

Crack Detection Methods Using Radio Frequency Identification and Electrically Conductive Materials

by

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ABSTRACT

In order to reduce life cycle costs of a building from construction to maintenance, it is very effective to monitor the structural health of a building. To generalize structural health monitoring of a building, establishment of a low-cost sensor system is desired. Radio Frequency Identification (RFID) tag is a promising device for the management of a huge number of products at a very low cost. In this study, two types of electrically conductive materials are considered. In this system, an electrically conductive paint or printed sheet is applied to a part of structure in which crack will occur. Copper wire is connected to the attachment on the structure and a RFID tag. When a crack occurs, the paint or printed sheet is broken, resulting in an increase in resistance of the measured current. Crack width can be estimated by the ability of an RFID transmitter to communicate with the tag, because electrical resistance value will vary with crack width. By bending tests of concrete specimens, the relationships between crack width and conductivity of the materials applied to the structure are examined. It is shown that the level of crack width which the specimen experienced can be related to the ability of the paint or printed sheet to conduct electricity or not.

KEYWORDS: Crack detection, Electrically Conductive Paint, Health Monitoring, RFID-tag,

1. INTRODUCTION

If we have to reduce life cycle costs of a building from construction to maintenance, it is very effective to monitor structural health of a building. Most buildings built during 1970's construction rush in Japan seem to rapidly deteriorate, and it is necessary to establish structural health estimation of these buildings. In

2002, performance certification mark system of existing housings is started in Japan, and structural performance will be displayed by visual inspection and structural design data, etc. However, in this performance evaluation, measurement such as acceleration is not carried out because of technical difficulties. The decisions from the inspection by experts according to manuals tend to be judged to safe side. It is important to carry out measurement to evaluate damages objectively and quantitatively. Damage detection and health monitoring are classified into two methods. The first method is based on vibration measurement, and the other one is based on phenomena such as cracking or heat. Each method has its strong points and its weak points. A damage identification system based on vibration measurements is effective for damage detection of whole structures or the story of a structure but it is not effective for damage detection of a specific portion of a building such as its structural members. On the other hand, damage detection based on phenomena such as cracking or heat is effective for damage detection of a specific portion of a building such as its structural members. By combining these two methods, it becomes possible to monitor structural health precisely.

A damage identification system based on vibration measurements has a possibility to find out the process of damage, but in such system, maintenance of sensor and data acquisition system costs very much. In some cases, it is not economical to measure for all time. It is very difficult to install such data acquisition system to many buildings because of high costs.

On the other hand, the techniques which grasp the local damage by use off-line system[1], such as carbon fiber lattice sensor or maximum value

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memory sensor are much more economical than vibration measurement system. In this study, crack detection sensor using Radio Frequency IDentification (RFID) tag and electrically conductive paint and printed sheets is proposed because of its low costs and easiness of the measurement. The RFID tag is generally used for distinction or management of human or products. By using this RFID tag and transmitter, radio communication is possible. In this proposed system, crack width is estimated by the propriety of this radio communication. In this study, fundamental experiments for the relationship between crack width and the resistance of electrically conductive materials are carried out, and possibility of application of this technique is examined.

2. OUTLINE OF SYSTEM

2.1 Radio Frequency Identification (RFID)

By the radio communication between RFID tag and transmitter with antenna and controller, the object can be recognized. Distance of this communication depends on the type of transmitter and tag. At the present time, there are RFID products whose communication distance is 2[m] to 9[m]. It is possible to communicate with a myriad tag by one transmitter because of the mobility of the transmitter. The price of tag itself is much more economical than conventional sensors.

2.2 Crack Detection System

Sensing part of this system shown in Figure 1 is a circuit in which electrically conductive material connects with copper wire part of the RFID tag. This sensing part is glued to detection objective part, and communication is carried out between transmitter and RFID tag. If the electrically conductive material is disconnected and the communication between RFID and transmitter is not possible, we can know the level of crack at the point electrically conductive material is applied. That is, the crack width is estimated by the ability of the electrically conductive material to conduct electricity. An example of coin type RFID tag is shown in

Figure 2.

2.3 Electrically Conductive Material

What is necessary for electrically conductive material applied to the detection part is shown below:

1) Electrically conductive material is disconnected at the crack width with the purpose.

2) It is comparatively easy to apply.

3) Material is economical.

In this study, two types of electrically conductive materials are tried. One is to apply paint directly which seem to be disconnected most easily, and the other is to glue a printed sheet which is suited to mass production. Both electrically conductive materials are very low cost, and the total installation cost with RFID-tag becomes very economical.

3. BENDING TESTS OF CONCRETE SPECIMENS ON RELATIONSHIP OF CRACK WIDTH AND CONDUCTIVITY OF THE ELECTROCALLY CONDUCTIVE MATERIAL

3.1 Material Property and Bending Test

Outline of bending test is shown in Figures 3. Strength of concrete material used for bending test is designed as $F_c=21\text{N/mm}^2$ and maximum size of coarse aggregate is 20mm. The dimension of the test specimen is 100mm×100mm×400mm. Fixed tensile force was given to the central part through PC reinforcement rod by a fixed torque. Electrically conductive paint and printed sheet are applied to the bottom of test specimen at midspan. Displacement transducers are respectively installed to both side of test specimen. Loading is carried out by use of 1000kN compression testing machine like Figure 4.

Measurements of load indicator and displacement transducers are carried out through static data acquisition system, and measurements of electrically conductive material resistance are carried out through a tester. Measurement data is acquired every 5kN loading before a crack occurs, and measurement data is acquired every 0.05mm of crack width after cracking. Unloading is started

from when crack width exceeds 1.9mm, and measurement data is acquired every 5kN loading until loading returns to the zero.

As a result of cylinder test, concrete compression strength is 37.7N/mm². Torque pressure is set at 19600Nmm, and axial force of PC reinforcement rod is estimated as 6530N. Bending crack moment M_{cr} is estimated as following[2];

$$M_{cr} = \left(\frac{5}{3} \times \sigma_t + N / A\right) \times Z$$

$$\approx \left(\frac{5}{3} \times \sigma_c / 10 + N / A\right) \times Z = 1156100 \text{ N} \cdot \text{mm}$$

where:

σ_t = Concrete tensile strength

σ_c = Concrete compression strength

N = Axial force of PC reinforcement rod

A = Cross section of specimen

Z = section modulus of specimen

Load F in which bending crack occurs is estimated as following;

$$F = 1156100 / 75 = 15400 \text{ N} = 15.4 \text{ kN}$$

3.2 Outline of Applied Electrically Conductive Material

In this study, two types of electrically conductive materials are tried as followings;

- 1) electrically conductive paint applied directly
- 2) printed sheet adhered with adhesive

In 1), coating material is one liquid acrylic paint (ShintronE-3801 made by SHINTO PAINT Co.) which includes carbon for filler, and 20mm length and 2mm width of paint is applied to specimen directly. Frequency which paint is applied is 1 time and the thickness of paint is about 30 μm as a result of measurements. In 2), the pattern of the electrically conductive printed coating (SS423 made by Nippon Achison) is printed like Figures 5 at a sheet (0.1mm thickness) of polycarbonate. The mesh wire diameter of printing is 35 μm , and thickness of the electrically conductive printed coating is adjusted about 5 μm .

Line widths on the printed sheet are 0.2mm,

0.3mm, 0.4mm and 0.6mm. Test specimen with this printed sheet and paint is shown in Figure 6.

3.3 Adhesive For the Printed sheet

In this crack detection test, printed sheet should break with crack occurring. The following three types of adhesives were examined for their adhesive properties in cracking.

- 1) two liquid epoxy adhesive
- 2) instantaneous adhesive for the concrete (CN-E made by Tokyo instrument)
- 3) instantaneous adhesive for strain gauge (CN made by Tokyo instrument)

In 1) and 2), there are some cases in which adhesive extends without transmitting the rupture. On the other hand, in 3), printed sheet tends to make a brittle fracture with crack occurring. From this fact, printed sheets are glued by instantaneous adhesive for strain gauge.

3.4 Results of Experiments

A crack in this test specimen and electrically conductive material after unloading is shown in Figure 7. In most cases, only one crack occurs like Figure 7 and electrically conductive material breaks by a crack. There are some cases in which two cracks occur. In the following results, only the case in which one crack occurs is shown. An example of the relationship between crack width and load is shown in Figures 8, and an example of relation between crack width and electrical resistance is shown in Figures 9. Crack width is gathered from mean value of installed two displacement transducers, because electrically conductive materials are located at center of test specimen. A crack occurs at about 15[kN] and unloading is started from about 1.9[mm] of crack width as shown in Figures 8. (In Figure 8, residual crack width is 0.37[mm].)

As shown in Figure 9, electrical resistance of electrically conductive material rapidly increases when crack width reaches to some value. The electrical circuit is considered to be broken when the resistance exceeds 10[M Ω]. Resistances over 20[M Ω] are all shown as 20[M Ω] in Figure 9 because of the range of the

tester with 20[MΩ]. The resistance value remains over 20[MΩ], even after unloading once if resistance value exceeds 20[MΩ]. From this result, electrical conductivity is not regained after unloading and this sensor seems to have some memory function.

For eleven concrete specimens, static loadings are carried out and crack widths are examined when the electrical circuit is broken. Results of each electrically conductive material are shown in Table 1 and Figures 10. In Table 1 and Figures 10, 2mm shows the case in which electrically conductive paint are applied directly and others show the case in which printed sheets are glued. The 2mm cases in which conductive paint are directly applied to test specimens are most sensitive to cracks and break first from the results of Table 1. In the cases of printed sheets, wire breaking crack width tends to increase, as the line width is generally thicker, though there is variation in the data. The reason for the variation is that the glued condition is not uniform. Though it is difficult to estimate crack width correctly, it is possible to predict the crack width level considering this variation.

4. UTILIZATION OF THE CRACK DETECTION SENSOR

In this crack detection sensor, the crack width is estimated from the line width of electrically conductive material that breaks. From results of experiments, there is some variation at wire breaking crack width. It is necessary to allow some variation in estimation of crack width from these results. For example, by using three types of line width electrically conductive materials, 2mm, 0.2mm and 0.6mm, prediction of crack level is possible such as small, medium or large size crack. Three types of level can be predicted from three types of electrically conductive materials.

It is possible to use this crack detection sensor for the health monitoring of piles in which visual inspection is very difficult. In such cases, the sensor is beforehand installed around at pile top or points of stratum changing in which cracks are predicted to occur. By the propriety of the communication with the RFID tag, the crack width is estimated.

On disconnection of electrically conductive material, it is necessary to prevent disconnection by the factor other than crack. About the printed sheet, it is possible to apply the laminate technology for protection of printed circuit board which is installed in products like cars or housing electric appliances.

5. CONCLUSIONS

Health monitoring is important to attempt life-lengthen and life cycle cost reduction of building structures. For popularization of health monitoring, establishment of more economical sensor system is desired. In this study, crack detection sensor which consists of an RFID tag and electrically conductive materials are examined. Conclusions of this study are shown in the below:

- 1) By crack detection sensor which consists of an RFID tag and electrically conductive material, continuity of the electrically circuit can be known from the propriety of radio communication. Crack detection is possible from continuity condition.
- 2) By bending tests of concrete specimens, difference of wiring breaking crack width is examined by glue type or width of electrically conductive material. It is proven that estimation of crack width level in which test specimen has experienced is possible by property of radio communication.
- 3) Estimation of crack width by this technique is not so accurate, but it is proven that it is possible to estimate crack by allowing some variation.

Static loading experiments at the laboratory level are carried out in this paper. As future problem, following items are mentioned.

- 1) Examination of loading speed effect
- 2) Examination of sensors with protects
- 3) Application to actual structure.

6. REFERENCES

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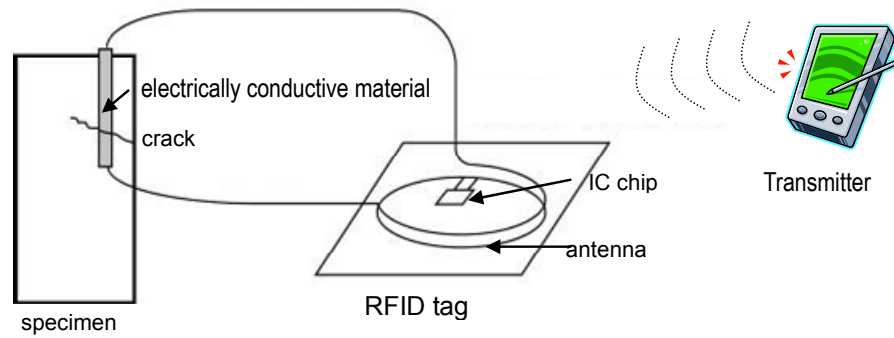


Figure 1 : Outline of crack detection system

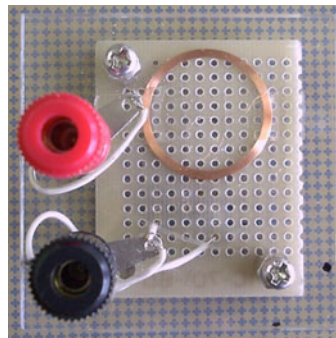


Figure 2 : An example of coin type RFID tag

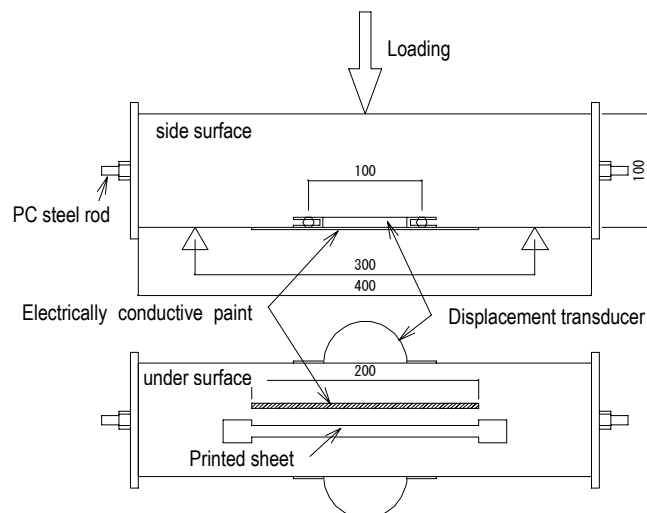


Figure 3 Outline of bending test



Figure 4 Specimen and testing machine

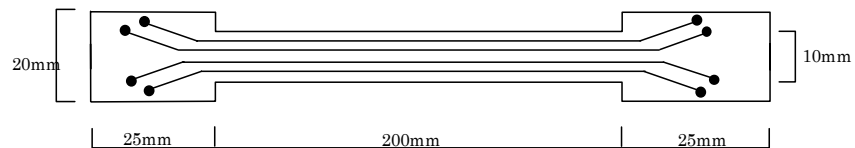


Figure 5 Print pattern



Figure 6 Specimen with printed sheet and paint



Figure 7 : Crack in this test specimen and electrically conductive materials after unloading

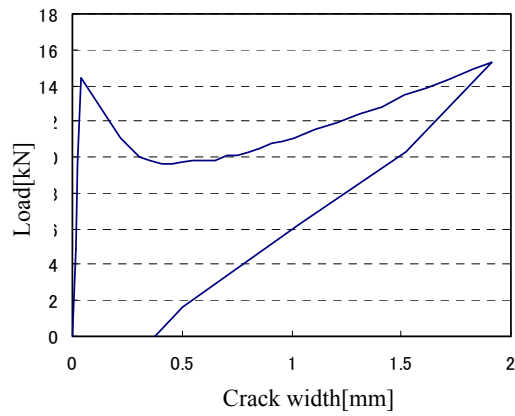


Figure 8 : An example of relationship between load and crack width

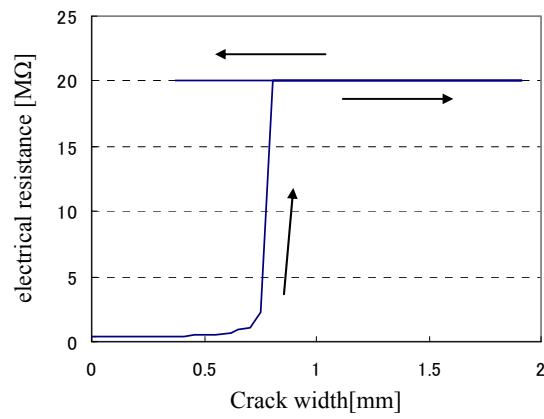


Figure 9 : An example of relationship between electrical resistance and crack width

Table 1 : Wire breaking crack width

(2mm : Paint are directly applied、0.2~0.6mm : Printed sheet are glued)

Case No.	2mm	0.2m m	0.3m m	0.4m m	0.6m m
1	0.14	0.65	1.2	0.88	1.1
2	0.35	0.45	0.95	0.85	1.02
3	0.50	0.65	0.9	0.85	0.95
4	0.30	0.30	0.8	0.45	0.71
5	0.32	0.90	0.70	1.8	1.46
6	0.24	0.93	0.93	0.98	1.1
7	0.33	0.33	0.72	1.13	1.41
8	0.38	0.86	1.51	1.71	1.48
9	0.22	0.67	0.39	0.32	0.68
10	0.45	0.45	0.71	0.71	0.85
11	0.52	1.08	1.08	1.08	1.22
average	0.341	0.661	0.899	0.978	1.089
Standard deviation	0.118	0.260	0.296	0.455	0.283

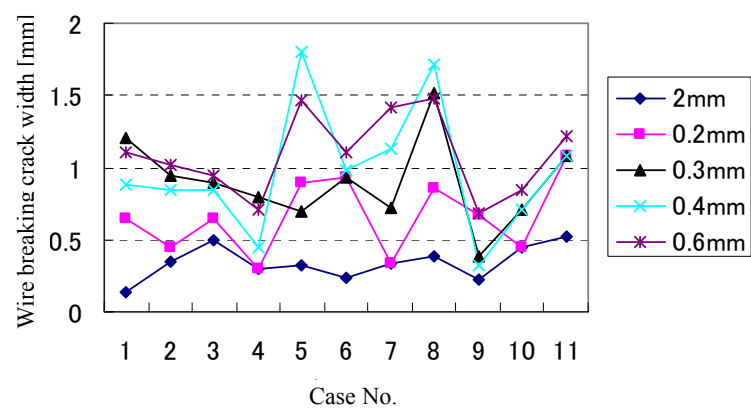


Figure 10 : Wire breaking crack width