

CRACK DETECTION METHODS USING RADIO FREQUENCY IDENTIFICATION AND ELECTRICALLY CONDUCTIVE MATERIALS

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ABSTRACT :

Radio Frequency Identification (RFID) tag is a promising device for the management of products at a very low cost. Huge number of such low-cost sensors can be installed to the structure beforehand, after a disaster we can access to these sensors wirelessly and very easily. In this system, a 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 printed sheet is broken, resulting in an increase in resistance. Crack width can be estimated by the ability of an RFID transmitter to communicate with the tag. By fatigue test of steel specimen with a notch, the relationships between crack width and conductivity of the materials are examined. It is shown that the level of crack width can be related to the ability of the printed sheet to conduct electricity or not. Very small steel crack can be detected by this sensor.

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

1. INTRODUCTION

In recent years, much attention has been given to structural health monitoring technology to diagnose the condition of structures using a sensor attached to them, and the number of research projects on the health monitoring of architectural structures is on the rise.

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 (Wood, S.L. and Neikirk, D.P.(2001)), such as carbon fiber lattice sensor or maximum value 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 buildings that were damaged by the Great Hanshin-Awaji Earthquake, the examination of steel structures covered with fire-resistant material required considerable effort, including removal of the material to detect cracks and breakdowns that occurred at the end of steel beams and in other parts of the buildings, and it was extremely difficult to investigate the inside of fire-resistant materials. (The Great Hanshin-Awaji Earthquake Investigative Report Editorial Committee (1997)) Such types of damage should be examined carefully because they are highly likely to lead to the breakdown of beam ends and other parts of the building in the event of a large earthquake.

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[cm] 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.

As shown in Figure 1, JB-1000 RFID tags (Japan Information System Co., Ltd.) were used in this study, and relatively low-priced tags of 2.45-GHz frequency and a long reading distance were chosen. These tags are readable and rewritable, and their maximum reading distance is 130 cm.

The tags mentioned above are commercially available, but in this study, RFID tags with a tamper switch were prepared.

The tags were read using the antenna and the scanner shown in Figure 2, as well as a notebook personal computer.



Figure1 : RFID-tag



Figure 2 : Antenna and Scanner

2.2. Crack Detection System

Figure 3 shows an outline of the crack detection system using an RFID tag with a tamper switch. The reader/writer can read the ID number of the RFID tag with a tamper switch connected to a detection sheet and determine whether the connected switch is on or off. The reader/writer determines that the switch is off if the lead wire on the detection sheet is broken, and vice versa. If the switch is off, the reader/writer determines that there is an abnormality in the sheet, but the cause of the switch being off is limited to the detection sheet. (Even if the switch is off, communication is established between the reader/writer and the RFID tag, and the ID number can be retrieved.)

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 reader/writer shows the switch off, we can know the level of crack at the point electrically conductive material is applied.

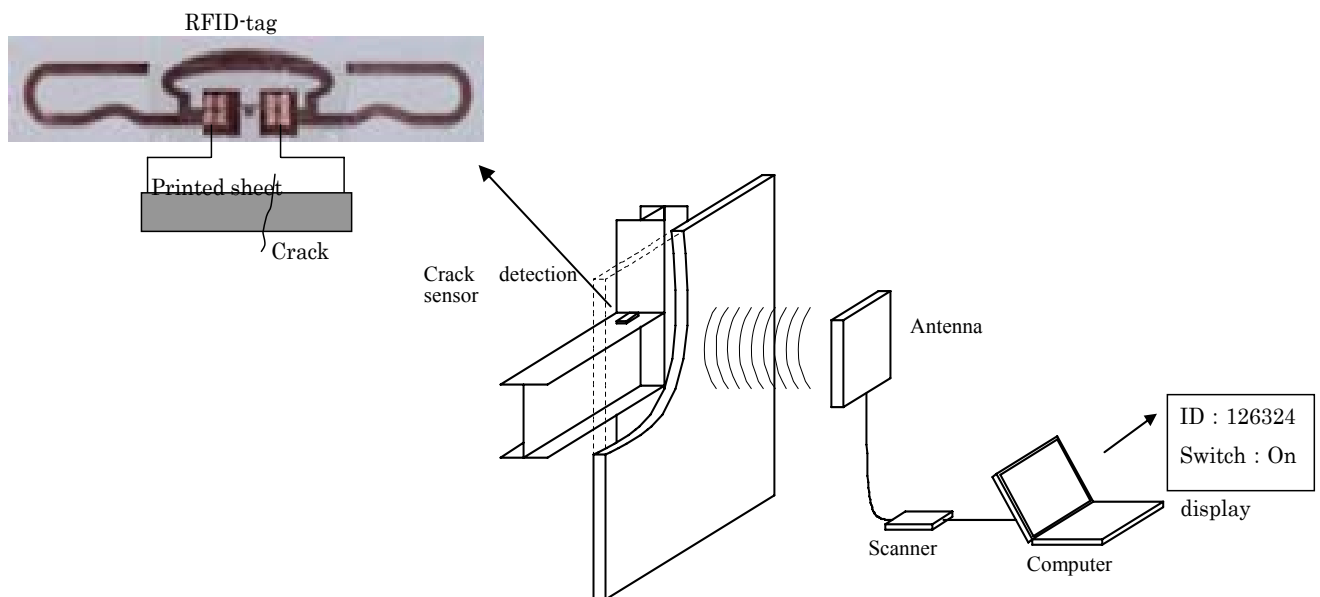


Figure 3 : Outline of crack detection system

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, a printed sheet which is suited to mass production is tried. This electrically conductive material is very low cost, and the total installation cost with RFID-tag becomes very economical.

2.4. Tag Reading Penetration Tests

The crack detection system described in Section 2.2 assumes that detection sheets (electrically conductive printed sheets) and RFID tags installed at the end of steel beams and in other parts of a building are read from outside. The question is whether radio communications can penetrate fire-resistant material when the tags are read, as shown in Figure 3.

The maximum readable distance was investigated by placing fire-resistant and other materials between the antenna and the tag. The results are shown in Table 1.

Fire-resistant materials, such as perlite board, rock wool board, and ceramic wool, are basically used to cover steel structures. Ceramic wool is directly wound around steel beams and columns. The maximum readable distance varies depending on material thickness, although all materials allow tags to be read up to a distance of

100-110 cm.

Glass allows tags to be read at a slightly shorter distance. Neither metals nor reinforced concrete walls are penetrable by radio communications.

These results should be taken into account when determining the tag installation position.

Table 1: Maximum Readable Distance for Various Materials

Material and thickness	Readable distance	Average
Pearlite board (6mm thick)	95cm, 114cm, 95cm	101cm
Pearlite board (10mm thick)	85cm, 85cm, 90cm	87cm
Pearlite board (10mm thick)x2	62cm, 75cm, 65cm	67cm
Pearlite board (10mm thick)x3	62cm, 65cm, 65cm	64cm
Pearlite board (10mm thick)x4	55cm, 62cm, 58cm	58cm
Rock wool acoustic board (12mm thick)	116cm, 115cm, 120cm	117cm
Rock wool board (25mm thick)	100cm, 115cm, 92cm	102cm
Ceramic wool (30mm thick)	110cm, 110cm, 108cm	109cm
Ethyl carbonate (20mm thick)	93cm, 103cm, 95cm	97cm
Laminated wood (15mm thick)	75cm, 85cm, 76cm	79cm
Lubber (2mm thick) + Carpet (5mm thick)	100cm, 90cm, 110cm	100cm
Brick (105mm thick)	44cm, 52cm, 50cm	49cm
Glass (7mm thick)	33cm, 30cm, 32cm	32cm
Metallic mesh	Not transmittable	
Reinforced concrete wall (200mm thick)	Not transmittable	

3. EXPERIMENTAL INVESTIGATION AND RESULTS

3.1. Outline of Fatigue Test

A steel sheet (SS400; 3.2 mm thick) having a notch of the shape shown in Figure 4 was prepared to induce cracks in the sheet, and fatigue tests were conducted. Referring to the method in Reference (Tomatsu, T. and Mimura, H.(2005)), these tests were conducted by changing the target load from 26 to 35 kN and following JIS Z 2273 standards. The load was applied by a 2000-kN servo testing machine (Figure 5).

A printed sheet was attached to the center of a steel specimen to measure the resistance of the electrically conductive paint on the sheet using a tester.

A clip-type displacement transducer (UB-2; Tokyo Instruments, Inc.) was installed near the notch to measure crack width.

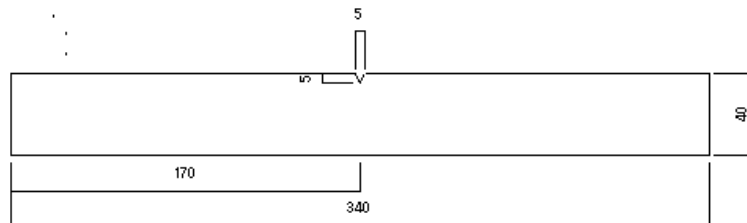


Figure 4 : steel specimen for fatigue test



Figure 5 : Testing machine.

3.2. Description of Applied Printed Sheet

Figure 6 shows the printed sheet used to detect cracks.

As indicated in Figure 6, eight types of paint coating widths were used: 0.1 mm, 0.2 mm, 0.3 mm, 0.4 mm, 0.5 mm, 0.6 mm, 0.8 mm, and 1.0 mm. Lines were printed using four types of widths to create the first printing pattern A and another four to create the second printing pattern B.

The four types of paint listed below were used for printing.

- (1) Electrically conductive carbon paint with high hardness
- (2) Electrically conductive carbon paint with low hardness
- (3) Silver paint
- (4) Mixed silver-carbon paint

Five types of materials were used as printed sheets: polycarbonate sheets of 0.1 mm or 0.13 mm thickness, as well as polyimide sheets of 0.05 mm, 0.075 mm, or 0.125 mm thickness.

An instantaneous adhesive for strain gauge (CN; Tokyo Instruments, Inc.) was used to adhere the sheets.

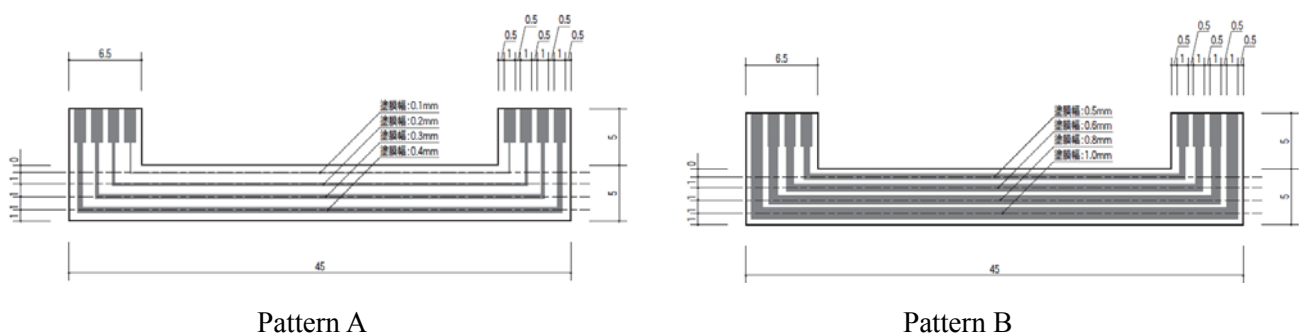


Figure 6 : Printed sheet for steel crack

3.3. Experimental Results and Discussion

Various combinations of sheets and electrically conductive paints described in Section 3.2 were examined, but the results showed few marked differences attributed to the type of paint used. When polyimide sheet was used, the wire of the electrically conductive paint did not break even if a crack occurred on the polyimide sheet.

The following are the results of tests using 0.1- and 0.13-mm-thick polycarbonate sheets and silver paint. A tester was used, electric resistance could not be recorded at short intervals, and cracking progressed at a certain speed. For these reasons, the width of cracks that occurred when the resistance of each type of electrically conductive paint exceeded 20 M Ω was basically examined.

Figure 7 shows an example of cracks in the steel specimen and the printed sheet after load removal. In most cases, the printed sheet fractured at the same time that a crack occurred on the steel specimen.

Table 2 lists the crack widths observed when cracks were detected on an electrically conductive paint line.

In all cases, when target load was 30 kN or more and crack width was around 0.08 mm or more, the printed sheet fractured and the wire was broken at the same time that a crack occurred. When the target load was around 26 or 27 kN and the crack width was around 0.05-0.07 mm, some sheets fractured while others did not, indicating the tendency that wire breaking occurred easily in a 0.1-mm-thick printed sheet.

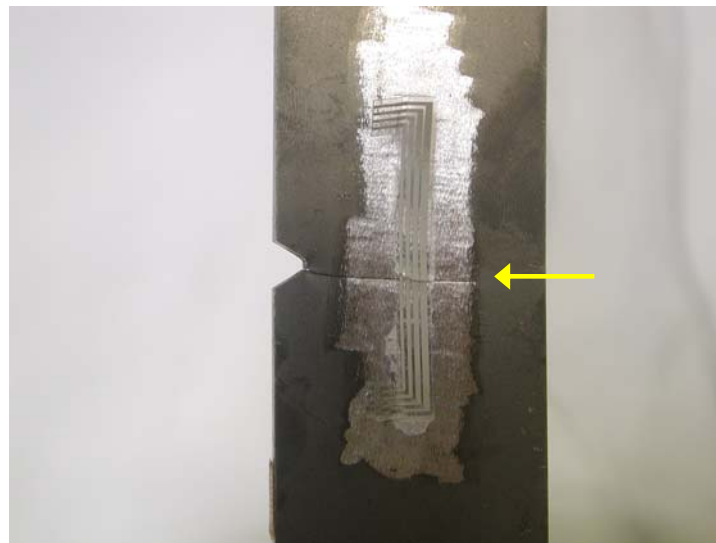


Figure 7: Crack in the specimen and printed sheet after unloading.

Table 3 : Wire breaking crack width in mm

Sheet Thickness	Printed Pattern (line width)	Target Load [kN]	Wire breaking crack width in mm			
			0.1mm 0.5mm	0.2mm 0.6mm	0.3mm 0.8mm	0.4mm 1.0mm
0.1mm	A 0.1-0.4mm	35	0.111	0.117	0.123	0.126
		30	0.0945	0.102	0.113	0.148
		27	0.0777	0.0866	0.0936	0.103
		26	No Breaking	0.0716	No Breaking	No Breaking
	B 0.5-1.0mm	35	0.136	0.143	0.158	0.172
		30	0.0804	0.0875	0.0875	0.112
		26.5	No Breaking	No Breaking	No Breaking	No Breaking
0.13mm	A 0.1-0.4mm	35	0.131	0.157	0.170	0.186
		30	0.0866	0.0892	0.103	0.117
		27	No Breaking	No Breaking	No Breaking	No Breaking
	B 0.5-1.0mm	35	0.119	0.132	0.146	0.191
		30	0.107	0.108	0.108	0.110
		27	No Breaking	No Breaking	No Breaking	No Breaking

4. CONCLUDING REMARKS

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 fatigue tests of steel specimens, it is proven that printed sheet made by polycarbonate can detect crack whose width is 0.08 mm or more.
- 2) 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) Application to actual structure.

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