Report of Burial Technology Applicable to Traffic Zone N6 in Dynamic Wireless Power Transfer

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ABSTRACT: For dynamic wireless power transfer, the development of technology for embedding the coils in the road is important. In order to embed coils in the road, both electrical and mechanical properties are required. In this paper, eleven coils were used to verify the optimal burial technique by varying the type of coil and burial method. The electrical characteristics of this coil are evaluated before and after burying them. Moreover, the mechanical strength of the road after burying the coils is evaluated by FWD test. A comprehensive evaluation of the electrical and mechanical properties of the synthetic resin coils when paved was performed. Three coils and their burial methods were experimentally shown to be suitable.

KEY WORDS: Dynamic wireless power transfer, ferrite-less and capacitorless coils, road paving, synthetic resins

1. Introduction

Global warming is an unavoidable issue, and the same is true for the transport sector. The dynamic wireless power transfer (DWPT) is being looked at as a way to reduce CO_2 emissions in the transport sector in a sustainable system[(1)-(8)]. This technology is based on the premise of embedding coils, but there are few reports of embedded coils. Furthermore, there are very few studies that aim to combine electrical and mechanical properties, although a predecessor report to this project has been published[(9)-(11)]. In this paper, 11 coils were used to verify the optimal burial technique by varying the type of coil and burial method. The electrical characteristics of the coil are verified in terms of efficiency and power. The mechanical properties of the coils will be verified by FWD (Falling Weight Deflectometer) tests to determine the mechanical strength of the road. From the results, the durability of the road is calculated for how many years the road can be used at the equivalent of N6 traffic volume. Both electrical and mechanical properties are comprehensively evaluated.

2. Overall view of the coil burial project in 2021

2.1. Overview of projects for fiscal year 2021

The research and development of coil burial technology for DWPTs in this paper is part of the MLIT "Research and Development of Technology to Improve the Quality of Road Policy" project. The project aims to bury coils in asphalt roads and establish coils and construction methods that can be used on public roads with both electrical and mechanical properties. In FY2020, a feasibility study (FS) will be conducted for one year[(9)], after which the project will transition to a three-year full-scale study. This paper describes the research and development conducted in the first year of the full-scale study in FY2021, which is aimed at designing a road design that can withstand N6 traffic volume equivalent and achieve high power consumption. Eleven coils will be buried under different conditions and evaluated.

2.2. DWPT Roads and Coils Location

The experiment is conducted on a 110 m DWPT road in the Noda campus of Tokyo University of Science. Although the road environment here allows for up to 70 km/h, we will conduct the experiments in a stationary state to accurately measure the characteristics of the vehicle. About 30 m of this area was used as the coil burial section for this experiment (Fig.1, Fig.2).

Fig.1 Photo after completion of coil burial work

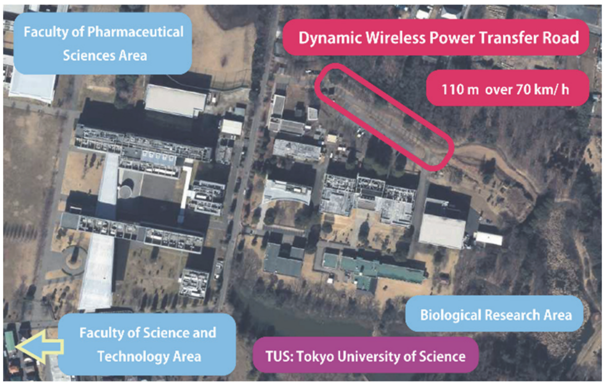


Fig.2 Aerial view of the DWPT section. Prepared by processing an aerial photograph taken by the GSI (2013).

2.3. 11 types of power transmission coils

A coil that does not require an external resonant capacitor and is capable of self-resonance is an open type coil. On the other hand, coils that require a resonant capacitor are short type coils. The open type coils are coils numbered 1, 2, 3, and 4, and the short type coils are coils numbered 5, 6, 7, 8, 9, 10, and 11. Photographs of 11 transmission coils and one receiving coil are shown in Fig.3.

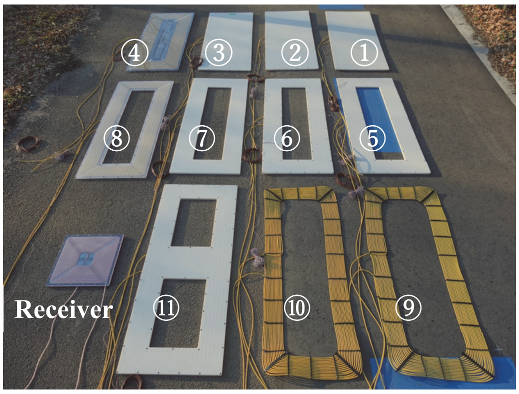


Fig.3 Eleven types of transmission coils and one receiving coil

2.4. Different burial methods

One of the major differences from the previous study, last year's FS, is the road design and coil design assuming N6 traffic volume. The mixing rate of large vehicles is about 5 times higher in N6 traffic than in N5 traffic. Therefore, a more robust road is needed. Therefore, the road has been improved from the roadbed and designed to withstand 10 years. Cross-sectional view of the location and depth of the buried coil and the burial method is shown in Fig.4. Table 1 is transmitting coil specifications.

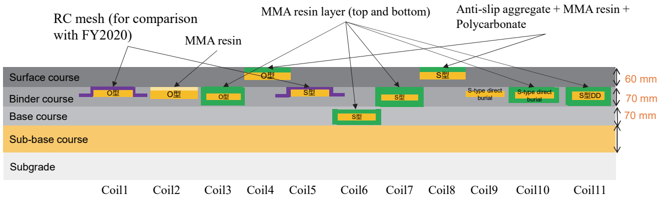


Fig.4 Cross-sectional view of the location and depth of the buried coil and the burial method

Table 1 Transmitting coil specifications

Specifications of Coils for Buried Experiments and Power Receiving Coils Coil Type	Open-type (Capacitor-less)	Short-type (Circular)	Short-type (DD)
Coil size [mm]	600×1600	600×1600	600×1600
Case size [mm]	660×1650×20	660×1650×20	660×1650×20
Number of layers	2	1	1
Number of turns	42 (21+21)	15	13
Pitch between layers [mm]	6.1 mm	-	-
Pitch between wires[mm]	9	9	9
Distance between lines [mm]	3.9	3.9	3.9
Line length [m]	148	60	60
Litz wire weight [kg]	6.0	6.0	6.0
Gross weight [kg]	30.9 (PC resin; 33 kg)	18.9 (PC resin; 20 kg)	20

The coil and buried method features are shown in Table 2, which is based on a circular coil type with a case and an intermediate layer. The coil burial method is the use of resin. The intent of using resin is to maintain the separation distance from the asphalt and to improve adhesion to the road. In addition, all of the transmission coils have one thing in common: they do not use ferrites in order to reduce cost. However, the 420 x 420 size receiving coils still use ferrite for the purpose of reducing the influence of metal on the car body and to suppress leakage magnetic fields.

Table 2 Characteristics of buried coil, No. is the coil number, O is open type, S is short type

No.		Feature
1	O	Reference coil, for comparison with last year, RC mesh, no adhesive with pavement
2	O	Adhesive only, MMA resin and silica sand (3mm) on top, adhesive below
3	O	Resin isolation, top and bottom MMA resin poured (20 mm)
4	O	Surface setting, adhesives only, MMA resin and silica sand (3mm) on top, adhesive below
5	S	Reference coil, for comparison with last year, RC mesh, no adhesive with pavement
6	S	Base course installation, resin isolation, top and bottom MMA resin poured (20 mm)
7	S	Resin isolation, top and bottom MMA resin poured (20 mm)
8	S	Surface setting, adhesives only, MMA resin and silica sand (3mm) on top, adhesive below
9	S	Caseless, direct burial (no adhesive)
10	S	Caseless, resin isolation, top and bottom MMA resin poured (20 mm)
11	S	DD coil, resin isolation, top and bottom MMA resin poured (20 mm)

In order to further promote cost reduction, caseless coils were also newly adopted as Coils 9 and 10. The coil material was mainly ABS resin for its heat resistance, strength, and adhesiveness with pavement adhesives. Only coils 4 and 8, which are buried in the road surface, are made of polycarbonate resin for adhesion and bending strength.

Coil burial work is shown in Fig.5. Improvements are made from the roadbed. Coils are buried with resin is shown in Fig.6.

(a) Roadbed improvement (b) Coil set

(c) Completed

Fig.5 Pictures of coil burial work

(a) (b)

Fig.6 Coil 10 buried with resin, (a) coil installation after drying of MMA resin, (b) MMA resin + silica sand

2.5. Review of the Ritz line

In addition to the coil case, the coil wires were also reviewed. This year, Litz wire was reviewed in order to produce a coil that can generate a large power of up to 20 kW class even after burial. In FY2021, a new Litz wire diameter of 0.05 mm and 4,000 wires will be used, compared to 0.1 mm and 460 wires in the previous fiscal year(Fig.7). As a result, the allowable current of the Litz wire can now handle up to 38 A. Thus, the coil can withstand even relatively high currents.

In addition, the Litz wire must be able to withstand the harsh environment of high temperatures and rolling pressure during construction. To counter the effects of burial in asphalt pavement, all coils in the burial experiment were covered with polyolefin insulation to improve waterproofing. Polyolefin has the heat resistance to withstand continuous use at temperatures of 150 to 200 ºC.

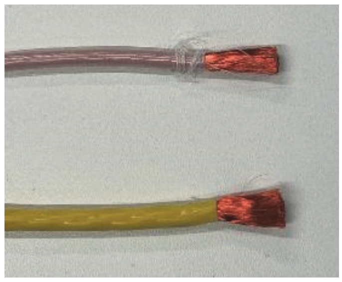


Fig.7 Litz wire wound with thread (top) and litz wire with polyolefin sheath (bottom)

3. Experimental result of electrical characteristics

The distance between coils is unified to 200 mm. The measurement results of efficiency and power are shown in Fig.8. Since the measurements are made with a VNA (Vector Network Analyzer) for small-signal measurement, the input voltage is set to be 600V in conversion and the value of the load that maximizes the allowable current of the Litz wire is considered. This voltage value is set because the low voltage regulation of AC is 600V. In addition, a resonant circuit configuration with resonant capacitors inserted in series for both transmitting and receiving is used in the study. This condition is the same in other studies in this paper.

When the coils are buried, the coils are subjected to rolling pressure by road rollers and other means and to the heat of the asphalt, which can damage the coils. It should be mentioned earlier that coils 2 and 4 may have affected the electrical properties because of the large warping observed in the coil cases. Some of the coils are described in references (10), and (11), but this section is inclusive of all 11 coils.

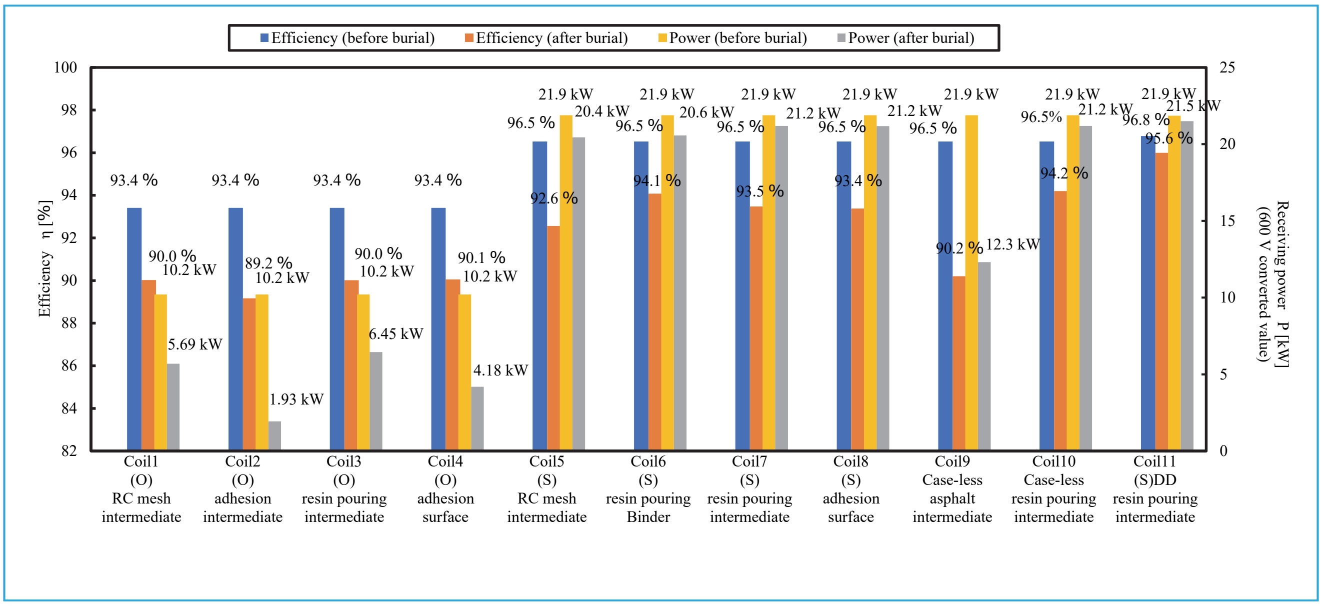


Fig.8 Efficiency and power for 11 coils

4. Experimental result of mechanical characteristics

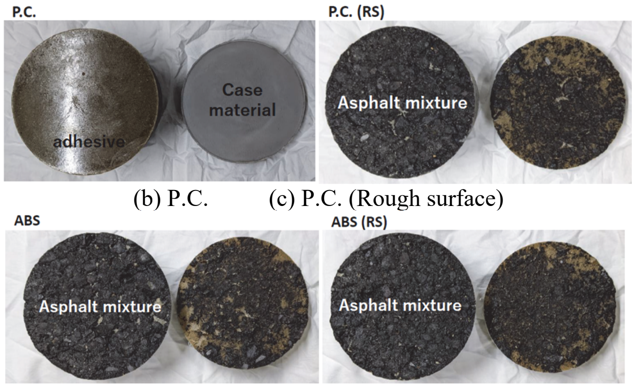
Mechanical characteristics were investigated through adhesion test and FWD (Falling Weight Deflectometer) test.

4.1. Adhesion evaluation

First, we discuss the adhesion evaluation. In a normal road, there are no coils in the asphalt. Therefore, it is important to know how well the asphalt and the coil are bonded and integrated with the asphalt. It is not good if they are easily detached from the asphalt. Therefore, a tensile strength test is performed to evaluate the adhesion between asphalt and coils.

A photograph of the tensile test is shown in Fig.9. The test temperature shall be 20°C. The tensile speed is 60 mm/min. The test piece is formed into a cylinder to match the shape of the jig. Roughened surfaces for better adhesion are indicated as "Rough" (RS: Rough surface). Between the asphalt mixture and the resin coil case material there is an adhesive with MMA resin as the main agent.

(a) Setup of tension test.



(b) P.C. (c) P.C. (Rough surface)

(d) ABS (e) ABS (Rough surface)

Fig.9 Tension test setup

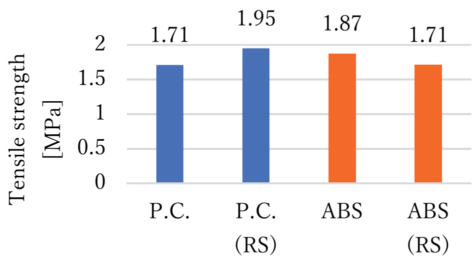


Fig.10 Result of tensile strength

4.2. FWD test and road durability

The FWD test is a test using a device that simultaneously measures the amount of deflection that occurs on the pavement surface when a weight is dropped on the road surface at multiple points. Based on the measured deflection, it is possible to calculate the usable life of the road. FWD test is shown in Fig.11. In summary, compared to As pavement where is no coil, coil number 2,4,6,8,9,10 acquired enough values as durability.

Fig.11 The FWD test scene

5. Comprehensive evaluation of electrical and mechanical properties

Table 3 shows the overall ratings of electrical and mechanical properties. The good ratings are shown in pink, the bad ratings in blue, and the conditional evaluation, which remains a good possibility, is shown in green.

Table 3 Overall evaluation considering electrical and mechanical properties

	Coil 1	Coil 2	Coil 3	Coil 4
Q	155	73.6	174	128
Efficiency [%]	90	89.2	90.0	90.1
Power [kW]	5.69	1.93	6.45	4.18
Allowable year of load wheels [years] (N6)	2.0	10.8	3.8	22.3

	Coil 5	Coil 6	Coil 7	Coil 8
Q	268	464	471	275
Efficiency [%]	92.6	94.1	93.5	93.4
Power [kW]	20.4	20.6	21.2	21.2
Allowable year of load wheels [years] (N6)	4.1	14.0	4.7	14.8

	Coil 9	Coil 10	Coil 11
Q	264	371	1053
Efficiency [%]	90.2	94.2	95.6
Power [kW]	12.3	21.2	21.5
Allowable year of load wheels [years] (N6)	16.7	10.9	5.8

4. Conclusion

The compatibility of electrical and mechanical properties is very important in wireless power transmission while driving. In this paper, eleven power transmission coils were embedded in an asphalt road, starting with the construction of a road designed for 10 years to withstand the equivalent of N6 traffic. The coils were buried from the surface layer just below the surface to the middle and base layers. Open, circular, and DD coils were used to eliminate the need for external resonant capacitors. Resin was also poured to integrate the coils and the road. A caseless coil, which does not use a coil case, was also introduced, and combinations of coils and burial methods that could be used for roads equivalent to N6 traffic volume were verified. As a result, very good characteristics were obtained for six combinations, and in particular, three combinations showed excellent performance in terms of low-voltage 600 V drive conversion, although they were converted values. These show sufficient driving durability on a road designed for 10 years.

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