

Research Article

Application of Conductive Materials to Asphalt Pavement

Hai Viet Vo and Dae-Wook Park

Department of Civil Engineering, Kunsan National University, 558 Daehak-ro, Kunsan, Jeonbuk 573-701, Republic of Korea

Correspondence should be addressed to Dae-Wook Park; dpark@kunsan.ac.kr

Received 19 March 2017; Revised 15 May 2017; Accepted 1 June 2017; Published 5 July 2017

Academic Editor: Hainian Wang

Copyright © 2017 Hai Viet Vo and Dae-Wook Park. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Snow-melting pavement technique is an advanced preservation method, which can prevent the forming of snow or ice on the pavement surface by increasing the temperature using an embedded heating system. The main scope of this study is to evaluate the impact of conductive additives on the heating efficiency. The electrical resistivity and thermal conductivity were considered to investigate effects of conductive additives, graphite, and carbon fibers on the snow-melting ability of asphalt mixtures. Also, the distribution of the conductive additives within the asphalt concrete body was investigated by microstructural imaging. An actual test was applied to simulate realistic heating for an asphalt concrete mixture. Thermal testing indicated that graphite and carbon fibers improve the snow-melting ability of asphalt mixes and their combination is more effective than when used alone. As observed in the microstructural image, carbon fibers show a long-range connecting effect among graphite conductive clusters and gather in bundles when added excessively. According to the actual test, adding the conductive additives helps improve snow-melting efficiency by shortening processing time and raising the surface temperature.

1. Introduction

Snow and ice on pavement surfaces at airports have been classified as some of the major concerns causing infrastructure deterioration and flight delays or cancellations during winter in cold regions. Much worse, serious, and deadly accidents may happen as the aircraft is landing or taking off. Moreover, there are hundreds of traffic accidents caused by snow and ice every year [1]. Applying chemical melting agents on asphalt pavements has been used in metropolitan areas; however, they are incompletely effective and unfriendly with the environment. Also, employing mechanical methods such as snow ploughing vehicle could lead to pavement surface and structural damage followed by high maintenance costs [2, 3]. Environmentally friendly snow-melting agents have been developed recently [4], but they are still ineffective in removing snow under low temperatures with increased need for labor. A thermal or electrical snow-melting asphalt pavement has a great potential to alternative snow removing technique, for improving the safety in airports and highways during winter without negative impacts on the surroundings [5].

An experiment was conducted on melting processes of artificial and natural ice and snow on concrete pavement. It was assumed that the formation of ice on roads should be avoided to reduce energy consumption, and it is feasible to utilize geothermal tail water of about 40°C for melting ice and snow on winter roads [6]. The conductivity of asphalt mixtures is an essential key parameter related to the efficiency of the asphalt solar collector and snow-melting system. Therefore, improving the mixture conductivity can technically enhance the snow-melting performance [7]. Wu et al. [8] investigated the electrical conductivity of asphalt mixture containing conductive carbon fibers, carbon black, and graphite as conductive media and demonstrated that conductive fibers improve conductivity more effectively than adding conductive filler. In previous works [9–12], it was found that graphite and carbon fibers are able to improve the rutting resistance of asphalt binder. Moreover, stiffness, dynamic modulus, and tensile strength of asphalt mixture are also enhanced with an addition of carbon fibers. Vo et al. [13] investigated the thermal conductivity of asphalt pavement with an addition of graphite powder as a conductive filler. It was concluded that the time for snow-melting

process could be shortened by increasing the amount of graphite content; about half amount of the time could be reduced with a 20 percent of graphite added. Zhang et al. [14] have recently implemented snow-thawing experiments outdoor using 10 μm thick graphite interlayer as a self-heating element. It was found that the system was verified promising potential in snow-thawing applications with the desirable feasibility, high efficiency, long-term stability, low economic cost, and environmental protection. However, no extended research has focused on those conductive additives for developing asphalt mixtures for an actual snow-melting application.

The thermal and electrical conductivity of asphalt mixture modified with conductive additives was investigated in this study for snow-melting technique by an embedded heating system. The combination of graphite and carbon fibers was also considered as a mixed additive. Measurements of thermal conductivity and electrical resistivity were conducted using thermal analyzer and resistance tester, respectively. The microstructural views within asphalt mixture were observed by a scanning electron microscope (SEM) to assess the conduction mechanism. Lastly, an actual test was implemented using a test box model to determine the snow-melting efficiency.

2. Materials and Methods

This section covers the materials used to produce asphalt mixtures followed by the sample preparation, measurements, SEM imaging, and actual test modeling of this study.

2.1. Materials. Asphalt binder, PG64-22 type, with a penetration of 65 at 25°C, the ductility of 167.3 cm, and a softening point of 51.5°C, was used for all mixtures in the study. Conductive materials, graphite (G), with particle size of 150 μm and thermal conductivity 80 to 120 W/m·K, and carbon fiber (F), with diameter of approximately 10 μm , average length of about 5 mm, and thermal conductivity around 140 W/m·K, were used as conductive additives for the asphalt mixture. Dense graded asphalt concrete mixture was used in this study with aggregates obtained from local sources that consisted of crushed basaltic material (size between 0.075 mm and 12.5 mm) and mineral filler (size less than 0.075 mm) with a bulk density of 2.93 g/cm³. The mix design at air voids of 4 percent includes an optimum asphalt content of 5.3 percent for the aggregate gradation shown in Table 1, according to a research done previously [15].

2.2. Sample Preparation. The asphalt binder was firstly mixed with four different conductive additive contents of 5, 10, 15, and 20 percent for graphite and 1, 2, 3, and 4 percent for carbon fibers by volume of the asphalt binder. The aggregate was preheated to the mixing temperature of 170°C in a high-performance oven. By proceeding with the mixing method done by Bai et al. [11], wet process, mixing conductive additives with asphalt binder prior to mixing with aggregate, was found to be appropriate. Conductive additives were blended into the asphalt using a high-speed shear mixer and a hotplate. The asphalt was heated in a high-performance

TABLE 1: The aggregate gradation.

Sieve size (mm)	Total passing (%)	Individual retention (%)
19	100	0
12.5	92	8
9.5	80	12
4.75	51	29
2.36	30	21
0.6	17	13
0.3	11	6
0.15	7	4
0.075	3	4

oven to a temperature of 180°C. The conductive filler was then added to the asphalt slowly and stirred from 500 to 3500 rpm for 30 minutes until full dissolution is obtained. After mixing, the full dispersion was achieved and no phase separation was noticed during the mixing process. The mix of asphalt binder and conductive filler was stored one hour in the oven at the mixing temperature before mixing with the aggregate. The conductive additive content was substituted for the mineral filler with the same amount to ensure the volumetric property of the mixture. All asphalt mixtures were prepared in the laboratory using a mechanical, rotational mixer. Compaction following the Superpave volumetric mix design procedures to mold 100 mm diameter and 64 mm height specimens was performed. After 24-hour curing at room condition of 20°C, the specimen was then cut into 3 equal portions for the measurement purpose. There were total 26 specimens with two replicates for each mixture type.

2.3. Thermal Conductivity and Electrical Resistivity Measurements. Thermal conductivity describes material's ability to conduct heat of asphalt mixture, while electrical resistivity indicates the property to oppose electrical current. The measurements of the thermal conductivity and thermal capacity were done using a Heavy-Duty Thermal Constant Analyzer-Hot Disk TPS 1500 as seen in Figure 1(a), which meets ISO Standard 22007-2 [16]. A hot disc probe was designed with a diameter of 40 mm, based on the specimen size. A heat pulse in the form of a stepwise function is produced by an electrical current through the probe to generate a dynamic temperature field within the specimen. The increase in the temperature of the probe is measured as a function of time. The probe operates as a temperature sensor unified with a heat source. The response is then analyzed in accordance with the assumed boundary conditions. The thermal conductivity is calculated based on the temperature difference between initial temperature and final temperature after applying heat. The accuracy of the test is better than 5 percent. Accordingly, averages of the thermal conductivity and heat capacity were determined from recorded values.

Electrical resistance, R , was measured using a resistance tester connected to two circular electrodes of aluminum on both sides of the specimen as seen in Figure 1(b). The

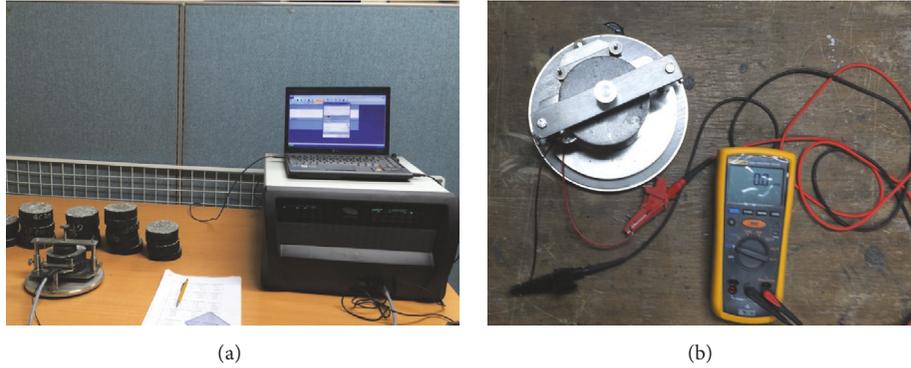


FIGURE 1: Measuring devices: (a) thermal constant analyzer and (b) resistance tester.

electrical resistivity, ρ , was then calculated as (1). A low resistivity is expected to obtain good electrical conduction.

$$\rho = \frac{RS}{L}, \quad (1)$$

where $S = 7850 \text{ mm}^2$, the cross-section area of the tested specimen, and $L = 20 \text{ mm}$, the distance between two circular electrodes.

2.4. SEM Imaging. Micrographs of the asphalt mixtures are captured using a scanning electron microscope, SEM (model S-4700 Hitachi, Japan), which provides high-resolution imaging of surfaces and was applied for learning the distribution and the mechanism of thermoconduction improvement of conductive additives within asphalt mixture. Because the SEM utilizes vacuum conditions and uses electrons to form an image, special preparations are required. Specimens were cut into small pieces of approximately $20 \times 20 \times 10 \text{ mm}$ for testing. All water must be removed from the specimens because the water would vaporize in the vacuum. The specimens were then coated with a thin film of carbon on a scanned surface to obtain conductivity without affecting observed surface morphology as seen in Figure 2. Detailed viewing was done with a magnification of 200 times. The study of micromorphology is performed in the environmental mode.

2.5. Actual Test Modeling. The test box was sketched and built as detailed in Figure 3. Two square boxes of $50 \times 50 \times 20 \text{ cm}$ were assembled with wood panels, which were qualified to be tough to withstand compaction (see Figure 3(a)). Asphalt mixture placed inside the box consists of 2 layers: an upper layer and a lower layer with the same thickness of 50 mm. One box fully contained asphalt mixture without conductive additive added, and the other had asphalt mixture with conductive additives applied to the upper layer. The asphalt mixture was mixed and compacted as it was in the above sections. Heating coil was laid and fixed on the top of the lower layer prior to placing the upper layer so that the coil was in between the two layers (see Figure 3(b)). The heating temperature was controlled from a controlling box connected with a power source to provide a constant heat of



FIGURE 2: SEM sample preparation.

60°C , which is adequate for the snow-melting purpose during winter, according to Vo et al. [13]. Although this analysis was based on a quite simple model, the method was verified as an adequate predictor of pavement heating rates. Many of the pavement conditions that were assumed to be constant probably were not, but the purpose of this analysis was to gain a preliminary understanding of the efficiency that conductive additive has on the pavement.

3. Results and Discussion

This section covers the results and discussion of the thermal conductivity, electrical resistivity, microstructure analysis, and actual test. Samples are symbolized as the abbreviation followed by the corresponding content value.

3.1. Thermal Conductivity. Figure 4, the thermal conductivity versus amounts of conductive additives including graphite, carbon fibers, and their combination, indicates that all except the mixes with carbon fibers exhibited a similar increase in thermal conductivity as the amounts of conductive additives increases. Very little is known about how the thermal conductivity varies with the content of carbon fibers; there is a decrease as fiber content is higher than 1 percent. The decrease might have resulted from the tendency to gather into bundles and increase air voids in the asphalt mixture. On the other hand, the mixes containing carbon fibers until 1 percent show the increase in thermal conductivity; the excessive 2, 3, and

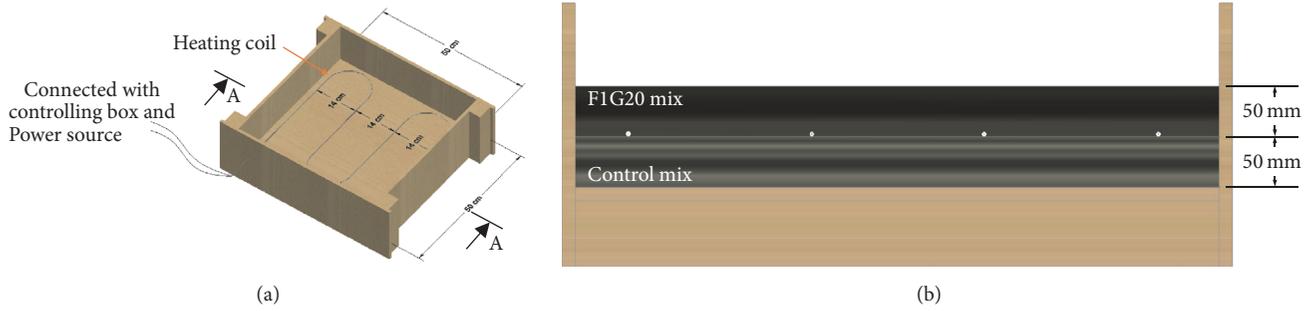


FIGURE 3: Sketch of (a) test box model and (b) cross-section A-A.

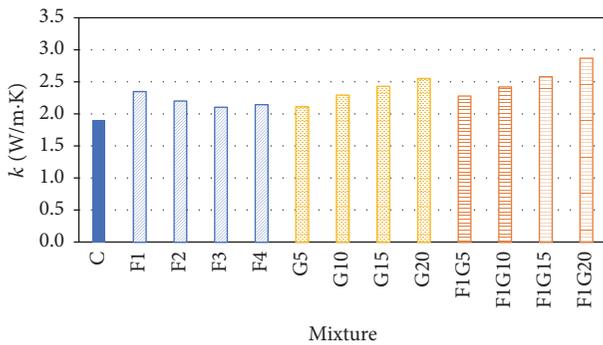


FIGURE 4: Average thermal conductivity result.

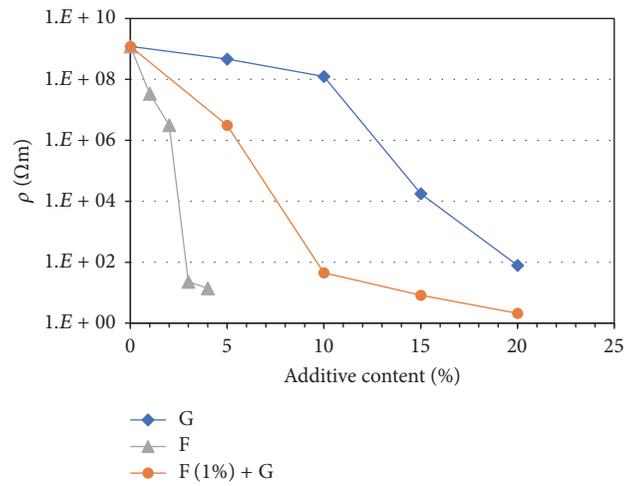


FIGURE 5: Average electrical resistivity result.

4 percent cause the decrease due to bad dispersion within the mixture, which might be seen in microscale. One percent carbon fibers was, therefore, used in the combination with graphite. The snow-melting technique expects the material to conduct the heat quickly. Therefore, it can be considered that graphite and carbon fibers, with an appropriate amount, can help the heat diffuse quickly into the asphalt mixture. The combination of carbon fiber, at 1 percent, and graphite shows advances and efficiency in improving thermal diffusivity of asphalt mixture as compared to a large amount of single conductive additive. The thermal conductivity can reach up to 2.873 W/m.K as a maximum in this study.

3.2. Electrical Resistivity. The effect of conductive additives on the electrical resistivity of asphalt mixtures is shown in Figure 5. In general, the electrical resistivity decreases as conductive additive content increases. When additive content reaches a certain level, approximately 15 percent for graphite, 3 percent for carbon fibers, and 10 percent for graphite combined with 1 percent carbon fibers, the resistivity reduced dramatically. A low content of additives in asphalt stays as isolated clusters and is unable to form the continuous conductive path; hence, the resistivity of the system has no significant change. A conductive network can be formed as a certain content level is reached. Beyond that level, the conductive network grows and spreads in all directions with the mixture. However, the further increase does not improve the conductivity significantly but probably affects the related pavement properties of asphalt concrete. The average thermal conductivity and electrical resistivity values, presented in

Table 2, along with the coefficient of variation (COV), varying from 1.08 to 4.25 percent and 1.58 to 16.7 percent, respectively, indicate that the tests were reasonably acceptable.

3.3. Microstructure Analysis. Figure 6 shows SEM images of asphalt concrete specimens containing conductive additives. The images in Figure 6(a) show that graphite particles scatter within the asphalt binder and form conductive clusters, which play thermoconduction role in the asphalt mixture; hence, the thermal properties would be improved. Carbon fibers play a long-range conduction role in asphalt mixture (see Figure 6(b)). Due to a linking effect, fibers may link several isolated conductive areas formed by graphite or fibers in the conductive network and bypass the obstacles created by some aggregates and, therefore, connect conductive areas or chains together to form conductive paths as in Figure 6(c). However, the fibers probably form into bundles in the mixture (see Figure 6(d)) and lower conduction effect due to improper mixing and/or excessiveness of fibers.

3.4. Snow-Melting Process. The test was performed with 1 percent carbon fibers and 20 percent graphite added to the asphalt mixture as a combination (FIG20), with the controlled mixture (C), and without conductive additive, for comparison purpose. In Figure 7, the test box with FIG20

TABLE 2: Summary of thermal conductivity, thermal capacity, and electrical resistivity results.

Sample	k		C_p (J/kg·K)	ρ	
	Average (W/m·K)	COV (%)		Average (Ω m)	COV (%)
C	1.900	2.67	1.689	$1.21E + 09$	5.44
G5	2.117	3.42	2.075	$4.66E + 08$	2.82
G10	2.296	3.21	2.105	$1.25E + 08$	2.72
G15	2.434	3.53	2.113	$1.76E + 04$	10.69
G20	2.556	1.47	2.026	$7.95E + 01$	4.42
F1	2.352	3.83	2.084	$3.13E + 06$	0.99
F2	2.205	1.25	1.917	$4.49E + 01$	9.54
F3	2.107	2.86	1.982	$8.28E + 00$	16.09
F4	2.148	4.25	2.052	$2.12E + 00$	16.70
FIG5	2.281	1.08	2.015	$3.40E + 07$	1.58
FIG10	2.423	2.52	2.019	$3.16E + 06$	2.99
FIG15	2.584	2.19	2.048	$2.31E + 01$	8.84
FIG20	2.873	2.46	1.977	$1.40E + 01$	6.33

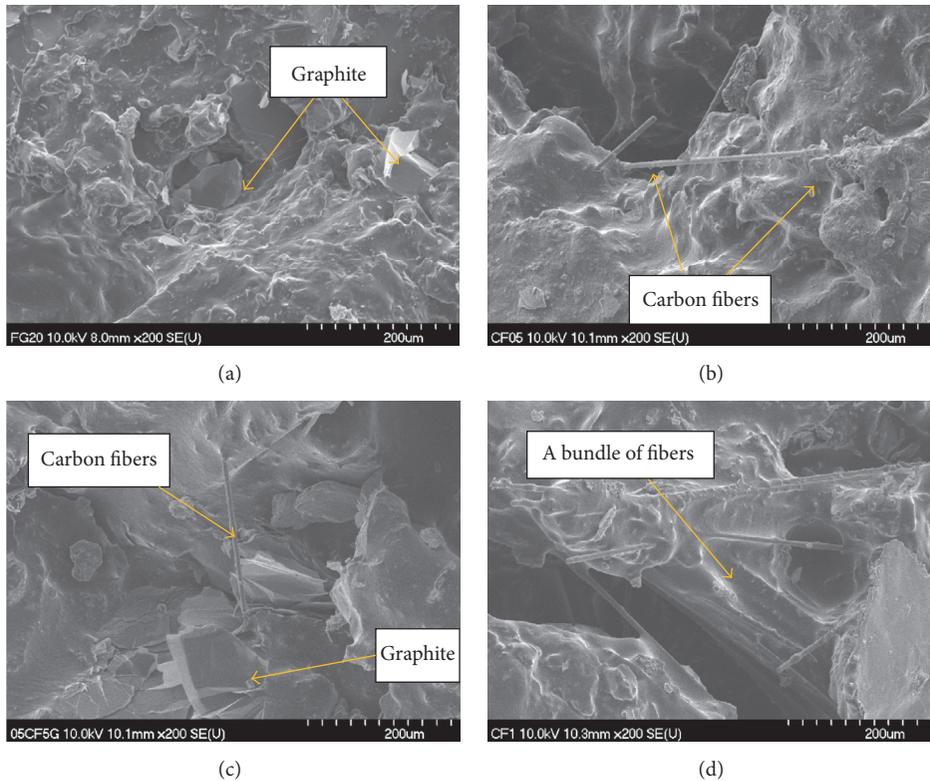


FIGURE 6: SEM images of asphalt mixture containing (a) graphite, (b) carbon fibers, (c) carbon fibers and graphite combined, and (d) carbon fibers in a bundle.

mixture is on the left side, and the other is on the right. The test was conducted in snowy weather at the ambient temperature of -3°C and wind speed of 4 m/s on January 13, 2017. Initially, the test boxes were exposed to the snow and obtained a 10 cm thickness of snow layer as seen in Figure 7(a). The performance of the snow-melting process has been recorded by digital images with the time interval between the photos of 5 minutes. As melting has progressed, stripes appear and the snow-free area increases until snow clearance is achieved.

Generally, the snow-melting process was faster for the box on the left and is described as follows: snow level was getting lower after 5 minutes (see Figure 7(b)); after 20 minutes, the snow was melting along the heating coil in the box on the left (see Figures 7(c) and 7(d)); the box on the left was almost free of snow while snow-melting stripes appeared along the heating coil in the other box in the following 5 minutes (see Figure 7(e)); snow clearance was reached in the box on the left in less than 25 minutes, while about 5 minutes more were

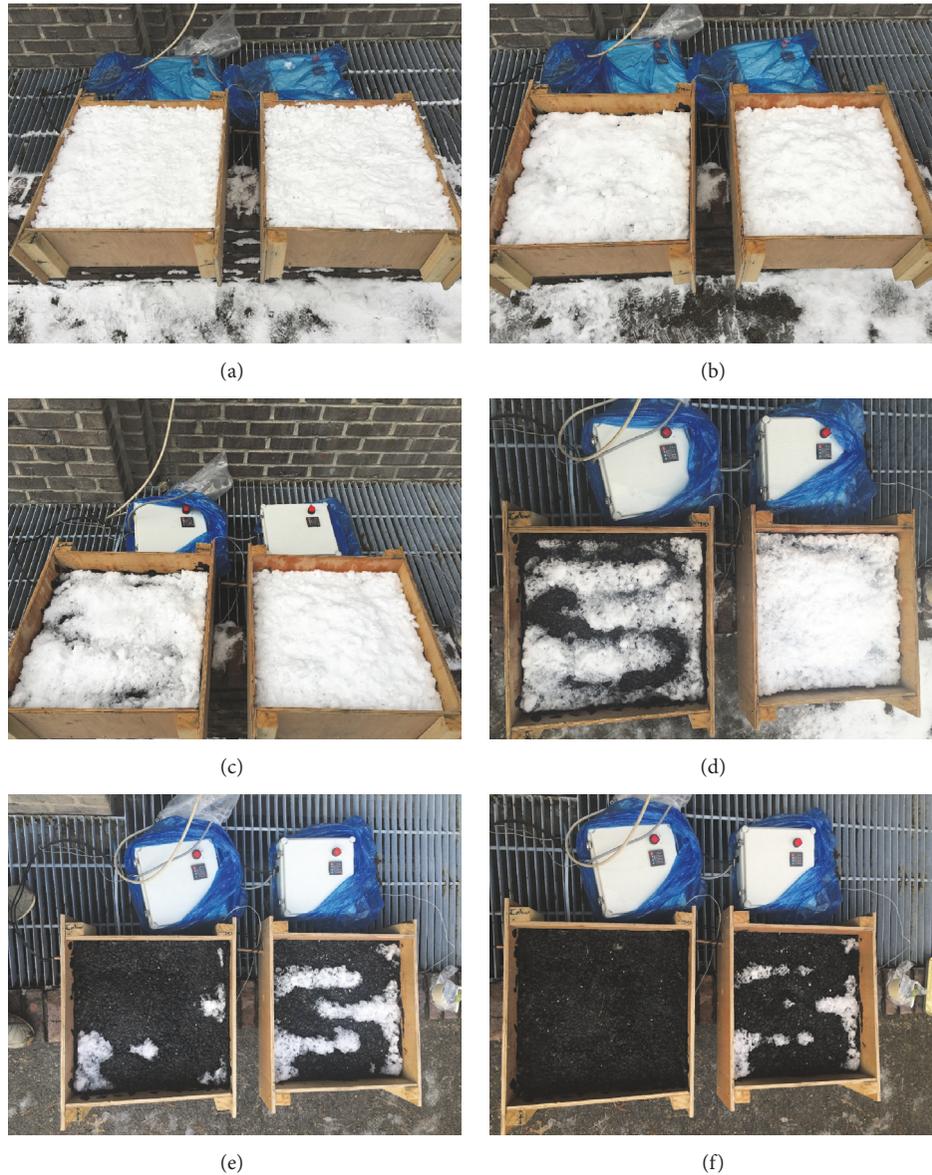


FIGURE 7: Actual test results: (a) at beginning, (b) 5 minutes, (c) 10 minutes, (d) 15 minutes, (e) 20 minutes, and (f) 25 minutes.

needed for the other box to obtain snow-free condition as the total time for snow-melting process (see Figure 7(f)). The surface temperature at the center was recorded as about 11°C and 8°C in the box on the left and the right, respectively, as the snow had completely melted. Water from melted snow ran off to the side of the boxes and partly penetrated into the asphalt mixture. Therefore, there was no water observed on the surface after all the snow has been melted. The total snow-melting process was about 10 minutes earlier for the box with FIG20 mix compared to the one with the controlled mix.

4. Conclusions

In this study, the laboratory and actual testing were presented to evaluate the potential of using thermoconductive asphalt mixture for snow-melting purpose with an embedded heating

system. Although the initial costs may be high and the system is not uneconomical, a fully automatic operation allows reducing the number of shifts of winter maintenance works. Moreover, it may not be practical to heat an extended section of a highway or an entire runway with this system. However, heating critical areas such as sloped areas, toll-gate entrance, bridge deck, tunnel portals, and especially hardstands at the airport would be more beneficial from a safety and economic standpoint. The thermal and electrical characteristics of the asphalt mixture play important roles for the design and efficiency of the snow-melting technique. It is found that both graphite and carbon fibers individually have ability to improve thermal properties and lower electrical resistivity of asphalt mixture and additionally are superior with the combination. However, carbon fibers need to be added in a sufficient amount to prevent gathering in bundles.

The entire snow-melting time is shorter using the conductive mixture compared to the one without adding conductive additives. In other words, carbon fibers and graphite with certain amounts in the asphalt mixture can accelerate the snow-melting process. In summary, the major findings of this research show that it is possible to optimize the thermal properties of asphalt mixture by several conductive additives needed for snow-melting purpose.

Conflicts of Interest

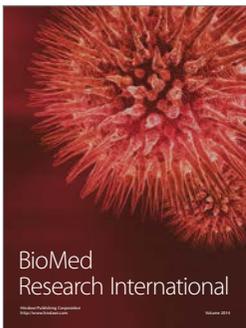
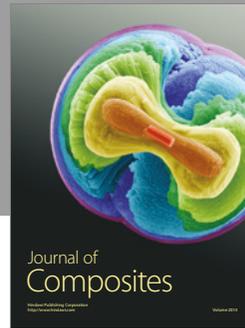
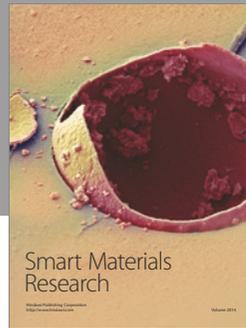
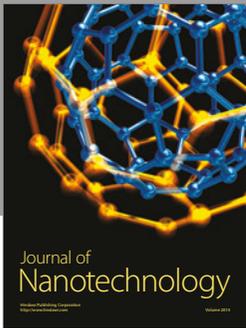
The authors declare that there are no conflicts of interest regarding the publication of this paper.

Acknowledgments

This research was supported by a grant from Infrastructure and Transportation Technology Promotion Research Program funded by the Ministry of Land, Infrastructure and Transport of Korean Government (Code 16CTAP-C114670-01).

References

- [1] S. Yehia and C. Y. Tuan, "Conductive concrete overlay for bridge deck deicing," *ACI Materials Journal*, vol. 96, no. 3, pp. 382–390, 1999.
- [2] F. Hutchinson, "Environmental pollution from highway deicing on highways," *Journal of Soil Water Conservation*, vol. 25, pp. 144–146, 1970.
- [3] W. A. Nixon, "Improved cutting edges for ice removal," Strategic Highway Research Program Report, SHRP-H-346, Strategic Highway Research Program, Washington, DC, USA, 1993.
- [4] Y. H. Wu, "Study on environmentally-friendly snow -melting agents application," *Advanced Materials Research*, vol. 709, pp. 923–927, 2013.
- [5] B. Jelisejevs, "Alternative methods of de-icing on highways," *Motorways*, vol. 3, pp. 31–34, 2001.
- [6] S. Wu, L. Mo, Z. Shui, and Z. Chen, "Investigation of the conductivity of asphalt concrete containing conductive fillers," *Carbon*, vol. 43, no. 7, pp. 1358–1363, 2005.
- [7] M. Chen, S. Wu, H. Wang, and J. Zhang, "Study of ice and snow melting process on conductive asphalt solar collector," *Solar Energy Materials and Solar Cells*, vol. 95, no. 12, pp. 3241–3250, 2011.
- [8] S. Wu, M. Chen, and J. Zhang, "Laboratory investigation into thermal response of asphalt pavements as solar collector by application of small-scale slabs," *Applied Thermal Engineering*, vol. 31, no. 10, pp. 1582–1587, 2011.
- [9] M. J. Khattak, A. Khattab, H. R. Rizvi, and P. Zhang, "The impact of carbon nano-fiber modification on asphalt binder rheology," *Construction and Building Materials*, vol. 30, pp. 257–264, 2012.
- [10] M. J. Khattak, A. Khattab, and H. R. Rizvi, "Characterization of carbon nano-fiber modified hot mix asphalt mixtures," *Construction and Building Materials*, vol. 40, pp. 738–745, 2013.
- [11] B. C. Bai, D.-W. Park, H. V. Vo, S. Dessouky, and J. S. Im, "Thermal properties of asphalt mixtures modified with conductive fillers," *Journal of Nanomaterials*, vol. 2015, Article ID 926809, 6 pages, 2015.
- [12] H. V. Vo, D. Park, W. Seo, and B. Yoo, "Evaluation of asphalt mixture modified with graphite and carbon fibers for winter adaptation: thermal conductivity improvement," *Journal of Materials in Civil Engineering*, vol. 29, no. 1, 2017.
- [13] H. V. Vo, D. Park, and S. Dessouky, "Simulation of snow melting pavement performance using measured thermal properties of graphite-modified asphalt mixture," *Road Materials and Pavement Design*, vol. 16, pp. 696–706, 2015.
- [14] Q. Zhang, Y. Yu, W. Chen, T. Chen, Y. Zhou, and H. Li, "Outdoor experiment of flexible sandwiched graphite-PET sheets based self-snow-thawing pavement," *Cold Regions Science and Technology*, vol. 122, pp. 10–17, 2016.
- [15] S.-H. Lee, D.-W. Park, H. V. Vo, and S. Dessouky, "Asphalt mixture for the first asphalt concrete directly fastened track in Korea," *Advances in Materials Science and Engineering*, vol. 2015, Article ID 701940, 6 pages, 2015.
- [16] ISO Standard, "Plastics - Determination of thermal conductivity and thermal diffusivity - Part 2: Transient plane heat source (hot disc) method," ISO Standard 22007-2, Geneva, Switzerland, 2008.



Hindawi

Submit your manuscripts at
<https://www.hindawi.com>

