Proposed Method of Embedding Transmission Coils in Reinforced Concrete Pavement with Resin Pavement Material in Dynamic Wireless Power Transfer

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***Abstract*— In Dynamic Wireless Power Transfer, the embedment of power transmission coils in the road surface is essential. Previous studies have reported that coil characteristics deteriorate during embedment in reinforced concrete pavement due to the effects of rebar and concrete. In this paper, precast reinforced concrete pavement slabs employing insulated steel bars were used to simulate the embedment of coils in the pavement, and the coil properties due to the embedment were measured. An embedment method using polyurea resin is proposed to reduce the effect of concrete on the coil properties. The results of the embedment simulation test showed that the use of polyurea resin successfully improved the Q-value of the coil by about 85 % compared to the case where concrete was used. Furthermore, the transmission characteristics were evaluated using a vector network analyzer (VNA), and a transmission efficiency of 95.8 % was obtained over a transmission distance of 170 mm.**

Keywords—Dynamic Wireless Power Transfer, Reinforced Concrete, Coil embedment, Resin pavement materials

I. INTRODUCTION

The global trend toward decarbonization has made the transition from gasoline and diesel vehicles to electric vehicles (EVs) a priority worldwide. However, EVs have a short cruising range, lack of charging infrastructure, heavy battery weight and high cost, and other issues that have slowed the spread of EVs. DWPT (Dynamic Wireless Power Transfer) is one way to solve these problems and is being actively researched [1]-[6].

For the practical application of DWPT, it is essential to bury the transmission coils in the road. However, it has been reported that burying the coils causes a decrease in electrical and transmission characteristics such as the internal resistance and Q-value of the coils due to the influence of the surrounding environment such as rebar, concrete, and asphalt [7]-[16]. In this paper, we focus on the embedment about reinforced concrete pavement and propose an embedment method using resin pavement material in reinforced concrete pavement slabs employing insulated steel bars as a method to reduce the deterioration of coil embedment characteristics. The use of resin pavement material can be expected to reduce the impact of concrete and increase the waterproofing effect and pavement strength.

In Japan, asphalt pavements account for about 95 %, in the US and EU about 80 %, and in Korea about 40 %, with reinforced concrete pavements accounting for the remaining percentage. In Japan, the percentage of reinforced concrete pavements is small. However, in Japan, reinforced concrete pavements are used on rural trunk roads, metropolitan expressways, bridges, and tunnels, which are important for logistics and transportation. For practical use, it is essential to study not only embedment in asphalt pavements, but also in reinforced concrete pavements. Furthermore, compared to asphalt pavements, reinforced concrete pavements have received renewed attention in recent years because of their durability, water resistance, earthquake resistance, and lower maintenance and repair costs, and the percentage of implementation is likely to increase in the future.

Therefore, this paper examines methods of reducing property deterioration and improving transmission efficiency in reinforced concrete pavement slabs employing insulated steel bars by using resin pavement material to simulate buried measurements.

II. Resin Selection Test

A. Resin Embedment Test

In this proposal, we conducted tests to select the resin to be used.

As shown in Fig. 1, six turns, 300 × 300 mm coils were buried in a 350 × 350 × 50 mm resin block, and the electrical characteristics of the coils were measured before and after burial to confirm which resin had the least influence on the coil characteristics. Candidate resins were

(a) Epoxy Resin 1

(b) Epoxy Resin 2

(c) MMA Resin 1

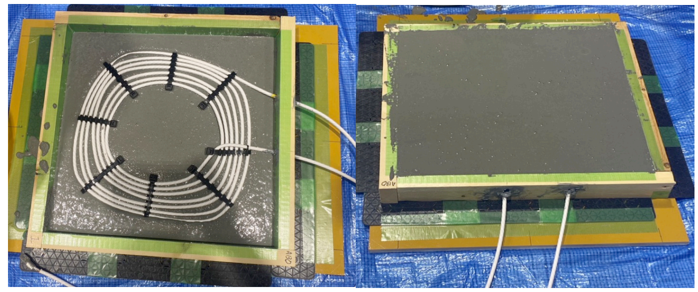
(d) MMA Resin 2

(e) Polyurea Resin

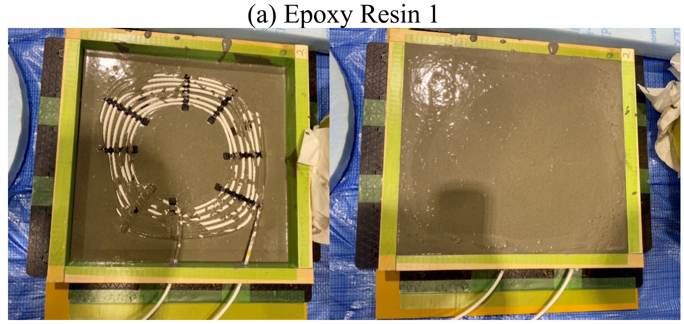
Each resin is used for concrete repair. In addition, differences in aggregate and other materials exist among similar resins.

The embedment tests were conducted on these five types.The results of the embedment tests are shown in Fig. 2.

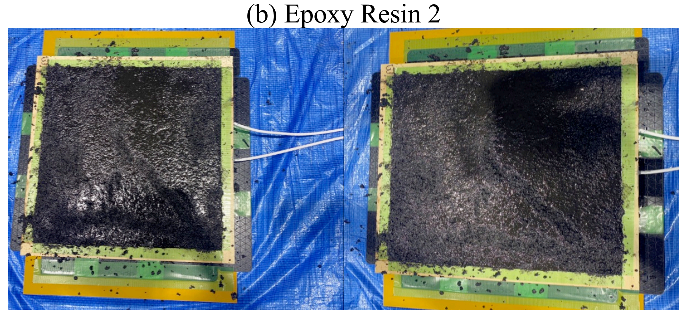
The results in Fig. 2 show that Polyurea Resin is the resin that has the least influence on coil properties.



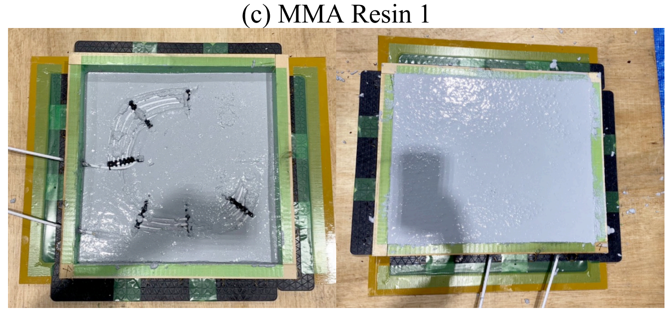
(a) Epoxy Resin 1



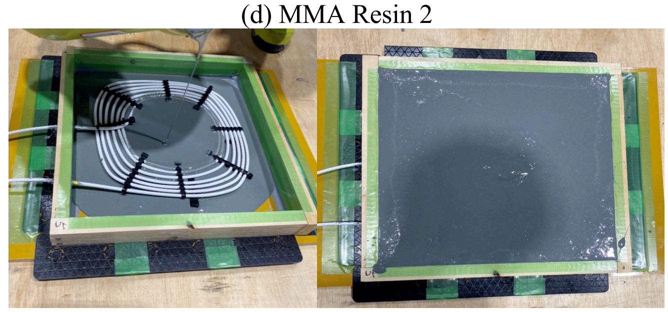
(b) Epoxy Resin 2



(c) MMA Resin 1

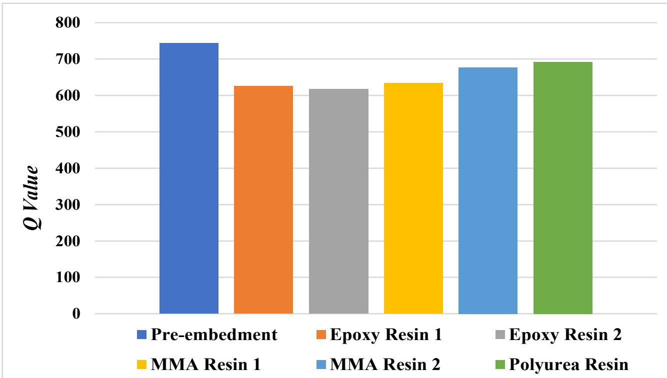


(d) MMA Resin 2

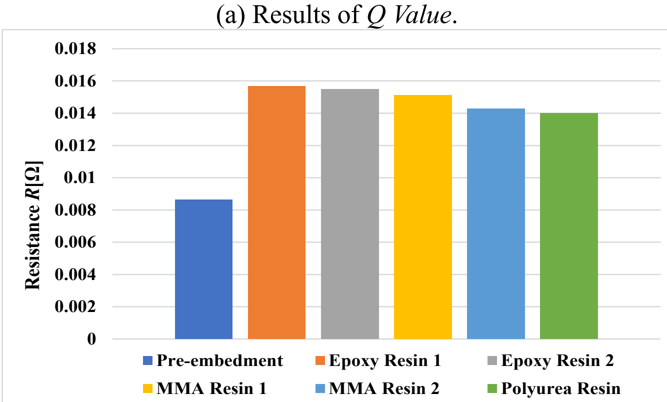


(e) Polyurea Resin

Fig. 1. Coils embeded each resin.



(a) Results of *Q Value*.



(b) Results of Resistance.

Fig. 2. Results of electrical characteristics before and after embedment.

B. Confirmation of adhesion between concrete and resin

In this test, the adhesion between concrete and resin was verified. When resin is used in actual pavement, a layer of resin exists on top of concrete as shown in Fig. 3. If the adhesion between the resin and concrete is not sufficient, the resin may peel off or the pavement may be damaged when the vehicle runs on it.

As shown in Fig. 4, a 10 mm layer of resin was created on a 300 × 300 × 50 mm concrete block, and the resin layer was subjected to a tensile test to confirm adhesion. Tensile tests were conducted until the resin layer was peeled away from the concrete, and the results were checked to see if they exceeded the standard value of 1.5 N/mm2 for use in pavements. The results are shown in Fig. 5.

The results in Fig. 5 show that all resins exceeded the standard value. However, the small value for the polyurea resin is due to the incompatibility of the resin and adhesive, and the test may not have been conducted accurately. However, since this resin is used in actual pavements, there should be no problem in its use. Based on these results, the resin used was decided to be polyurea.

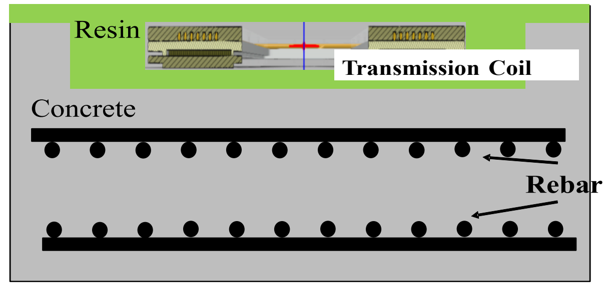


Fig. 3. Completion diagram when put into practical use.

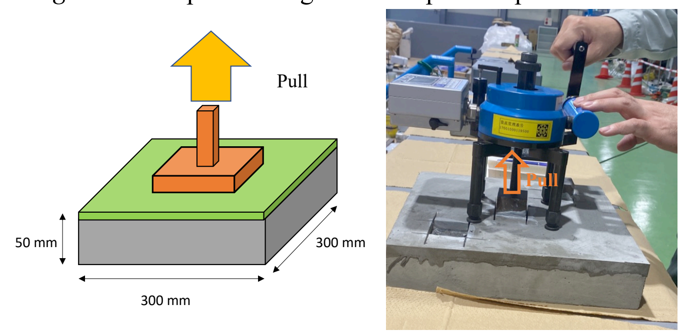


Fig. 4. Confirmation of adhesion between resin and concrete.

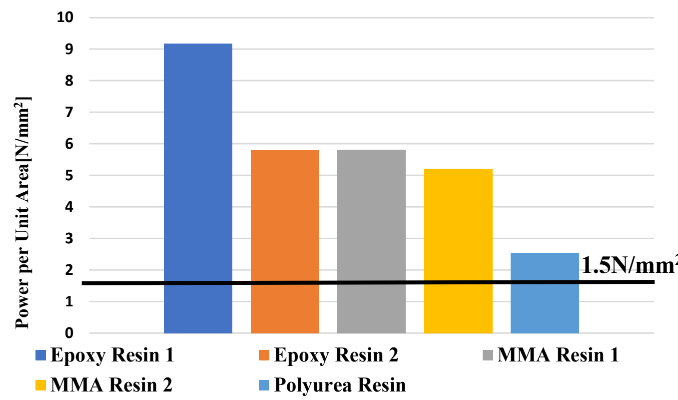


Fig. 5. Results of Confirmation of adhesion between resin and concrete.

III. Block Embedment Simulation Experiment

A. About Precast Rebar Concrete and Embedment Coils

Fig. 6 shows the reinforced concrete specimen used in this measurement. The dimensions of the specimen are 2000 × 1180 × 295 mm, with a box-cut portion 2000 × 980 × 120 mm on the specimen. The boxed-out area was defined as the area where the coil of precast RC slab would be embedded during the actual embedment. The distance from the rebar to the bottom of the box-cut is 30 mm. The rebar is a double-lattice structure.

Insulated rebars were used for the rebars of the PRC slab. The insulated rebar is realized by wrapping the intersections of the rebars with a double layer of soft polyvinyl chloride tape. (Fig. 7)

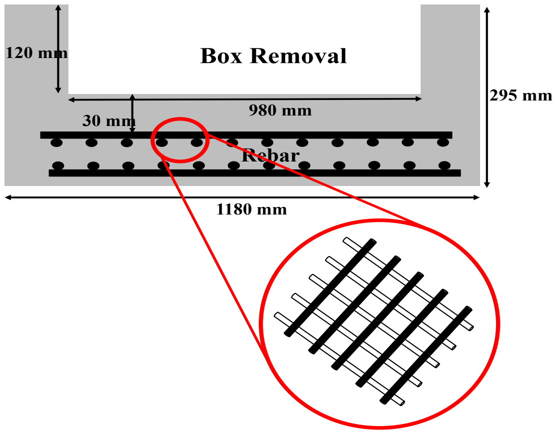


Fig. 6. Schematic diagram of Precast Rebar Concrete.

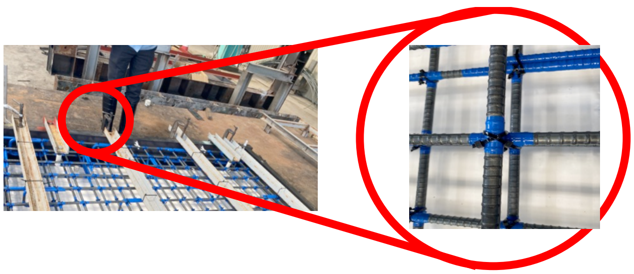


Fig. 7. Insulated Rebar

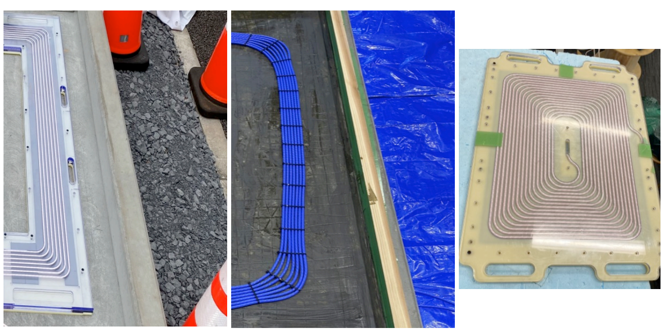


Fig. 8. Embedment coils and Receiver coil

(Left: Case coil, Center: Direct embedment coil, Right: Receiver coil)

The coil used for the measurement is shown in Fig. 8. A case coil is made by constructing the coil in a case and laying down ferrite. A direct embedment coil is a coil that is not in a case and has bare litz wire, and does not use a large plastic case, which is expected to increase pavement strength and reduce costs. The Litz wire for both the transmitter and receiver coils has 1000 strands with a wire diameter of 0.05 mm, and the direct embedment coils are covered with 0.5 mm thick FEP.

Each coil parameter is shown in Table1. Table2 shows the electrical characteristics before burial, and Fig.9 shows the measured scenery.

Table. 1. Each parameter of the coils

	Case coil	Direct embedment coil	Receiver coil
Coil size	1300×600 mm	1300×600 mm	580×420 mm
Coil holder size	1600×750 ×35 mm	-	800×550 ×35 mm
Number of turns	7	7	16
Line pitch	10.85 mm	10.85 mm	10.85 mm
Wire diameter	5 mm	5 mm	5 mm

Table. 2. Electrical characteristics in pre-embedment.

	Frequency [kHz]	R [Ω]	L [μH]	Q Value
Case coil	85	0.056	129.4	1224
Direct embedment coil	85	0.073	94.45	689
Receiver coil	85	0.054	148.1	1454

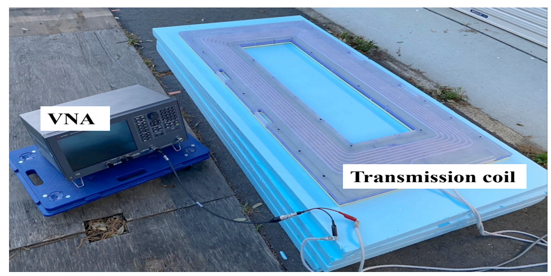


Fig. 9. Measurements Pre-embedment.

B. Experimenntal Method

The purpose of this experiment was to confirm the electrical characteristics and transmission efficiency of the coils by simulating the conditions under which power transmission coils would be buried in reinforced concrete pavement and making measurements under such conditions.

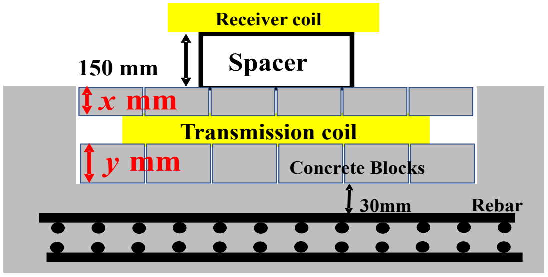
The concrete and resin blocks and coils were stacked on the specimen in Fig. 6 to simulate embedment in a reinforced concrete pavement. Fig. 10 shows a schematic diagram of the measurement.

For Fig. 10, measurements were made on a reinforced concrete plate, adjusted using concrete and resin blocks to achieve the following five patterns.

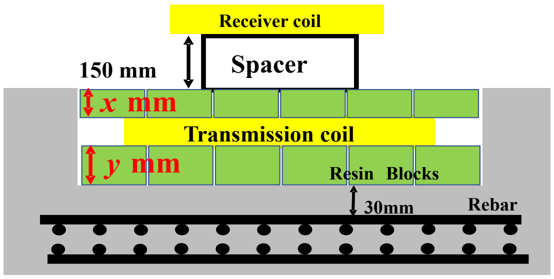
(i) x=80 mm, y=0 mm (ii) x=60 mm, y=20 mm

(iii) x=40 mm, y=40 mm (iv) x=20 mm, y=60 mm

(v) x=0 mm, y=80 mm



(a) Concrete Blocks.



(b) Resin Blocks.

Fig. 10. Schematic diagram of the measurement.

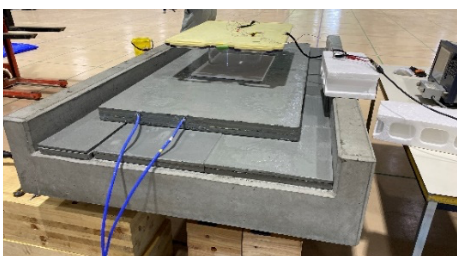


Fig. 11. Scenes of characteristic measurement.

The electrical characteristics of the buried coil under these conditions were measured using an impedance analyzer.

A schematic diagram of the transmission efficiency measurements is shown in Fig.10. In Fig.10, the measurements were made by fixing x=20 mm and varying the value of y in the following five patterns.

(i) y=0 mm (ii) y=20 mm (iii) y=40 mm (iv) y=60 mm

(v) y=80 mm

The VNA is a small-signal input device, and the input voltage at the VNA was set to 600 V, the resonance frequency was adjusted to 85 kHz using a resonance capacitor, the load Fig. 11 shows the measurement scenery.

In these measurements, two types of blocks were used: concrete blocks and resin blocks.

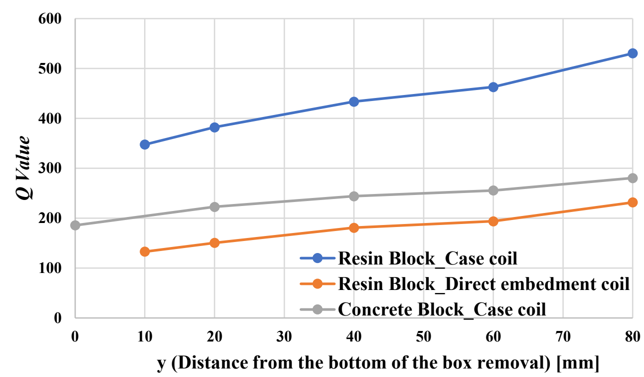
C. Results of Block Embedment Simulation Experiments

Fig. 12 shows the measurement results of electrical characteristics using an impedance analyzer and Fig. 13 shows the measurement results of transmission efficiency using a vector network analyzer for the buried simulation test using concrete and resin blocks.

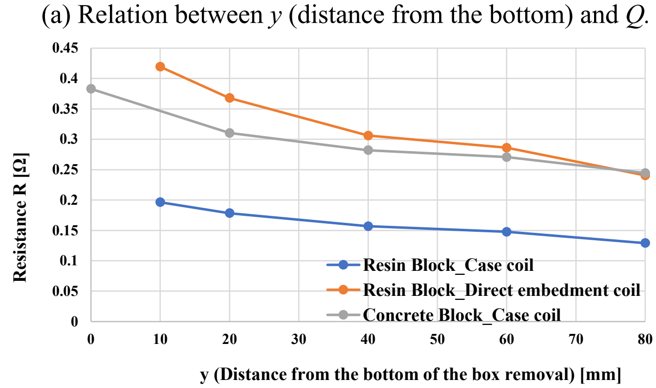
Fig. 12 shows that the resistance and Q values of the case coil changed by a factor of 4.32 and 0.22, respectively, before and after embedment, while the resistance and Q values of the direct embedment coil changed by a factor of 3.29 and 0.34, respectively, confirming the deterioration of the characteristics due to embedment.

In addition, by using polyurea resin (Ninja Seal), the method proposed in this paper, instead of concrete for the cased coil, the Q value was improved by about 85% and the resistance was successfully reduced by about 0.52 times at y=80 mm. In direct embedment coils, compared to case coils, the litz wire is in direct contact with the pavement material, resulting in a greater deterioration of the properties during embedment. However, the use of direct embedment coils can be expected to decrease costs, so we believe that improvements in coil design are needed.

As shown in Fig. 13, the maximum transmission efficiency of 95.8% was obtained for the cased coil and 93.2% for the direct embedment coil by using resin blocks. Changing the pavement material from concrete to resin improved the transmission efficiency by about 2.3%.



(a) Relation between *y* (distance from the bottom) and *Q*.



(b) Relation between *y* (distance from the bottom) and *R*.

Fig. 12. Electrical characteristic results.

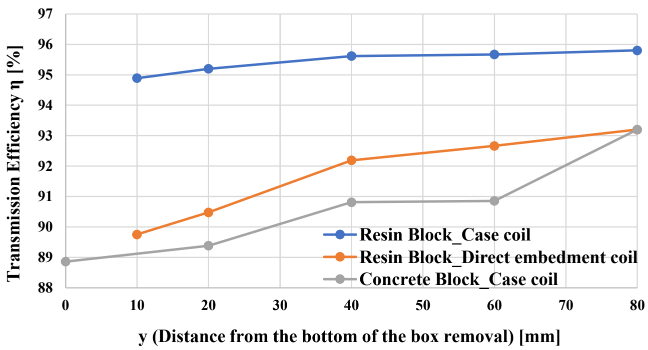


Fig. 13. Transmission efficiency results.

From these results, values suitable for practical use were obtained for both case coil, and the deterioration of coil characteristics due to resin was successfully reduced. Although there is a great merit in using resin for pavement, there is an issue of how much the amount of resin used can be reduced due to the large amount and high cost of resin used. We plan to verify these issues in the future.

IV. Conclusion

In this paper, we propose a method of reducing property deterioration in coil embedment in reinforced concrete pavement by using resin pavement material, and verify it by conducting measurements using a reinforced concrete plate. As a result, the resistance and Q-value were improved by 0.52 and 85 %, respectively, by using the resin pavement material. Furthermore, a transmission efficiency of 95.8% was obtained at a transmission distance of 170 mm, and the use of insulated steel bars successfully increased the efficiency by approximately 2.3%.

Future studies will be conducted under the condition of direct burial, which is similar to actual reinforced concrete pavement. In addition, the effect of water due to rain, etc., and heat generation when high power is applied will also be verified in consideration of practical use.

References

[1] A. Kurs, A. Karalis, R. Moffatt, J. D. Joannopoulos, P. Fisher, and M. oljacic, "Wireless Power Transfer via trongly Coupled Magnetic Resonances," cience, Vol. 3 , No. 5834, pp. 83-86, 2007.

[2] G. Covic and J. Boys, "Inductive Power Transfer," Proceedings of the IEEE, vol. 101, no. 6, pp. 1276-1289, JUN 2013.

[3] Takamitsu Tajima, Hideki Tanaka: " tudy of 45 -kW Ultra Power Dynamic Charging ystem," E Technical Paper 8-01-1343 (2018).

[4] B. J. Limb et al., "Economic Viability and Environmental Impact of In-Motion Wireless Power Transfer", IEEE Transactions on Transportation Electrification, vol. 5, no. 1, pp. 135-146, March 2019.

[5] Vincenzo Cirimele, Riccardo Torchio, Antonio Virgillito, Fabio Freschi and Piergiorgio lotto, "Challenges in the Electromagnetic Modeling of Road Embedded Wireless Power Transfer", Energies, vol. 12, pp. 2677, 2019.

[6] H. Fujimoto, O. Shimizu, S. Nagai, T. Fujita, D. Gunji and Y. Ohmori, "Development of Wireless In-wheel Motors for Dynamic Charging: From 2nd to 3rd generation," IEEE PELS Workshop on Emerging Technologies: Wireless Power (WoW), Korea, pp. 56-61, 2020.

[7] A. Torrisi and D. Brunelli, "Magnetic Resonant Coupling Wireless Power Transfer for Lightweight Batteryless UAVs," 2020 International Symposium on Power Electronics, Electrical Drives, Automation and Motion (SPEEDAM), Sorrento, Italy, 2020, pp. 751-756.

[8] Yuto Yamada Takehiro Imura, "An Efficiency Optimization Method of Static Wireless Power Transfer Coreless Coils for Electric Vehicles in the 85 kHz Band Using Numerical Analysis", IEEJ TRANSACTIONS ON ELECTRICAL AND ELECTRONIC ENGINEERING IEEJ Trans 2022, vol.17, Issue 10, pp. 1506-1516, October. 2022

[9] Yujin Jang, Jung-Kyu Han, Jae-Il Baek, G. -W. Moon, Ji-Min Kim and Hoon Sohn, "Novel multi-coil resonator design for wireless power transfer through reinforced concrete structure with rebar array," 2017 IEEE 3rd International Future Energy Electronics Conference and ECCE Asia (IFEEC 2017 - ECCE Asia), Kaohsiung, Taiwan, 2017, pp. 2238-2243.

[10] Seung-Hwan Lee , Member, IEEE, Myung-Yong Kim, Byung-Song Lee, and Jaehong Lee , Student Member, IEEE, "Impact of Rebar and Concrete on Power Dissipation of Wireless Power Transfer Systems", IEEE TRANSACTIONS ON INDUSTRIAL ELECTRONICS, VOL. 67, NO. 1, JANUARY 2020.

[11] K. Hanawa, T. Imura, Y. Hori and N. Abe, "Comparison of Circular Coil, Double-D Coil, and 85 kHz Self-Resonant Coil in Road Embedment for Dynamic Wireless Power Transfer," IECON 2022 – 48th Annual Conference of the IEEE Industrial Electronics Society, Brussels, Belgium, 2022, pp. 1-6

[12] Benny J. Varghese, Abhilash Kamineni, Nicholas Roberts, Marv Halling,Duleepa J. Thrimawithana and Regan A. Zane "Design Considerations for 50 kW Dynamic Wireless Charging with Concrete-Embedded Coils", 2020 IEEE PELS Workshop on Emerging Technologies: Wireless Power Transfer (WoW) November 15 - 19, 2020, Seoul, Korea

[13] S Laporte, G Coquery, V Deniau, A De Bernardinis and N. Hautière, "Dynamic Wireless Power Transfer Charging Infrastructure for Future EVs: From Experimental Track to Real Circulated Roads Demonstrations", World Electric Vehicle Journal, 2019.

[14] Zhe Feng, Osamu Shimizu, Hayato Sumiya, Sakahisa Nagai, Hiroshi Fujimoto, Masanori Sato,"Influence of Contamination Between Receiver Coil and Embedded Transmitter Coil for Dynamic Wireless Power Transfer System", 2021 IEEE Workshop on Emerging Technologies: Wireless Power (WoW)

[15] K. Hanawa, T. Imura and N. Abe, "Basic Evaluation of Electrical Characteristics of Ferrite-less and Capacitor-less Coils by Road Embedment Experiment for Dynamic Wireless Power Transfer," 2021 IEEE PELS Workshop on Emerging Technologies: Wireless Power Transfer (WoW), 2021, pp. 1-5.

[16] K. M. Koo, S. W. Park, S. H. Park and K. N. Oh, "Diagnosis and Modelling of Equivalent Circuit Combining WPT by Loosely Coupled Coils through CB Concrete Walls at SBO," 2021 International Conference on Advanced Technology of Electrical Engineering and Energy (ATEEE), Qingdao, China, 2021, pp. 51-55.

[17] Z. Wu, M. Chen, X. Duan, Q. Wang, L. Yan and C. Rong, "Analysis of Equivalent Circuit Model of Concrete WPT System," 2022 Asia Power and Electrical Technology Conference (APET), Shanghai, China, 2022, pp. 1-6.