# Proposal of Coil Embedding Method in Asphalt Road Surface for Dynamic Wireless Power Transfer


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***Abstract*—Transmitter coils used in dynamic wireless power transfer are embedded in the road, so it is important to improve the power transmission performance of the coils as well as the strength and durability of the pavement. This study proposes a method of embedding the coils in the surface course near the road surface. To compare the electrical characteristics of the proposed method with the conventional method in which the coil is embedded inside the asphalt pavement at a depth of 50 mm from the road surface. In addition, a comparison of case-less coils, hard plastic coil cases, and soft rubber coil cases was conducted to select coils suitable for embedment near the road surface. The results of coil embedment experiments on a road designed for a national highway showed that all coils could achieve more than 54 kW of power at an efficiency of 95% at a transmission distance of 200 mm and a 600 V equivalent value in the power transmission evaluation by VNA (Vector Network Analyzer). In addition, the results of pavement strength tests showed that surface embedment tended to have higher pavement strength than embedment at a depth of 50 mm from the road surface.**



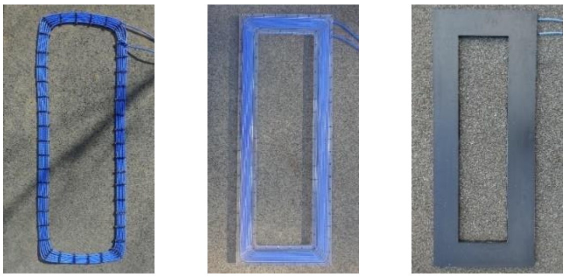
***Keywords—Wireless power transfer, dynamic wireless power transfer, coil embedment, road embedment experiment, resin pavement material, surface course embedment, FWD test***


## I. INTRODUCTION

In recent years, the research of wireless power transfer (WPT) has been active. Dynamic wireless power transfer (DWPT) is expected to solve the problems of high cost and short range of electric vehicles [1]-[9]. The transmitter coils in DWPT are embedded in the road, but it has been reported that pavement materials such as asphalt and concrete deteriorate the electrical characteristics of the coils [10]-[13]. Previous studies have proposed a method of embedding coils using MMA resin mixtures, which have better electrical characteristics than asphalt, and have achieved higher efficiency and more power than the method of embedding coils directly in asphalt pavement, and have achieved both electrical and mechanical characteristics [14]. However, in previous studies, the transmitter coils were embedded at a depth of about 60 mm below the road surface, so there are issues of increased transmission distance and poor maintenance when repaved roads. Therefore, this study proposes a method of embedding the coils at a depth near the road surface. To compare the proposed method with the conventional method in which the coils are embedded inside the asphalt pavement at a depth of 50 mm below the road surface. In addition, caseless coils, a hard plastic coil case, and a soft rubber coil case are compared. Based on the results of these comparative studies of electrical and mechanical characteristics, a coil suitable for the depth near the road surface is selected. The electrical characteristics are evaluated in terms of the basic characteristics of the internal resistance and *Q* values, and the transmission characteristics of transmission efficiency and output power. Mechanical characteristics are evaluated by FWD (Falling Weight Deflectometer) tests to determine the effect of the embedded coil on the pavement strength.

## II. ROAD EMBEDMENT COILS

The method proposed in this study, in which the coil is embedded near the road surface, is more affected by the load from vehicles passing over the coil head than the method in which the coil is embedded inside the pavement. Therefore, the durability and strength of the coil case are important, and this study compares the case-less coil without a coil case, a case coil made of hard polycarbonate plastic, and a coil with a soft chloroprene rubber (CR) coil case. Although hard plastic coil cases are often used for DWPT, this study adopts case-less coils for the purpose of reducing cost, reducing the installation area with the pavement, and improving pavement strength. In addition, a thick case coil is also considered, in which the thickness of the coil case is the same as the pavement. Fig. 1 shows case-less coil, case coil, and CR coil. Case-less coil does not use conventional plastic coil cases and are adopted to reduce cost and improve pavement strength. Fig. 2 shows a comparison of case coil and thick case coil thicknesses. The case coil in this study is 30 mm thick, while the thick case coil is 50 mm thickness, similar to the asphalt surface layer. Fig. 3 shows the receiver coil. A spiral-shaped short-end coil is used on both the transmitter and receiver sides. Table 1 shows the specifications of the embedded coil and the receiver coil. The specifications for both coils are similar in terms of size, number of turns, and litz wire. The litz wire specifications for the transmitter and receiver coils are 10000 strands with a strand diameter of 0.05 mm and an allowable current of 96 A. The litz wires are covered with a 0.5 mm thick FEP sheath. Also, ferrites are not used on the transmitter side for lower cost.



(a) (b) (c)

Fig. 1. Road embedded coils. a) Case-less coil, b) Case coil, c) CR coil.

(a) (b)

Fig. 2. 30 mm thickness vs. 50 mm thickness. a) Overall view, b) Case cross-section view.

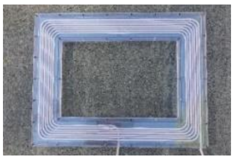


Fig. 3. Receiver coil.

Table 1. Specifications of embedded coils and receiver coil

| | Embedment coil | Receiver coil |
|---|---|---|
| Coil size | 600×1700 mm | 600×800 mm |
| Number of turns | 6 | 7 |
| Line pitch | 12 mm | 11 mm |
| Conductor Outer Diameter | 7.85 mm | 7.85 mm |
| Line length | 31.5 m | 22.6 m |

## III. PAVEMENT STRUCTURE

Fig. 4 shows a cross-sectional view of the pavement where the coils are embedded. The pavement is designed for a busiest national highway class with heavy vehicle traffic. Fig. 5~Fig. 8 show pavement cross sections of caseless coils, case coils, CR coils, and thick case coils. These coils are buried in the surface course near the road surface and in the intermediate course below the surface. In the previous study, coils were embedded in this middle course, but because it is a course below the surface course, it is not easy to maintain during resurfacing, and the transmission distance to the receiver coil increases. The surface-embedded coils proposed in this study are expected to solve this problem. Coils are embedded with an MMA resin mixture, which is a type of acrylic resin that has better electrical characteristics than asphalt mixtures and thus has less adverse effect on coil characteristics. Coils embedded in the middle and surface courses are constructed in the same way, with the only difference being the depth of embedment. Case-less coils are embedded at a depth of 10 mm from the road surface. Coils with a coil case in the surface course are buried so that the surface of the case is almost flush with the road surface. The coil case surface exposed to the road surface is treated with MMA resin mixture to prevent slipping. Since the surface of the coil case is almost a part of the road surface, the load from the vehicle passing overhead is transmitted more directly than the coil embedded in the middle course. Since the surface of the coil case is almost a part of the

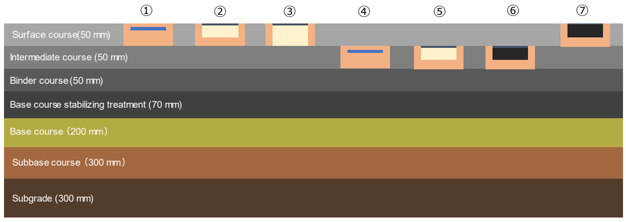



Fig. 4. Pavement cross section.

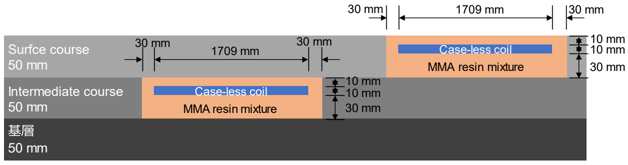



Fig. 5. Pavement cross section of case-less coil.

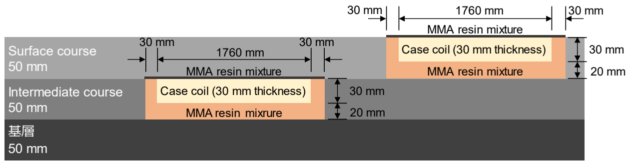



Fig. 6. Pavement cross section of case coil.

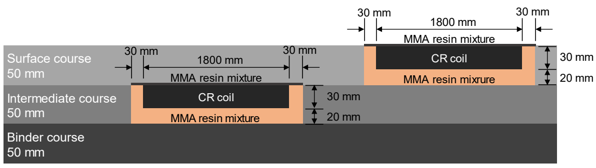



Fig. 7. Pavement cross section of CR coil.

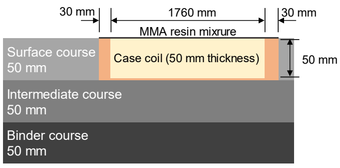



Fig. 8. Pavement cross section of thick case coil.

Table 2. List of experimental conditions for embedded coils

| Coil No. | Coil case materials | Embedment course | Embedment Depth |
|---|---|---|---|
| 1 | Case-less | Surface | 10 mm |
| 2 | Polycarbonate | Surface | 3 mm |
| 3 | Polycarbonate | Surface | 3 mm |
| 4 | Case-less | Intermediate | 60 mm |
| 5 | Polycarbonate | Intermediate | 50 mm |
| 6 | CR | Intermediate | 50 mm |
| 7 | CR | Surface | 3 mm |

road surface, the load from the vehicle passing overhead is transmitted more directly than the coil embedded in the middle course. Therefore, the durability and strength of the coil case are important. This study compares hard plastic polycarbonate coils, soft rubber CR coils, and caseless coils that do not use a coil case.

## IV. ASPHALT ROAD EMBEDMENT EXPERIMENT OF COILS

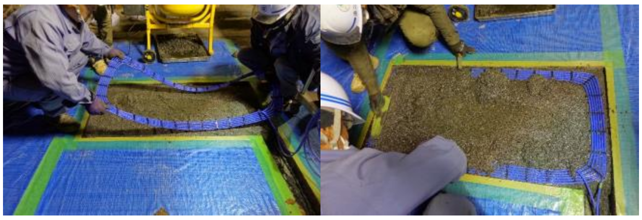
There are very few studies that have verified both electrical and mechanical characteristics such as coil characteristics, pavement strength, and durability by embedding coils in asphalt roads for DWPT. In this study, coils were embedded in asphalt roads and their electrical and mechanical characteristics were evaluated under actual road conditions. Fig. 9 shows the construction status of the asphalt road, and Fig. 10 shows the construction process of the coils embedded in the intermediate course.

(a) (b)

Fig. 9. Asphalt repaving situation. a) Laying asphalt. b) Rolling compaction.

(a) (b) (c)

Fig. 10. Construction process of intermediate course coils. a) Coil installation space. b) Status of coil construction. C) After embedment of intermediate course.



(a) (b)

Fig. 11. Embedding process of case-less coil. a) Coil setting. b) Coil embedding.

(a) (b)

Fig. 12. Embedding process of case coil. a) Coil setting. b) Coil embedding.

(a) (b)

Fig. 13. Embedding process of thick case coil. a) Coil setting. b) Coil embedding.

(a) (b)

Fig. 14. Embedding process of thick case coil. a) Coil setting. b) Coil embedding.

## V. Evaluation of Coil Characteristics in the Road Environment

The feasibility of the proposed method of embedding coils in the surface course of asphalt roads is evaluated from the measurement results of electrical characteristics. The internal resistance *R* and *Q*-values were measured after the coils were embedded using an impedance analyzer E4990A from Keysight Technologies, Inc. The measurement frequency was 85 kHz. Both coils were measured immediately after surface course construction. Fig. 15 shows the internal resistance *R* and *Q*-values after coil embedment. From the measurement results, *Q*-values of more than 300 were achieved for all coils. The case coil achieved the highest *Q*-value of over 600. The newly proposed CR coil embedded in the surface course achieved a *Q*-value of 500 or more, which is comparable to that of the case coil. The case coil embedded in the surface layer has a *Q*-value of more than 400, which is lower than the *Q*-value of the case coil and CR coil. This is considered to be because the litz wire is protected by the coil case and is not directly affected by the pavement material, resulting in better characteristics. Comparing the coils embedded in the intermediate and surface courses, it can be seen that the surface course coils tend to have higher *Q*-values than the intermediate course. This is considered to be due to the fact that the coils in the intermediate course are affected by the asphalt pavement in the surface and binder course. Therefore, the surface course embedment of the coils proposed in this study is shown to have better characteristics than the conventional method of embedding the coils in the middle course after embedment.

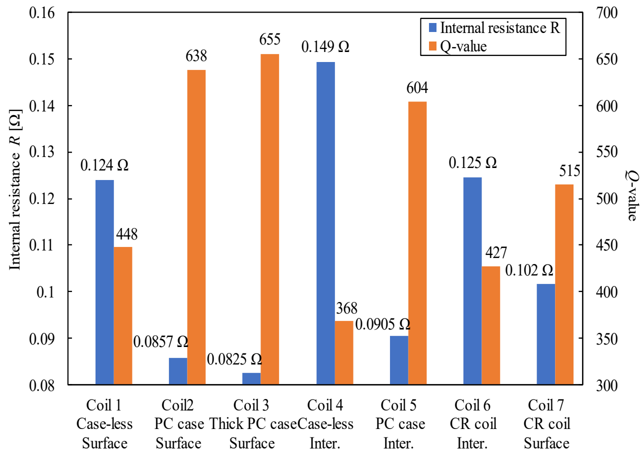



Fig. 15. Internal resistance *R* and *Q*-value measurements after road embedment.

Fig. 16. Status of power transmission evaluation with VNA.

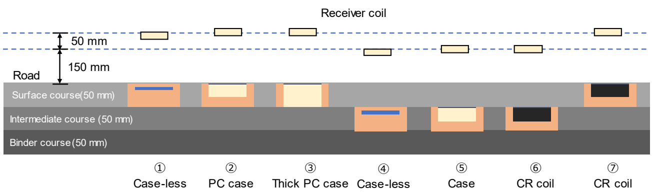



Fig. 17. Transmission distance =200 mm (distance between transmitter and receiver coils)

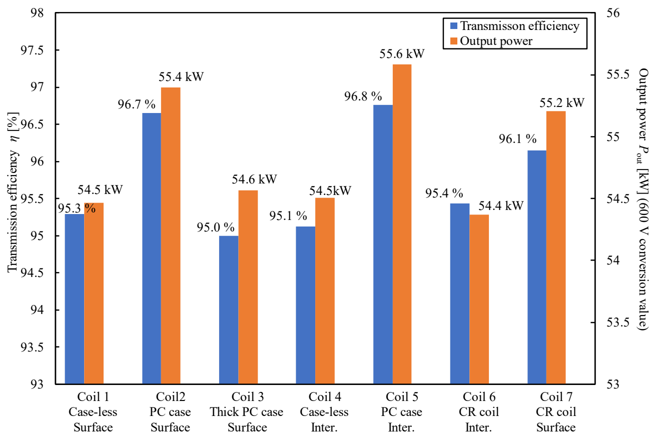



Fig. 18. Transmission characteristics after embedment (Transmission distance =200 mm).

The transmission efficiency and output power were measured with a vector network analyzer (VNA) E5061B. Since the VNA is a small-signal input device, output power results are converted values. This study uses an S-S circuit in which a resonant capacitor is connected in series with the transmitter and receiver coils. Fig. 16 showed the VNA measurements after embedment. The transmission distance is 200 mm, and the load is a value at which the input current is close to the allowable current value of the litz wire. Fig. 17 shows the positional relationship between the transmitter and receiver coils at a transmission distance of 200 mm. Measurement results of transmission efficiency $\eta$ and output power $P_{out}$ after coils were embedded are shown in Fig. 18. The efficiency in this study is the coil-to-coil efficiency. Measurements were carried out 22 to 23 days after the surface construction. From the results, comparing the caseless coil, case coil, thick case coil, and CR coil, the case coil achieved the highest efficiency and the highest power with an efficiency of over 96% and a power of over 55 kW (converted value). However, since both coils achieved an efficiency of over 95% and a power of over 54 kW, it can be said that their performance is sufficient for feeding power to a standard car. Therefore, the method of surface embedding the coils proposed in this study is an effective method for DWPT. Therefore, the method proposed in this study of embedding the coils in the surface course is an effective method of embedding the coils for DWPT.

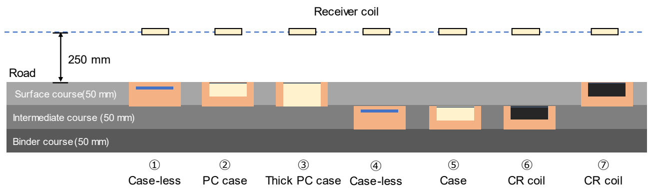



Fig. 19. Distance from road surface to receiver coil =250 mm.

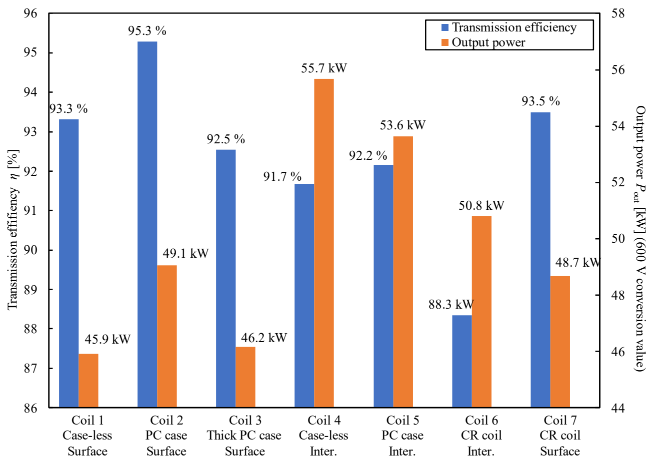



Fig. 20. Transmission characteristics after embedment (Distance from road surface to receiver coil =250 mm).

Comparison of surface and intermediate course embedment of coils was evaluated under the condition of a constant distance of 250 mm from the road surface to the receiver coil. Fig. 19 shows the positional relationship of the transmitter and receiver coils at a constant distance of 250 mm from the road surface to the receiver coil, and Fig. 20 shows the measured transmission efficiency and output power using VNA. Surface-course embedded coils have higher efficiency than intermediate-course embedded coils, but the output power tends to be smaller. This is because in an S-S circuit, the longer the transmission distance and the smaller the coupling coefficient, the lower the efficiency and the higher the power. Also, the VNA measurement results show that the output current value in all intermediate-course embedded coils exceeded the rated current value of 96 A for the Litz wire. Therefore, it can be said that the surface

(a) (b)

Fig. 21. Status of FWD test. a) FWD test car, b) Falling weight.

layer embedment of the coil is more advantageous than the intermediate-course embedment in terms of transmission distance and ease of road maintenance.

## VI. Evaluation of Pavement Strength in Wireless Electric Road

Pavement strength is also an important factor to be considered because the coils used in DWPT are embedded in the road. In this study, the effect of the embedded coils on the pavement was measured using a pavement strength test called the FWD (Falling Weight Deflectometer) test. Fig. 21 shows the status of FWD test. The weight was dropped at the center of the embedded coil. The impact load is 75 kN when the weight is dropped.

Fig. 22 shows the measured deflection of the road surface when a weight is dropped on the surface. The results for normal pavement without embedded coils are also shown for comparison. The vertical axis indicates the ratio of the pavement deflection of the embedded coil to the deflection of the normal pavement without the embedded coil as 1. In other words, if the ratio of pavement deflection of the embedded coil is smaller than that of the normal pavement, the pavement deflection is large and unstable, and the pavement strength is low. The results show that Coil 1, 3, 4, and 7 have pavement strength similar to that of normal pavement. Thus, the case-less coils were shown to be suitable for both intermediate and surface course. Coil 2 and coil 5 case-less coils resulted in lower pavement strength compared to case-less and CR coils.

Overall, based on the results of the electrical characteristics in the previous section and the mechanical characteristics in this section, the case coil had the best electrical characteristics but the worst pavement strength. The case-less and CR coils embedded in the surface course were able to achieve both electrical and mechanical characteristics. Among these coils, the case-less coil is the lowest-cost coil that also satisfies both electrical and mechanical characteristics, making it the most suitable coil for DWPT.

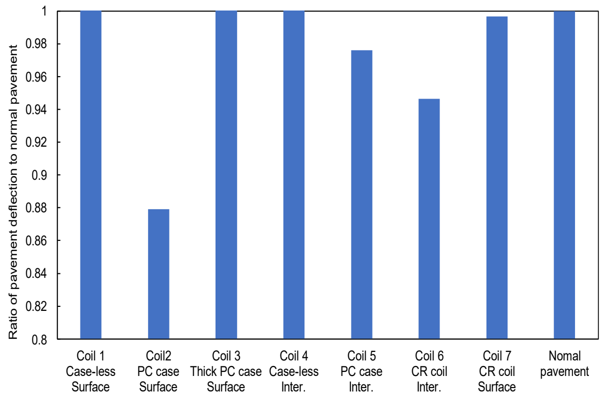



Fig. 22. Amount of pavement deflection.

## VII. Conclusion

This study proposed a method of embedding coils in the road surface to improve maintenance and shorten the transmission distance on asphalt road where the coils are embedded for DWPT. The results of road embedment experiments showed that surface embedment of case-less coils achieved sufficient feasible levels of transmission efficiency and output power for feeding power to standard vehicles despite the low cost of the coil, and achieved pavement strength similar to that of normal pavement without embedded coils.

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