Development of Ingredients for Electromagnetic Wave Absorbing Pavement

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Abstract In ETC, when communicating, road surface reflection spreads out of a communication area, and the case which produces incorrect communication was checked. As this measure, we developed the electromagnetic wave absorption pavement material which absorbs generating for a road surface reflective wave. This report summarized the result of material testing of electromagnetic wave absorption pavement material, and examination pavement.

Keyword ETC, Wave Absorbing Pavement, Carbon Fiber, Soft Magnetic Metal Powder

1.Introduction

Because of the beginning of service using ETC (Electric Toll Collection System) in 2001, the number of users is expected to increase. This will be due to the reduction of traffic previously caused by cash payment, and the existence of a service that works towards better mileage and usage frequency. The increase of ETC users will inevitably lead to the increase in ETC lanes, and a higher level electromagnetic environment within the payment booth will be desired. Since the electromagnetic wave signals are sent towards the road surface from a height of 6m above the ground, it can be expected that some of the reflected waves will pass into areas outside communication area. It can also be seen that there may be mistaken connections that occur with cars that are not subject cars, thus preventing proper functioning of the system. In order to solve this problem, we started the "development of electromagnetic wave absorbing pavement," which would allow the pavement surface to absorb magnetic waves and prevent the reflection of electromagnetic waves. This document describes the results of indoor experiments concerning electromagnetic wave absorbing pavement, and tested pavement.

Figure_1　Kenodo Hinode IC, ETC Toll Booth **(September, 2001, Actualization of the Electromagnetic Wave Absorbing Pavement)**

2. The Electric Characteristics of the Pavement Material

2.1 Permittivity of the Basic Ingredient

We have measured the electric characteristics of asphalt and aggregates used in basic pavement

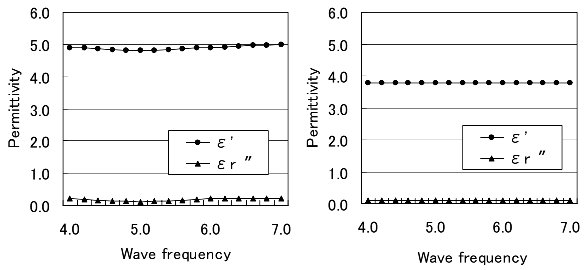

Figure_2　The Electrical Characteristics of Aggregates and asphalt

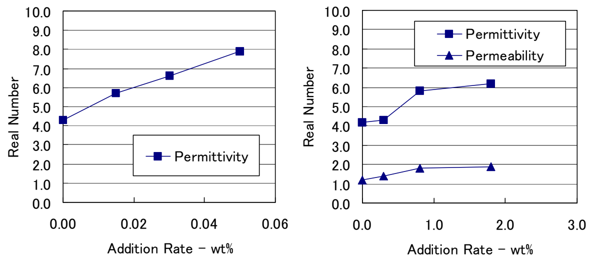

Figure_3　The Electric Characteristics of Pavement Ingredient

$\dot{S}_{TM}$: Reflection Coeffecient of the TM waves.
$\dot{S}_{TE}$: Reflection Coeffecient of the TM waves.
$\dot{Z}_{TM}$: Characteristic Impedence of Absorber
$\dot{Z}_{TE}$: Characteristic Impedence of Absorber
Z_0 : Characteristic Impedence of Free Space
θ : Angle of Wave Entry
$\dot{\varepsilon}_r$: Complex Relative permittivity Constant of the Absorber
$\dot{\mu}_r$: Complex Relative Permeability of the Absorber
λ_0 : Wavelength of Electromagnetic Waves in Free Space

material using a waveguide method. Figure 2 shows the measured dielectric constants of aggregates and asphalt. Figure 3 shows the measured results of the measurement. As shown in the figure, Dielectric constant of aggregate is εr=4.92-0.188i, at 5.8GHz. And dielectric constant of asphalt is εr=3.76-0.0492i. at 5.8GHz.They are both dielectrics.

2.2 Permittivity and Permeability of Drainage Type Pavement

We measured the electric characteristics of a drainage type pavement with added electromagnetic wave absorbing ingredients using the free space method. We did this while keeping in mind that the particle diameter of the pavement-use aggregate was 0_13mm and the apertures in the interior of the pavement were not homogenous. In the case where carbon fibers (fiber length 5mm, fiber diameter 8 μ m) or soft magnetic metal powder is used as an electromagnetic wave absorbing ingredient, we can adjust the electric characteristics of the drainage type pavement through mixed ratios. With the carbon fiber, we can change the permittivity (Real number) to 4.0_8.0 with a mixed ratio of 0 _0.05wt%. Also, with the soft magnetic metal powder, we can change the permittivity (Real number) to 4.0_6.2 and the permeability (Real number) to 1.0_2.0 with a mixed ratio of 0 _1.8wt%.

3. Electromagnetic Wave Absorbing Characteristics of Drainage Type Pavement (double layers)

3.1 Theoretical Formulas for Absorption Characteristics

Figure_4 shows the structure of a drainage type pavement. Since drainage type pavement, which has added electromagnetic wave absorbing ingredients, has the same electrical characteristics as common electromagnetic wave absorbing ingredients, we used the following theoretical formulas to calculate the electromagnetic wave absorbing efficiency.

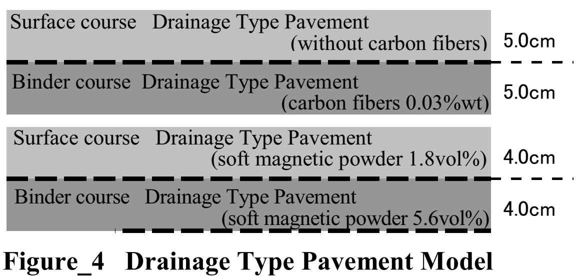

Figure_4 Drainage Type Pavement Model
Upper: Carbon Fibers Lower: Soft Magnetic Powder

3.2 Absorption Characteristics of Drainage Type Pavement with Added Electromagnetic Wave Absorbing Ingredients.

We created a test piece of electromagnetic wave

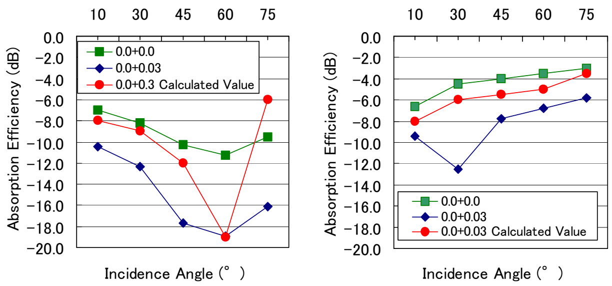

Figure_5 Absorption Efficiency of Carbon Fibers (Comparison of the Calculated Values and the Measured Values)

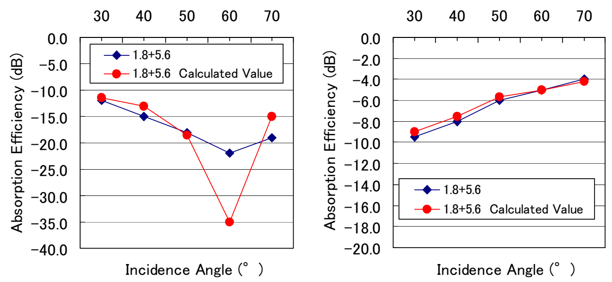

Figure_6 Absorption Efficiency of Soft Magnetic Powder (Comparison of the Calculated Values and Measured Values)

absorbing pavement with added carbon fibers and soft magnetic powder. We have measured the absorption efficiency and compared it to our thoretical calculations. Figure_5 and Figure_6 shows a result of the experiments and theoretical calculation.

3.2.1 The Effects of Adding Carbon Fibers

The electromagnetic wave absorbing pavement has increased absorption efficiency when incidence angle of the TM waves is increased. With the increase of incidence angle of TE waves, the absorption efficiency tends to decrease. The absorption efficiency of the TM waves is in the range of -10_-19db, and the absorption efficiency of the TE waves is in the range of -6_-12dB. We can observe that overall; the calculated values are less than the measured values. One of the reasons for this is that the carbon fibers and aggregates were mixed and during this process the fiber length of the carbon fibers became shorter. Also, there were differences in the thickness of the test piece layers and differences in the number of bumps and dimples may have caused mismeasurements. This is why the calculated values may have been different from the measured values.

3.2.2 The Effects of Adding Soft Magnetic Powder

In the case of soft magnetic powder, the calculated values and measured values were mostly equal, and we feel that we achieved results that correctly show the permittivity and permeability of the pavement ingredient. The absorption efficiency according to incidence angle was the same as in the case of carbon fibers: the absorption efficiency would increase with the increase in incidence angle, and with the TE waves, the opposite would happen, in that the absorption efficiency would decrease with the increase in angle. The absorption efficiency for TM waves was in the range of -12_-22dB, and the absorption efficiency for TE waves was in the range of -4_-9dB. Through adding electromagnetic wave absorbing materials like carbon fibers and soft magnetic powder to the drainage type pavement, it was possible to add capabilities that are the same as existing electromagnetic wave absorbing bodies. The electric qualities change according to the type of electromagnetic wave absorbing ingredient, but at an incidence angle of 60° we are able to achieve an absorption efficiency of -10_-20dB for TM waves, and -5_-10 for TE waves .

4. Trial Pavement (Kenodo: Hinode IC)

4.1 Construction of the Pavement

We made the construction of the pavement follow standard methods, so that the surface course is drainage type pavement and the binder course is SMA (crushed mastic stone pavement). Figure_7 shows the structure of the pavement. We used carbon fibers for the electromagnetic wave absorbing ingredient, so that its mix made up 0.015% of the surface course and 0.03% of the binder course. Figure_8 and Figure_9 shows constructional situation of the pavement.

Surface course (absorbing material)	Added CF Amount 0.015%	40㎜
Binder course (SMA)	Added CF Amount 0.03%	40㎜
Foundation (Water Resistant Layer)	Concrete Pavement	

Figure_7 Drainage Type Pavement Model

4.2 Absorption Efficiency

We arrived at the efficiency value for the electromagnetic wave absorbing pavement by measuring the absorption efficiency at the actual position (as shown in Figure_11), and by confirming whether it had fulfilled the prescribed efficiency. In Figure_10, we display the measured results at the actual position using the arch method. There was a tendency for the absorption efficiency to increase when incidence angle of the TM waves increased, and in the opposite manner, a tendency for the absorption efficiency to decrease when incidence angle of the TE waves increased. On the Kenodo and the Hinode IC, we confirmed that the absorption efficiency of the ETC entrance and exit lanes cleared the objective efficiency. The measurement is shown in Figure_10. However, the measuring locations were widely scattered, and this may have caused the variations in the dispersal of electromagnetic wave absorbing ingredients mixed into the pavement material, and also in the amount of bumps and dimples in the pavement surface. We confirmed the absorption efficiency of the electromagnetic wave absorbing pavement by using the arch method at the actual position.

Figure_8 Pavement Condition (Spreading and Levelling)

Figure_9 Pavement Condition (Rolling)

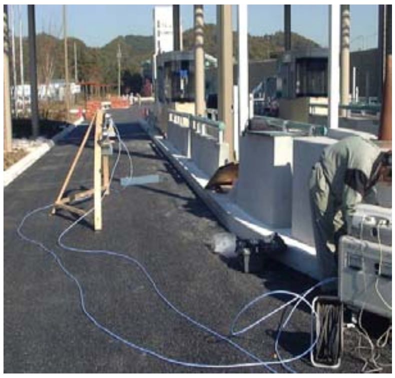

Figure_10 Absorption Efficiency of Electromagnetic Wave Absorbing Pavement

Figure_11 Mesuring the received power
Left: Dried Middle: Damp Right: Reflection

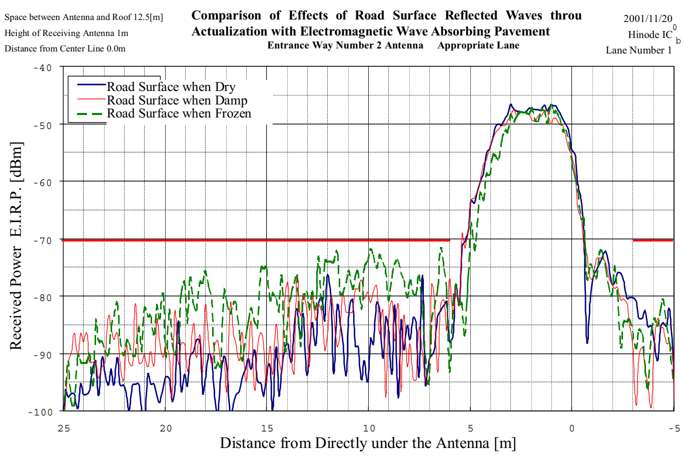

Figure_12 Measurement Results of the Received Power

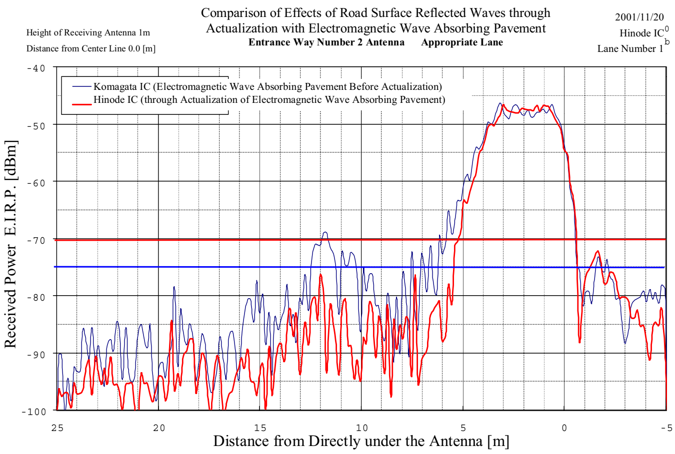

Figure_13 Measurement Results of the Received Power

4.3 Applied Effects of the Electromagnetic Wave Absorbing Pavement

We set up a temporary ETC antenna and measured the received power inside the toll gate. Figure_12 and Figure_13 shows the measurement results. We figured out the effects that the reflection conditions on the pavement surface had on the received power. In order to do this, we set up three types of road surface conditions: dried road surface, damp road surface, and reflection road surface (laid out boards of aluminum). We figured out the applied effects of the electromagnetic wave absorbing pavement by measuring effects at a toll booth that had a similar structure to the one at the Hinode IC tollbooth.

- The received power differed according to the pavement road surface reflection condition (dried, damp, total reflection) and the road surface reflection waves had an effect on the electrical values that went outside communication area.

  The dried road surface was reduced to less than -80dBm outside communication area.
  The damp road surface had received power that was measured to be about 5dBm greater than the dried road surface.
  The reflection road surface is meant to serve as a substitute for when water or ice covers the pavement surface. There is a 10dBm or greater difference compared to the dried surface, and it was possible for it to go over -70.5dBm outside communication area.
- Regarding the applied effects of electromagnetic wave absorbing pavement, we confirmed the ability to hold back the spread of waves outside communication area.

  There was the effect of stopping interference between reflected waves off the road and direct waves. It clarifies the separation between the signal area and non signal area. If we compare it to dense pavement road surface, a difference of 5_10dBm is measured. Since the road surface reflections are held back, we were able to prevent any effect on the neighbouring lanes.

5. Conclusion

Electromagnetic wave absorbing pavement has the ability to absorb road surface wave reflections. We confirmed that we could hold back electromagnetic dispersal of secondary reflection and later. We can conclude that this can set up an electromagnetic environment that is suitable for complementary communication, and that it is a support technology that is efficient in improving signal reliability. At the present stage, in order to improve the construction precision of the electromagnetic wave absorbing pavement, we are doing the following: proceeding with investigations into the set number of materials that are desired, and at the same time choosing the ingredients that are most advantageous as electromagnetic wave absorbing materials.

Reference

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