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Measurement of Microwave Propagation Characteristics along a Fiberglass-Reinforced Plastic Mortar Pipe Using an Electro-Optic Sensor

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Abstract We have proposed a new nondestructive inspection method for fiberglass-reinforced plastic mortar (FRPM) pipes using microwave guide-mode propagation and photonic techniques. This method is based on the precise measurement of a microwave guided-mode propagated along an FRPM pipe-wall by use of an electro-optic (EO) sensor. In the previous research, we have confirmed that microwave can propagate along the FRPM pipe-wall as a guided-mode, and the microwave transmission characteristics propagated through the FRPM pipe are affected by defects or cracks in FRPM pipe-walls. By measuring transmission characteristics and electric field distributions by using the EO sensor precisely, we can detect small defects or cracks in/on the FRPM pipe nondestructively.

Keywords Microwave, Electro-optic sensor, Nondestructive inspection, Waveguide, FRPM pipe

1. Introduction

Our ICT-based daily life in the 21st century is supported by many infrastructure networks such as transportation networks (highway, high-speed train, subways), bridges, electric power networks, optical fiber and wireless communication networks, pipeline networks for water, gas and oils, and so on. Therefore, easy, fast and nondestructive inspection technologies for infrastructure networks are required [1],[2]. Fiberglass-reinforced plastic mortar (FRPM) pipes are widely used for these pipeline networks.

Since FRPM has high mechanical strength and high chemical corrosion resistance despite being lightweight, FRPM is used in many application fields such as protecting tube for power/communication cables, sewer pipes and agricultural pipes. Especially, the total length of the agricultural water pipelines made of FRPM is approximately 50,000 km in Japan. And the useful time of the FRPM pipe can be extend by regular inspection and maintenance.

An FRPM pipe can be inspected nondestructively by using magnetic resonance imaging (MRI), X-ray and ultrasonic waves [3]. However, these methods are unsuitable for inspection of long and buried FRPM pipelines, since these methods require large and specific measurement machines. Therefore, an inspection method for FRPM pipes has been needed.

We have found that FRPM is a dielectric material with relatively small loss in the microwave frequency range of 1~10 GHz, and we have proposed a new inspection method of FRPM pipelines by using the propagation of microwave along pipe-walls of FRPM pipes and measurement the change in microwave transmission characteristics caused by a deterioration, defects or cracks [4]. In the previous report, we confirmed that a microwave propagates along pipe-walls of FRPM pipes and the microwave transmission characteristics is affected by surface condition, defects or cracks.

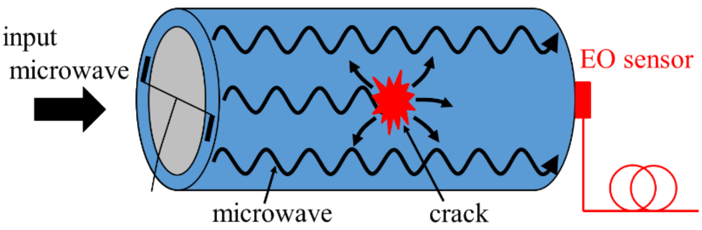


Fig.1 Schematic of the proposed inspection method.

In this paper, we discuss the results of measuring a microwave transmission characteristics and electric field distributions using a commercially available electro-optic (EO) sensor for the normal FRPM pipe and the damaged one with some defects or cracks. By using EO sensors with small distortion for the measurement electromagnetic fields, we can identify a change in microwave transmission characteristics precisely and can detect small them.

2. Basis of this inspection method

Schematic of the proposed inspection method is

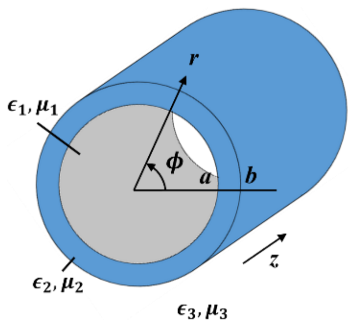
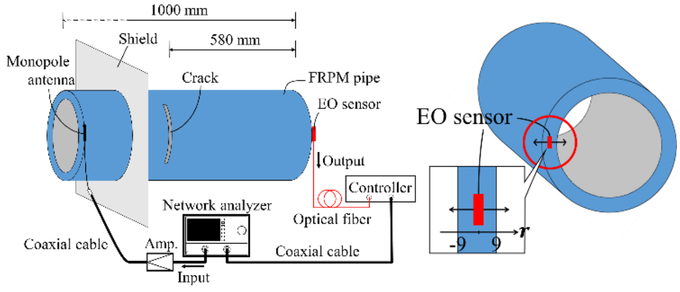
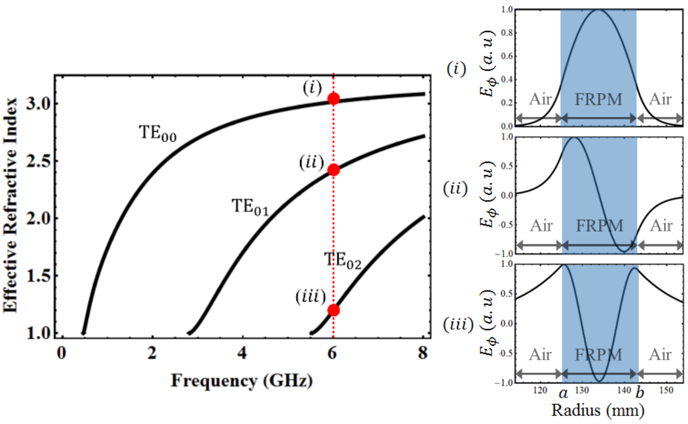


Fig.2 Structure of a hollow cylindrical dielectric waveguide.



(a) (b)

Fig.4 Experimental setup. (a)Whole view, (b)End view.



(a) (b)

Fig.3 (a) Dispersion curves. (b) Electric field distributions.

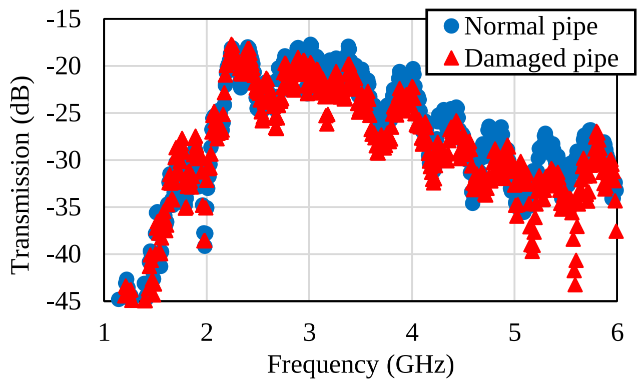


Fig.5 Microwave transmission characteristics propagated along the normal/damaged FRPM pipe.

shown in Fig.1. In this method, an FRPM pipe is used as a microwave transmission line. Microwave signals are input from one end of the FRPM pipe, and propagated along the FRPM pipe-walls. Then the propagated microwave signals detected at the other end of the FRPM pipe. If there are some defects or cracks in the FRPM pipe, the microwave signals propagating along FRPM pipe-wall are distorted by defects or cracks, and then, the propagated microwave signal level and the distribution of the microwave fields are changed. Therefore, we can detect defects or cracks in the pipe as the change in microwave transmission characteristics and distributions of the microwave field.

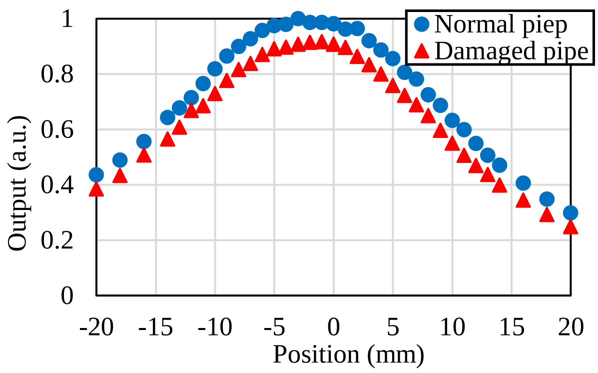
We analyzed microwave transmission characteristics propagating along the FRPM pipe. An FRPM pipe is considered as a hollow cylindrical dielectric waveguide, as shown in Fig.2, where a is an inner radius, b is an outer radius, $\epsilon_i\,(i = 1, 2, 3)$ is the permittivity and $\mu_i\,(i = 1, 2, 3)$ is the permeability in each region. From the Helmholtz equation, field distributions for transverse electric modes TE_{mn} and trans-verse magnetic modes TM_{mn} can be obtained. Then, eigenvalue equations are obtained from the continuity conditions of tangential components of electromagnetic fields at the boundary.

By solving the eigenvalue equations, we derived the dispersion curves of the effective refractive indices and electric field distributions, as shown in Fig.3, where the regions 1 and 3 are air ($\epsilon_1 = \epsilon_3 = 1$), the region 2 is FRPM of permittivity $\epsilon_2 = 10.24$, an inner radius a is 125 mm and an outer radius b is 143 mm [4]. From these dispersion curves, we can see that there is only a single guided mode (TE_{00}) around 2 GHz while there are three guided modes (TE_{00}, TE_{01} and TE_{02}) at 6 GHz.

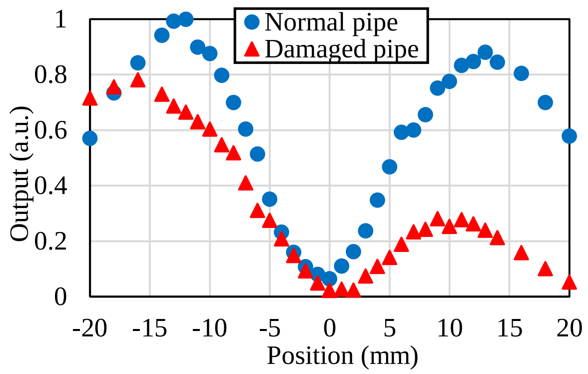
3. Measurement

The experimental setup is shown in Fig.4. Microwave signals from a network analyzer were input to an FRPM pipe (length $l = 1000$ mm, inner radius $a = 125$ mm and pipe thickness $t = 18$ mm) from the end by use of a monopole antenna. The electric field emitted from the monopole antenna was set to be along ϕ direction in Fig.2 to excite the TE-mode. The transmitted microwave signals along the FRPM pipe were received using an EO sensor (SEIKOH GIKEN CS-1210) located at the other end of the FRPM pipe.

Microwave transmission characteristics along the FRPM pipe were measured by use of a network analyzer. Microwave electric field distri-butions were also measured by scanning the EO sensor along the direction of radius (the r direction in Fig.4 (b)) with a 1 mm-step at end of the pipe. We measured the microwave transmission and



(a)



(b)

Fig.6 Electric field distributions of microwave propagated along the normal/damaged FRPM pipe at (a) 2.4 GHz and (b) 6 GHz.

distributions both for a damaged FRPM pipe with some cracks and a normal FRPM pipe without cracks.

4. Results of measurement

Fig.5 shows a measurement results of microwave transmission characteristics when the EO sensor was set at the end of the FRPM pipe with the position of $r = 0$ shown in Fig.4 (b). There are two curves in Fig.5; one is a microwave transmission characteristics for the normal FRPM pipe and the other is for the damaged FRPM pipe. We can see a clear difference between the two results.

Fig.6 shows the measured electric field distributions at (a) 2.4 GHz and (b) 6 GHz by scanning the EO sensor at the end of the FRPM pipe, as shown in Fig.4 (b). In the results of the damaged pipe, the microwave signal levels were decreased. We believe that these change were caused by the cracks in the FRPM pipe. Since there is only one guided mode of the microwave propagating along the FRPM pipe at 2.4 GHz as shown in the dispersion curve in Fig.3 (a), the microwave amplitude is merely distorted by the defects or cracks. On the other hand, at 6 GHz there are three microwave guided modes propagating along the FRPM pipe as shown in the dispersion curves of Fig.3 (a). Then the microwave guided modes can be not only distorted but also mutually coupled by defects or cracks. Therefore, the change in the field profile at 6 GHz was rather definite compared with that at 2.4 GHz.

We can see that there is a big drop around the position of 13 mm between the normal and damaged FRPM pipe at 6 GHz in Fig.6 (b). Therefore, we believe that we can detect small cracks by measuring a microwave electric field distribution by use of the EO sensor precisely.

5. Conclusion

We discussed the proposed new nondestructive inspection method for the FRPM pipe. The microwave signals propagating along the pipe-wall are affected by cracks and surface condition of the pipe. The difference of microwave transmission and distributions between the normal FRPM pipe and the damaged one were clearly identified. Thus, we believe that small defects or cracks can be detected by measuring field distributions. Now, we are going to measure for buried FRPM pipes under the ground.

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