850 kg/ m^3
	Specific heat	0.47 kJ/kg℃
Corroded rebar	Thermal conductivity	0.07 W/m℃
	Density	5300 kg/ m^3
	Specific heat	1.20 kJ/kg℃

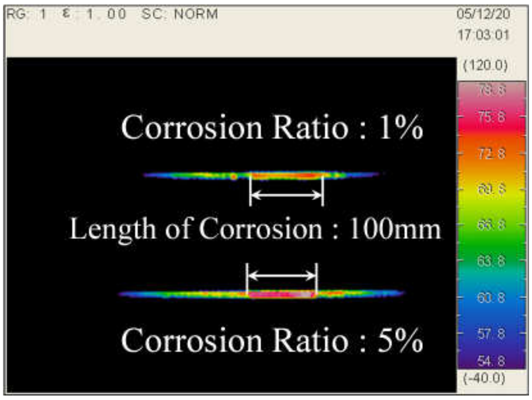


Figure 1 : Thermography of rebars at the time of finished heating by electromagnetic heating

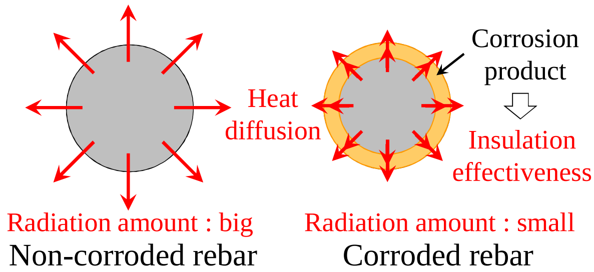


Figure 2 : Heat diffusion in rebar

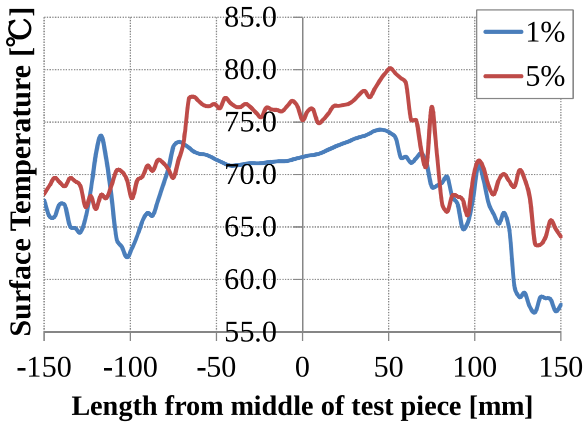


Figure 3 : Heat distribution diagram on heated rebar in Fig. 1.

product exist on rebar. This reason will be examined later again. Accordingly, the temperature difference enables us to distinguishing whether corrosion product exists or not.

2.1 Heat Characteristics of Corrosion Product

In general, corrosion product has insulation effectiveness because specific heat of corrosion product is high and its thermal conductivity is low.

Heat characteristics of non-corroded rebar and corroded rebar are shown in Table 1.

Thermal conductivity data is taken by the Laser-flash Method. For sample preparation, we take corrosion product from rebar which corroded by exposure in atmosphere. Specific heat and density are quoted from reference [2], and [3].

2.2 Diffusion Behavior Due to Existence of Corrosion Product

2.2.1 Diffusion Behavior in rebar

Figure 1 shows thermography of two rebars heated by the *proposed method*. The rebars corrode partly with the length of middle 100mm. The rebar in the test piece is corrode at the degree of 1% or 5% by exposure in the atmosphere.

To focus on surface temperature of rebar, it is shown that parts of corrosion become high temperature.

Figure 2 shows diffusion behavior in rebar which is heated by electromagnetic heating. In the following Figure 3, corrosion product has insulation effectiveness. Therefore, heat diffusion from rebar is inhibited by it.

In the case that rebar doesn’t corroded, heat actively diffuse to outside rebar. In contrast, in the case that the rebar is corroded, diffusing heat is saved by corrosion product.

2.2.2 Diffusion Behavior in Concrete

Figure of heat diffusion behavior in concrete is shown in Fig. 4. In ordinary, the heat diffuses radially to concrete from rebar when rebar is heated in concrete. However, in the case of rebar corrosion, radiation amount from rebar becomes small. For this reason, as

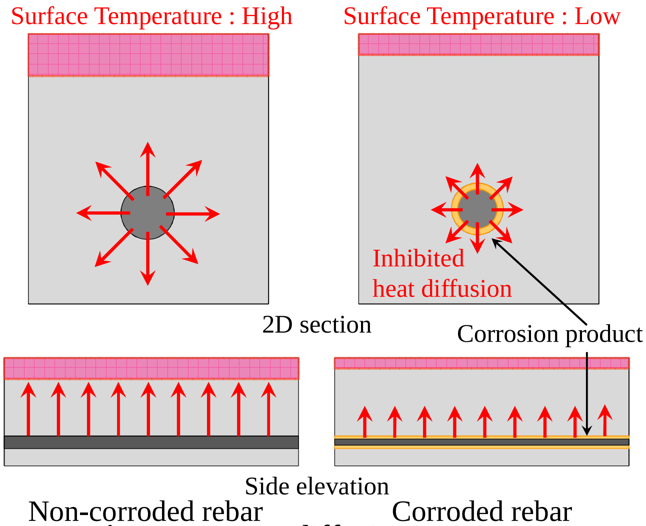


Figure 4 : Heat diffusion in concrete

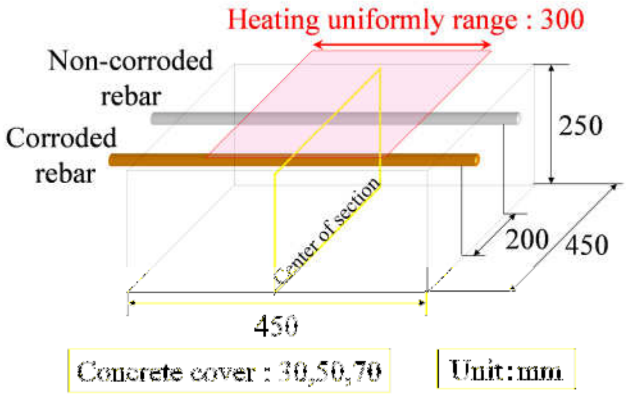


Figure 5 : Outline of test piece; In time to heat rebar by electromagnetic heating, we position heating uniformly range in coil on center of section.

we mentioned at 2.2.1, corrosion product inhibits heat diffusion.

Altogether, concrete absorbs a large amount of heat, however, corrosion product inhibits heat diffusion. In other word, corrosion product saves heat.

2.2.3 Influence of Corrosion Product on Concrete Surface Temperature

To focus temperature behavior on RC structure, surface temperature of concrete whose rebar is corroded is lower than that of concrete whose rebar is not corroded (Figure 4). This is due to the influence of the corrosion product.

Thus, the prediction of rebar corrosion degree by proposed method is based on these influences of the corrosion product for heat diffusion.

Table.2 : Condition of experiments; Average corrosion ratio and average corrosion thick are calculated from the ratio of rebar's weight change. Test pieces are named in the order of concrete cover, corrosion ratio.

Name	K30-C0.66	K50-C0.82	K70-C0.70
Heating time [sec]	320	540	780
Load electricity	2.0	6.0	6.0
Increase of rebar temperature [℃]	14.7	27.9	15.9
Average corrosion rate [%]	0.66	0.82	0.70
Average corrosion thick [mm]	0.039	0.048	0.041
Outside air temperature [℃]	23.7	21.2	21.8

3 PREDICTION OF REBAR CORROSION CHARACTERISTICS

3.1 Outline of Experiments

Figure 5 shows the outline of test piece. Dimensions of the test piece are 450*450*250mm, and two rebars which are D16 deformed bar are arranged at concrete cover 30, 50, 70mm.

First, The corrosion product on the rebar must occur uniformly. In general, the method of occurring rebar corrosion is exposure or electrolytic corrosion. Exposure method is spraying saltwater intrusion. However, both method make rebar occur uneven corrosion product due to the corrosion crack. Hence, The rebar is exposed in the atmosphere to make it corrode.

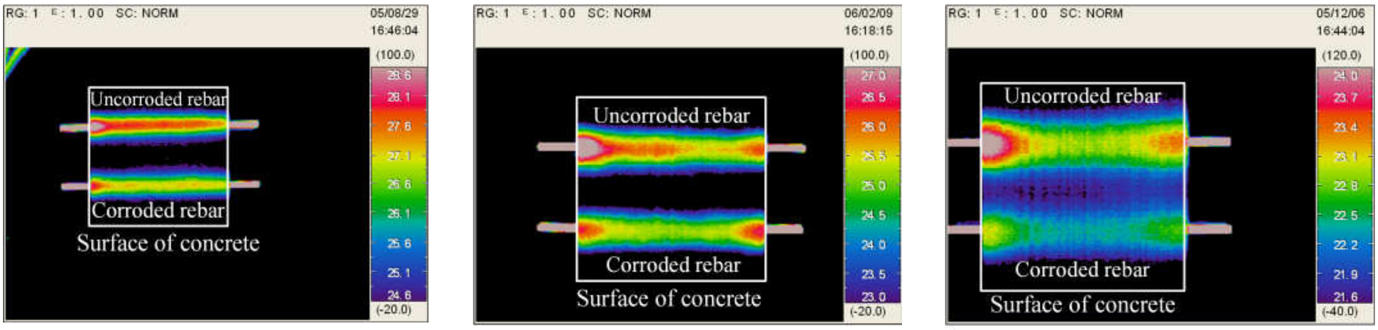
Second, concrete is deposited after arranging the non-corroded rebar and the corroded rebar at prescribed place to retain the uniform corrosion product.

In this study, the *proposed method* is applied to these test pieces which are made by this way.

3.2 Concrete Surface Temperature

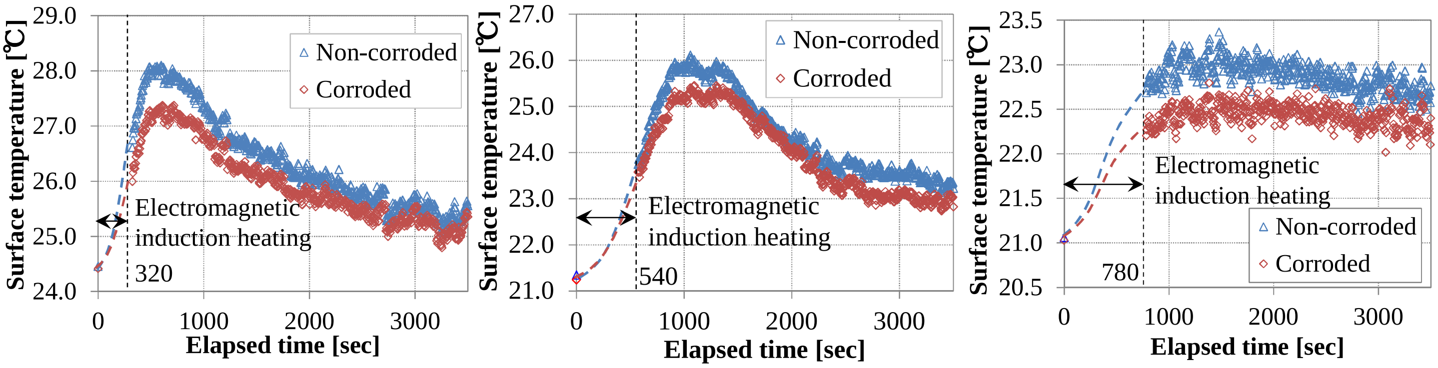
The thermographies of test piece are applied *proposed method*, as shown in Fig. 6.

It is shown that temperature of surface over the non-corroded rebar is higher than that of surface over corroded rebar in heating



(a) K30-C0.66 (b) K50-C0.82 (c) K70-C0.70

Figure 6 : Thermography of concrete surface; These thermographies are taken at the time passed of 180sec since finished heating by electromagnetic induction. All of its, uncorrode rebar is located in the upper side and corroded rebar is located in lower side.



(a) K30-C0.66 (b) K50-C0.82 (c) K70-C0.70

Figure 7 : Temperature log at middle of concrete surface over two rebars. These plots are measured by thermography camera since starting of electromagnetic heating.

uniformly range, moreover this trend is found at all of thermography. Similarly to chapter 2, this is due to the influence of the corrosion product.

Figure 7 shows temperature of concrete surface. It is found that surface temperature difference of right over the rebar is 0.5~0.9℃.

Figure 8 shows temperature distribution of concrete surface. Existence of rebar corrosion is represented in temperature distribution graph too. However, the dispersion of temperature increases with increasing concrete cover. Therefore, it is necessary to improve electromagnetic coil because of removing dispersion temperature.

Osada[4)] has reported prediction method of concrete cavitation using thermography. In the paper, threshold value is defined as 0.5℃. Thus, the threshold value is defined as 0.5℃ that judge rebar corrosion.

3.3 Estimation of Rebar Corrosion Degree[(8]

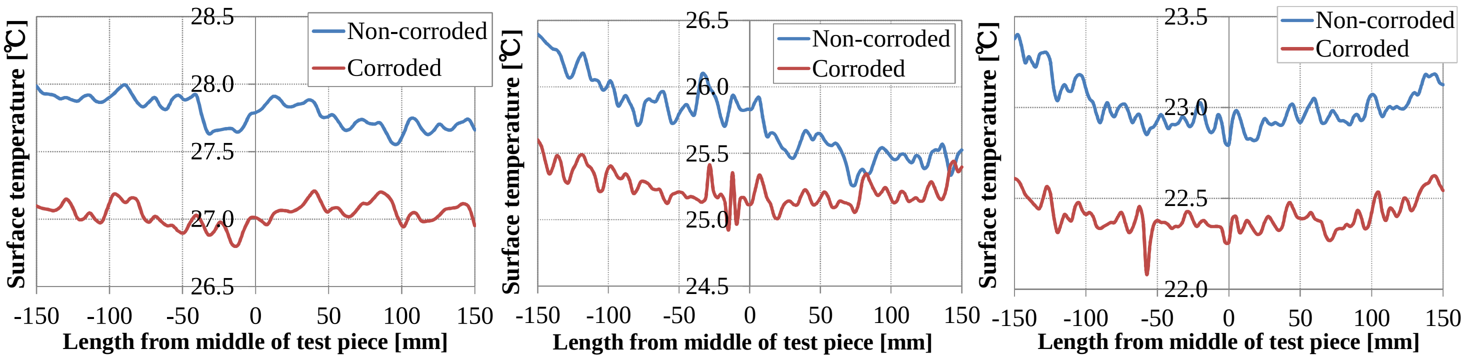
In this paragraph, we propose estimation model of rebar corrosion degree. As the Fig. 3 indicates, Corrosion product inhibits heat diffusion from non-corroded area on rebar to concrete. In other words, the inhibited heat depends on the rebar corrosion degree.

Hence, the rebar corrosion degree can be estimated if quantity of inhibited heat is estimated by quantity of increasing temperature on concrete surface.

We will discuss detailed estimation rebar corrosion degree.

3.3.1 Quantity of Inhibited Heat by Existence of Corrosion Product

In the case of non-corroded rebar, heat quantity W_{st} is accumulated in rebar. It influences the behavior of surface temperature.



(a) K30-C0.66 (b) K50-C0.82 (c) K70-C0.70

Figure 8 : Temperature distribution of concrete surface over two rebar. Horizontal axis is length from center of section in Fig. 5.

Beside, in the case that rebar corrode, corrosion ratio n increases with the decreasing of accumulated heat quantity. In addition, because of inhibited heat diffused by corrosion product, apparent quantity of heat W_{co} which effects surface temperature on concrete can be given by Equation (1):

$$W_{co} = (1-n)W_{st} + nW'_{co} \qquad (1)$$

where W'_{co} = accumulated heat quantity which is added to insulation effect of corrosion product. In other words, this is quantity of heat which is diffused to concrete.

In this study, assuming that heat quantity W'_{co} varies according to specific heat ratio of non-corroded rebar and corroded rebar. Thus,

$$W'_{co} = \frac{C_{st}}{C_{co}} \qquad (2)$$

where C_{st} = specific heat of rebar, C_{st} = specific heat of corrosion product.

Heat quantity rate $RlossW$ which is inhibited by influence of corrosion product is shown this Equation:

$$RlossW = \frac{W_{st} - W_{co}}{W_{st}} \qquad (3)$$

Eq. (3) may be written as follows by substituting Eq. (1) and (2) :

$$RlossW = \frac{C_{co} - C_{st}}{C_{co}} \qquad (4)$$

3.3.2 Decreasing Rate of Concrete Surface Temperature by Existence of Corrosion Product

Temperature decreasing ratio of concrete surface by influence of corrosion product RT is shown this Equation :

$$RT = \frac{\Delta T_{st} - \Delta T}{\Delta T} \qquad (5)$$

where ΔT_{st} = quantity of increased temperature on concrete surface over the non-corroded rebar, ΔT = quantity of increased temperature on concrete surface over the corroded rebar.

Eq. (4) and (5) become equal. However, this state only applies in the case of equality material. Therefore, in case of composite material like RC structure, we must consider the influence of their heat characteristics. To consider the difference of the heat characteristics of the concrete and the rebar, Eq. (5) can be rewritten as follows :

$$RT_{rc} = \frac{\Delta T_{st} - \Delta T}{\Delta T} \cdot \frac{C_{st} \cdot \rho_{st} \cdot S_{st}}{C_{con} \cdot \rho_{con} \cdot S_{con}} \qquad (6)$$

where C_{con} = specific heat of concrete, ρ_{st} and ρ_{con} = density of the rebar and the concrete. S_{st} and S_{con} are areas of cross section of the rebar and the concrete, as shown in Fig. 9.

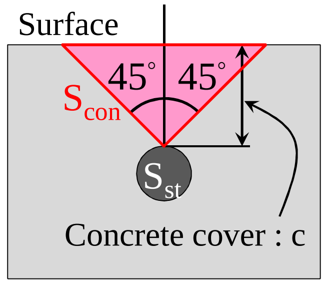


Figure 9 : Cross section of concrete ; It is shown range of heat diffusion from rebar

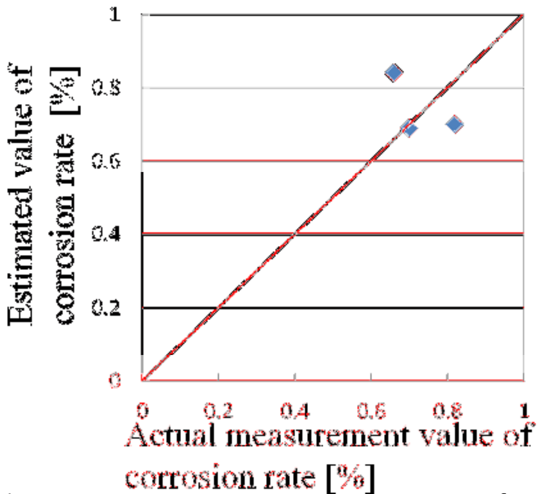


Figure 10 : Comparing corrosion rate of actual measurement value and that of estimated value. Actual measurement value and estimated value are equal on the red line.

3.3.3 Estimated Equation of Rebar Corrosion Degree

Finally, define the parameter α of heat diffusion shape in concrete, corrosion rate n may be written as follow :

$$n = \alpha \cdot \frac{\Delta T_{st} - \Delta T}{\Delta T} \cdot \frac{C_{st} \cdot \rho_{st} \cdot S_{st}}{C_{con} \cdot \rho_{con} \cdot S_{con}} \cdot \frac{C_{co}}{C_{co} - C_{st}} \quad (7)$$

where $\alpha = 0.0164c - 0.1$ (8)

c is concrete cover.

Calculate Eq. (7) so as to estimate corrosion ratio, which is shown Figure 10. It is found that this estimated equation have applicability because plotted point is near the red line.

4 CONCLUSIONS

(1) Corrosion product has insulation effectiveness because of its heat characteristics.

(2) In case that corrosion product occurred in RC structure, the concrete surface temperature becomes smaller than the case that rebar doesn't corrode.

(3) Estimated equation of the rebar corrosion degree which is proposed in this paper has applicability.

(4) For these consequence in this paper, it is found that there is applicability in proposed method.

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