# EVALUATION OF DEICING PERFORMANCE FOR THE ECO-FRIENDLY DEICER

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## ABSTRACT

This paper describes the results of laboratory and full-scale performance tests for Eco-Friendly Deicer (EFD) applicable to the highway deicing action. The EFD was developed using an organic acid from wastewater sludge and food waste. Various performance tests were conducted on the EFD, and test results showed that the eutectic point of EFD is about 17°C lower than Pre-Wetted Salt (PWS) indicating that the EFD can be used in wider range of temperature. The melting performance of EFD is almost equal to PWS in the early stage of spreading indicating that the liquid spreading of EFD is capable of improving the melting performance. The optimum concentration of EFD was found to be 45wt%. Full-scale field skid resistance test results showed that the recovering time from snowed and icy condition to the original condition on the surface are almost same in both EFD and PWS.

## RÉSUMÉ

Ce document décrit les résultats des essais de laboratoire et de performance à grande échelle pour que Deicer Eco-Friendly (EFD) est applicable à l'action de dégivrage de la route. L'EFD est développé à l'aide d'un acide organique à partir de boues des eaux usées et des déchets alimentaires. Les essais des performances différentes ont été menées sur l'EFD et leurs résultats ont montré que le point eutectique d'EFD est d'environ 17 °C qui est inférieure à celui de sel pré-humidifié (PWS) indiquant que l'EFD peut être utilisé dans une plus grande gamme de la temperature. Les performances de fusion d'EFD est presque égale à celles de PWS dans la première étape de la diffusion indiquant que la propagation de liquide de l'EFD est capable d'améliorer les performances de fusion. La concentration optimale d'EFD s'est avéré être 45% en poids. Les résultats des essais de résistance de dérapage au chantier en vraie grandeur ont montré que le temps de recuperation de l'état de neige et de l'état de glace à l'état initial sur la surface sont presque identiques dans les deux EFD et PWS.

## 1. INTRODUCTION

The skid resistance between pavement surface and tire is a very important factor in traffic safety. However, the ice and packed snow on the pavement surface in winter season can decrease the contact area of the vehicle tire and cause loss of skid resistance. This phenomenon can induce fatal car accidents due to the slippery of vehicle in the highway. Table 1 summarizes the friction coefficients and accident rates for given road surface condition. It is noted that the accident rate is defined as the number of accidents per $10^6$ vehicle kilometers. As indicated in the Table 1, the icy and snowed surface reduces the friction coefficient dramatically and the car accident rate in these conditions is more than three times higher than dry condition [*1*].

Table 1 - Friction Coefficients and Car Accident Rate for Given Surface Condition

| Surface Condition | Friction Coefficient | Accident Rate |
|---|---|---|
| Dry | 0.8～1.0 | 0.12～0.18 |
| Ice | 0.05～0.1 | 0.53 |
| Packed Snow | 0.2～0.3 | 0.31 |

The most important action in the winter road management is to remove the snow and ice from the road surface more efficiently and rapidly. Among various ice and snow removal methods, the chloride-containing deicer such as sodium and calcium chloride has been widely used due to its deicing performance and economic efficiency. In case of express highway in Korea, the pre-wetted salt (PWS) spreading method is currently being applied after experimental operation for many years [*2*]. This method is capable of improving the deicing performance through the immediate effect of calcium chloride aqueous solution and sustainability of sodium chloride.

Recently, the use of chloride deicer has been increased because the drivers need the driving safety in the winter season and the snow removal technique has been changed into the PWS spreading method. However, the excess use of chloride deicer can induce the soil and water pollution, concrete structure damage due to the corrosion, and spalling of concrete pavement. It is necessary to develop the new deicer by minimizing the quantity of chloride in the deicer and maintaining the melting performance at the level of existing deicer. Various performance evaluation and validation should be needed for the field application.

The main objective of this paper is to evaluate and validate the performance of Eco-Friendly Deicer (EFD) developed by our research team. A PWS widely used in Korea was selected as a comparison purpose. The laboratory tests such as freezing and eutectic point test, ice melting test and ice penetration test and field friction testing were conducted for evaluating the melting performance of deicer.

## 2. EVALUATION OF DEICING PERFORMANCE

The deicing mechanism can be separated into the de-icing and anti-icing actions. De-icing actions are applied to recover the skid resistance when there are snow and ice on the road surface, whereas, the anti-icing or precautionary actions are applied to maintain the skid resistance at certain level before snowing and icing. Wallman and Astrom compared the de-icing with the anti-icing actions in terms of the accident rate [*1*]. They reported that the anti-icing actions show lower accident rate and much less variations in the accident rate than de-icing actions. However, the performance of anti-icing actions can be maximized when incorporating with the roadway weather information system which providing for the accurate weather prediction and surface temperature and humidity information. When spreading the solid state of deicer on road surface without snow and ice, the skid resistance can be reduced because of rolling phenomenon of deicer particles between tire and pavement surface. Therefore, the spreading of deicer is considered as a de-icing action for snowing and icy condition. In this study, the performance evaluation of deicers has been conducted on the snowing and icy state of surface.

When spreading the deicer on the road surface, the snow and ice were changed into liquid state due to solubility and the dropping of freezing point. Where road surface is on icy condition, the deicer solution penetrates into the ice and cuts the connection between surface and ice [*3*]. After reviewing the impact factors affecting the melting performance of deicer, testing methods were selected for this study. The de-icing and anti-icing performance tests proposed by the Strategic Highway Research Program compose of ice melting, ice penetration, and ice undercutting test [*4*]. Since the ice penetration makes a great role in ice undercutting, this test was excluded in this study.

The eutectic point of a deicer should be lower than the exterior temperature for better de-icing reaction and prevention of the re-icing phenomenon. The ice melting tests are useful to estimate the de-icing performance of deicer approximately. These tests are designed to quantify the volume of ice that can be melted by a unit of deicer at varying temperatures. The ice penetration test is designed to assess the thickness of ice that can be penetrated by a deicer to allow it to reach the pavement surface and start to de-bond.

### 2.1. Deicer Materials

The Eco-Friendly Deicer (EFD) has been developed by our research team using the wastewater sludge and food waste. The effect of EFD on the plant, steel corrosion, and freezing-thawing damage has been studied. It was found that the level of damage is relatively lower than the typical chloride deicer.

A small amount of chloride, about ten percent of organic acid, was used in developing the EFD. The low chloride containing deicer has an advantage in preventing the corrosion in steel structure. The use of waste material in deicer can save large amount of budget in winter management. Table 2 shows the chemical components of deicers used in this study.

Table 2 - Chemical Components Used in for EFD and PWS
(◎: Major Component, ○: Minor Component)

| Deicer | NaCl | $CaCl_2$ | KOH | $CH_3COOH$ | $CH_3CH_2COOH$ | $H_2O$ |
|---|---|---|---|---|---|---|
| EFD | ○ | | ◎ | ◎ | ◎ | ○ |
| PWS | ◎ | ○ | | | | ◎ |

As a low chloride deicer, EFD has a chloride composed of about 10percent of organic acid. The EFD is manufactured using the organic acid obtained from food waste and sewage sludge. The distribution of acid fermentation liquid from food waste showed that 10 percent of organic is a chloride. It is reported from various research studies that the chloride in the deicer adversely affects the durability of concrete structure and ecological and soil environment. Yang et. al have studied on the effect of EFD on the plant, steel corrosion, and freezing-thawing damage and found that the level of damage is relatively lower than the typical chloride deicer.

## 2.2. Laboratory Testing

### *2.2.1. Deicer Test Methods*

*Freezing and Eutectic Point Test*

A freezing and eutectic point of EFD and PWS was measured in accordance with the ASTM D 1177 “Standard Test Method for Freezing Point of Aqueous Engine Coolants.” [*5*]. The temperatures of deicer solution were measured at intervals of two minutes by maintaining the ethanol temperature below -75 $^{o}$C using a dry ice. To obtain the freezing and eutectic point curve, the freezing point was measured by changing the concentration of deicing chemical solution at 15C of room temperature.

*Ice Melting Test*

The ice melting test was conducted for the EFD and PWS deicers based on the SHRP H-205.1/2 “Test Method for Ice Melting of Solid/Liquid Deicing Chemicals" [4]. After icing the water on the plate specially manufactured, the deicing chemicals was sprayed and then the weight of melting water was measured. In general, the deicer at liquid state is much easier for uniform spray on the road surface and has a faster melting speed than solid state. The amount of melting was measured by changing the concentration of EFD solution by 20, 30 and 45wt% and compared with that of PWS. To investigate the change in amount of melting with variation of temperature, the tests were conducted on -5 $^{o}$C and 10 $^{o}$C of temperatures.

*Ice Penetration Test*

The performance of ice penetration of EFD and PWD was evaluated based on the SHRP H-205.3/4 “Test Method for Ice Penetration of Solid/Liquid Deicing Chemicals". After injecting the water in the groove of penetration tester and icing using a freezer, the deicer is sprayed on the surface. The penetration depth of melting solution is measured with time. It is noted that the solution concentration similar to the ice melting test was used in this test.

### 2.2.2. Test results

*Freezing and Eutectic Point Test*

Figures 1 and 2 show the test results for freezing and eutectic points of EFD and PWS, respectively. As the temperature of deicer solution gradually decreases and approaches the freezing point, the material state changes into solid condition. The state change of material induces the temporary increase or no change in temperature. The eutectic points of a 5 wt% of EFD and 45 wt% of PWS solution cannot be measured in this test. Because of the chemical components in the EFD, The freezing and eutectic points of

PWS were observed more clearly than those of EFD in the curve for temperature change with time. A summary of freezing and eutectic points for each solution concentration was presented in Table 3.

Table 3 - Freezing and Eutectic Points for Each Deicer

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| EFD | Concentration (wt%) | 5 | 10 | 20 | 30 | 45 | Average Eutectic Point |
| | Freezing Point ($^oC$) | -0.5 | -3.3 | -10.7 | -17.6 | -38.5 | -44.7 |
| | Eutectic Point ($^oC$) | - | -45 | -44.2 | -44.8 | -44.9 | |
| PWS | Concentration (wt%) | 5 | 10 | 15 | 20 | 25 | Average Eutectic Point |
| | Freezing Point ($^oC$) | -1.8 | -5.9 | -8.3 | -12.7 | -16.7 | -27.8 |
| | Eutectic Point ($^oC$) | -30.5 | -28.5 | -25.6 | -26.6 | - | |

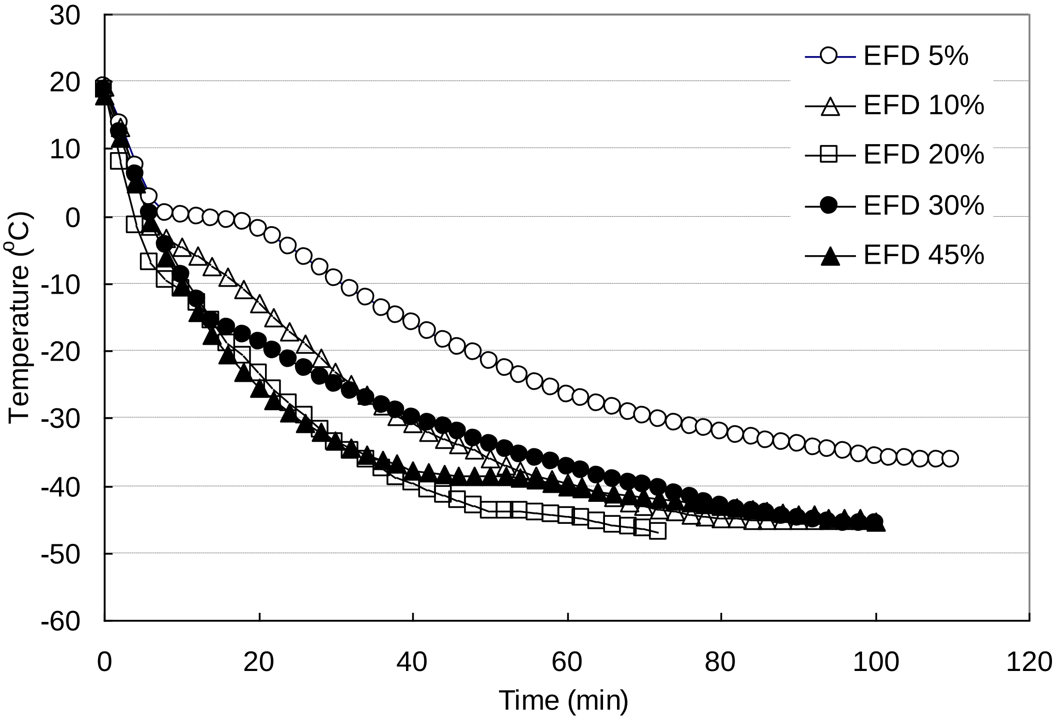


Figure 1 - Temperature Changes with Time for EFD.

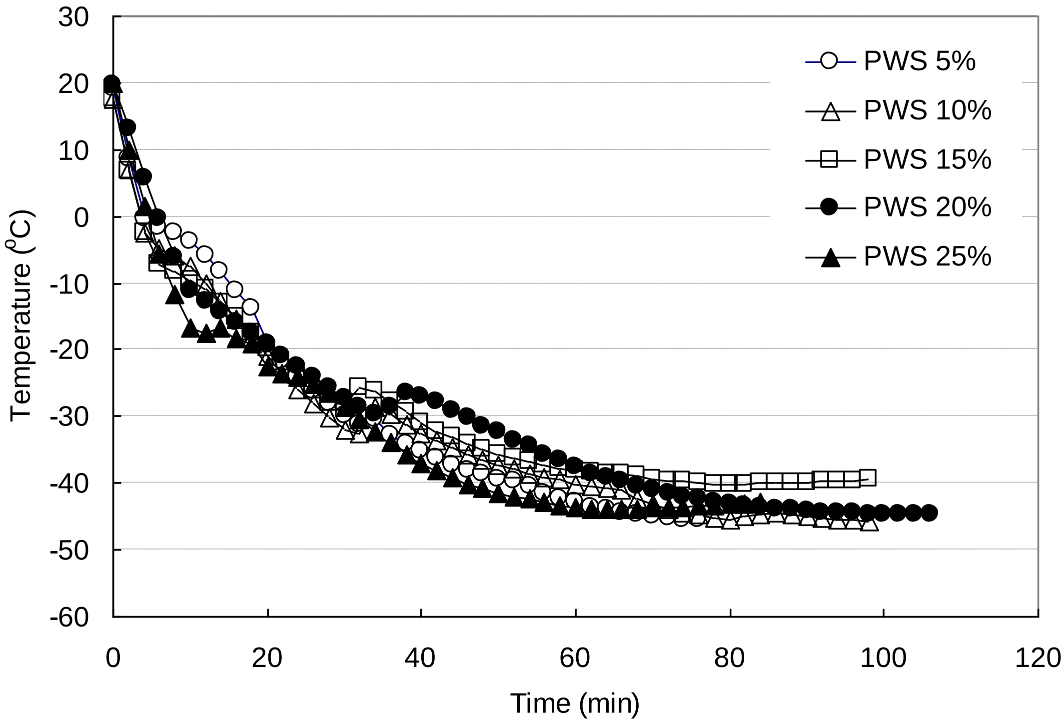


Figure 2 - Temperature Changes with Time for PWS**.**

Figure 3 shows the freezing point curve for EFD and PWS deicers. It is also found from this figure that the freezing point decreases as the solution concentration increases for EFD and PWS deicers. The eutectic point of PWS ranges from -25.6 to -30.5$^{o}$C whereas the eutectic point of EFD is about -44.7$^{o}$C. Although both deicers are applicable in the winter condition in Korea, the EFD with below -40$^{o}$C of freezing point can be used in extremely cold region.

There is no region 4 in Figure 3 when using the liquid type EFD deicer. Since the temperature is below the eutectic point in region 2, the deicer is self-iced and cannot be sprayed. To obtain the effective deicing performance, the temperature and concentration of deicer should be within the region 3. When approaching the region 1, the re-icing can be occurred and additional spray should be needed to obtain the continuous deicing effect.

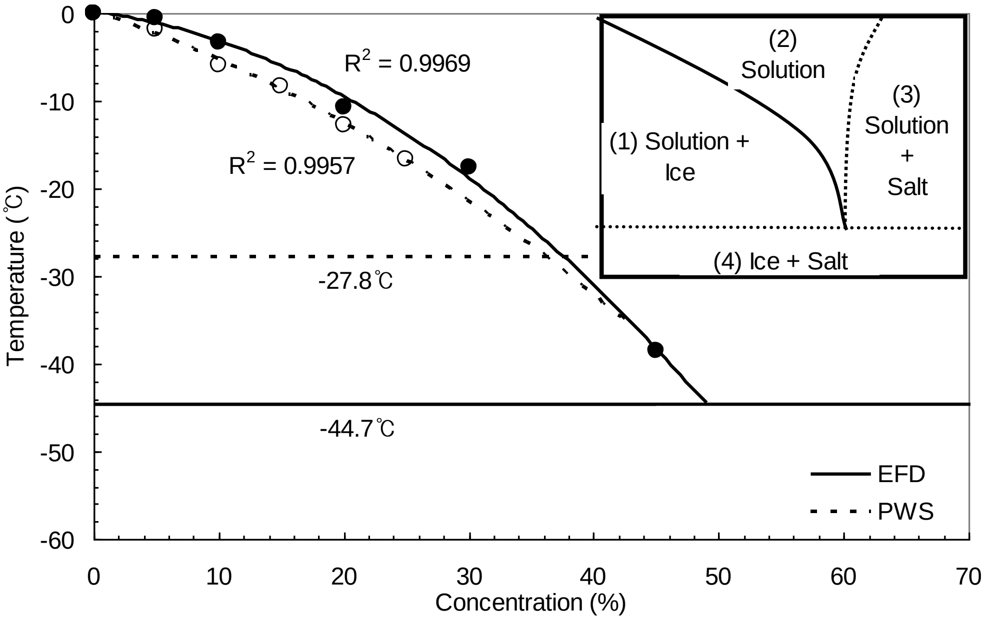


Figure 3 - Freezing Point Curves for EFD and PWS.

*Ice Melting Test*

The weight of ice melted per unit weight of deicer is measured from the ice melting test. For PWS and EFD chemicals, the changes in quantities of melted ice with time are shown in Figures 4 and 5 at -5 and -10$^{o}$C. It is observed from these figures that the PWS has better melting performance than EFD and the melting performance decreases as the solution concentration decreases. Since the freezing point of 20wt% of EFD in -10$^{o}$C is too low, a 20wt% solution of EFD at -10$^{o}$C is ruled out in this test. In case of a 20wt% solution of EFD, the melting performance from the initial to 10 minutes is similar to the PWS and tends to decreases with time.

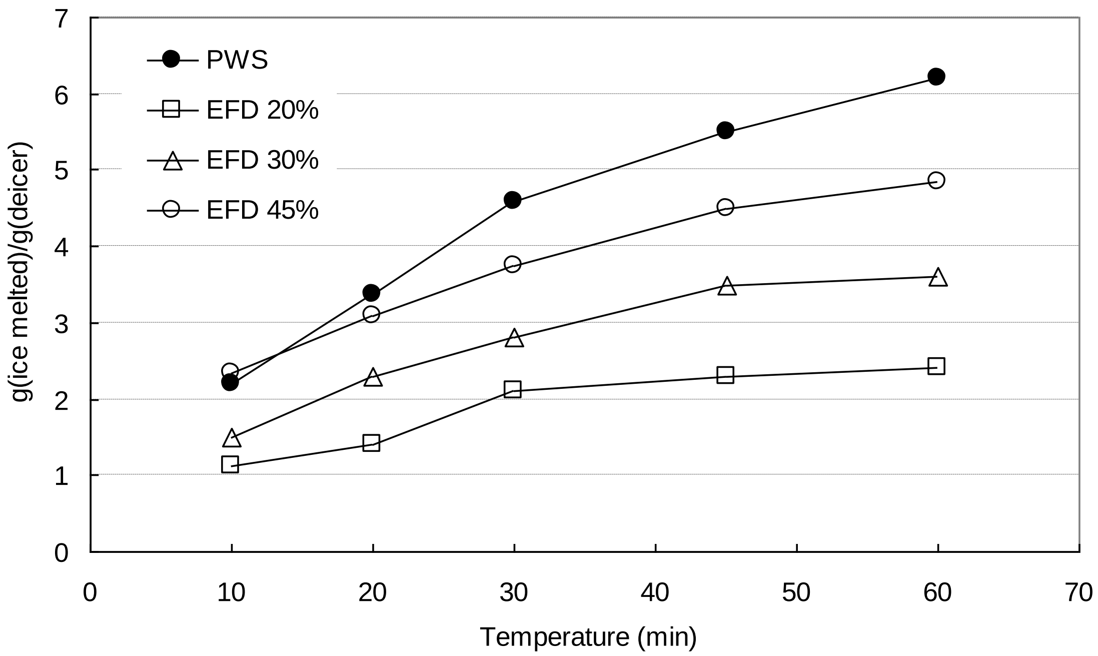


Figure 4 - Changes in Quantities of Melted ice with Time at -5°C Temperature.

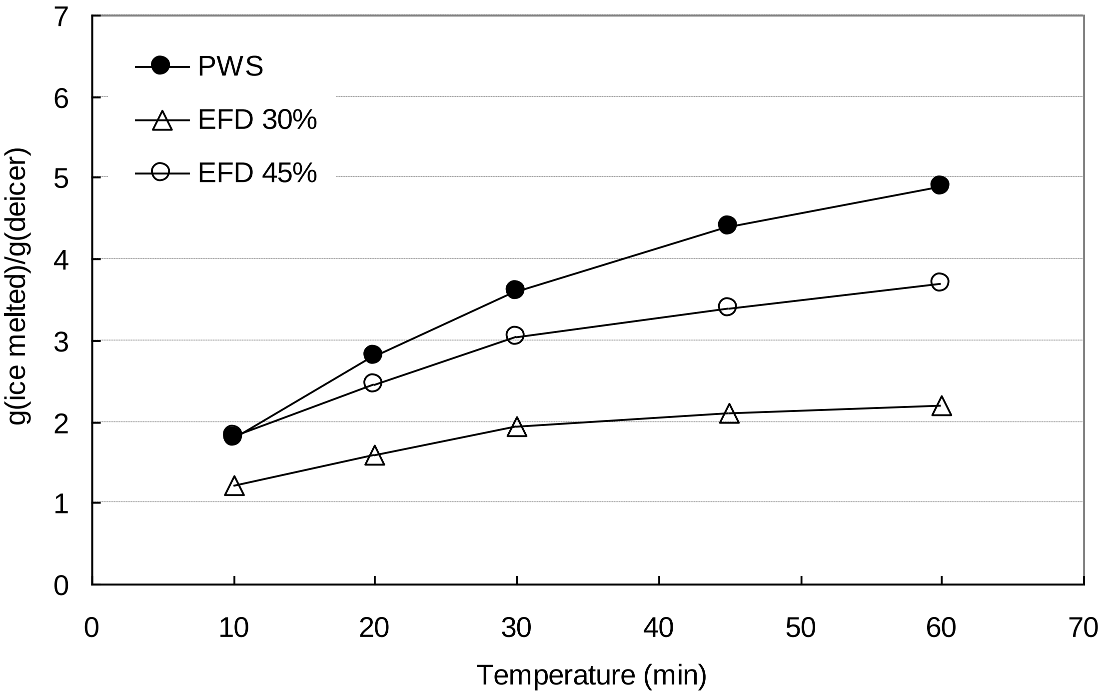


Figure 5 - Changes in Quantities of Melted ice with Time at -10°C Temperature**.**

*Ice Penetration Test*

Figures 6 and 7 show the test results for measuring the ice penetration depth at -5 and -10°C. At -5°C temperature, the EFD has about 70~80% of PWS penetration performance. Similar to the melting test, the penetration performance of both deicers is relatively same in the initial ten minutes. It is found from this test that the penetration depth did not increased after 20 minutes and observed the re-icing for 20wt% of EFD.

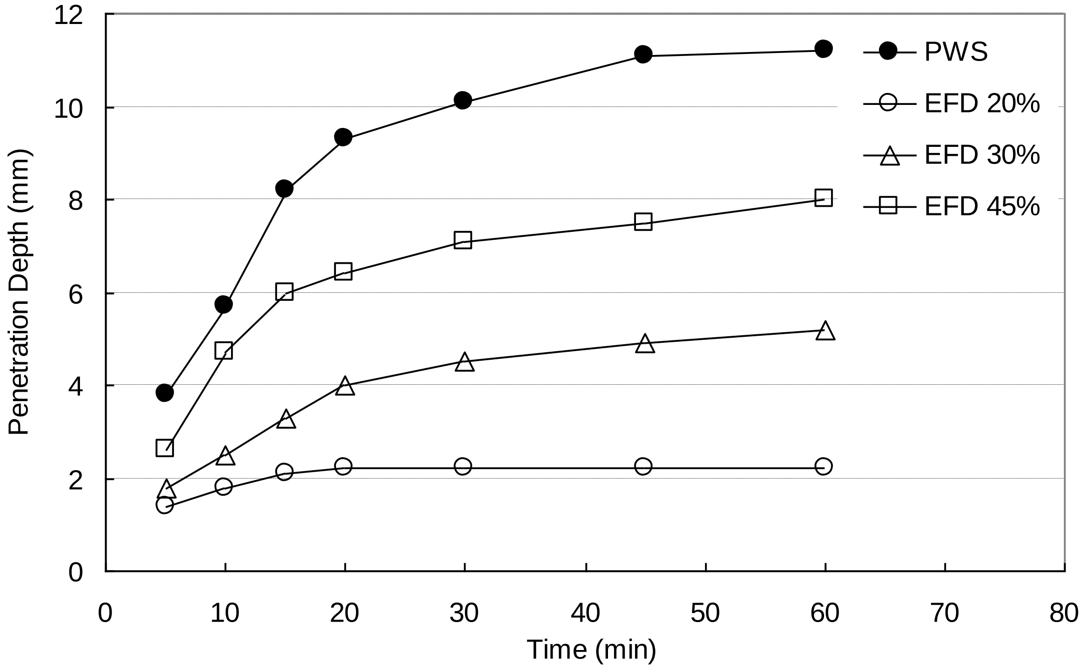


Figure 6 - Ice Penetration Depth with Time at -5°C Temperature.

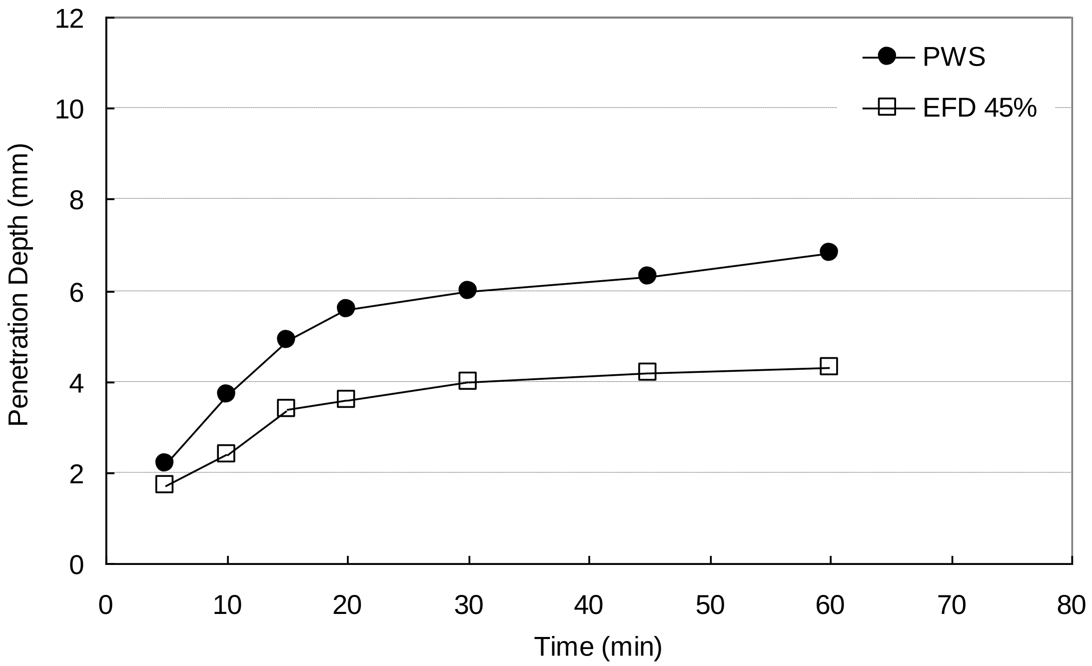


Figure 7 - Ice Penetration Depth with Time at -10°C Temperature.

## 2.3. Field Validation of Melting Performance

### *2.3.1. Introduction*

The ice melting performance of deicer in the field can be affected by various factors such as temperature, wind speed, and traffic passage. It is necessary to evaluate the field performance of deicing chemical at different surface and climate condition. As a field testing, the full-scale skid resistance testing was conducted using pavement friction tester (PFT) to evaluate the ice melting performance (*6*). Test site is located at rest area near local road 456 in Gangwon Province, Korea. Details on the test section are shown in Figure 8. EFD and PWS deicer were sprayed twice separately on the icy and compacted snow surface. The skid resistance for each section was measured and recorded every 15 minutes.

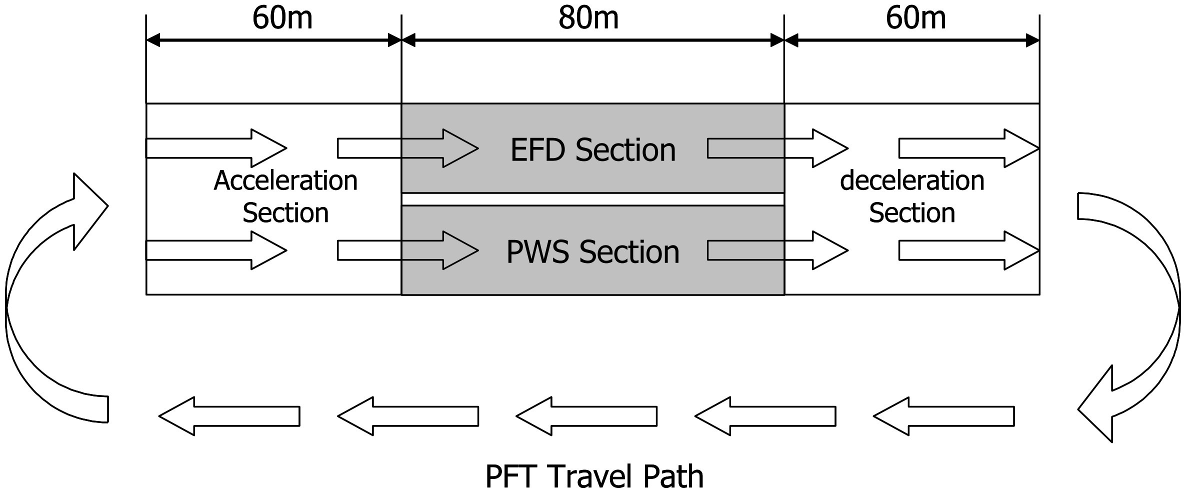


Figure 8 - Test Section for Full-Scale Skid Resistance Test.

### *2.3.2. Test Results*

First, the friction test was conducted on 2~4mm thickness of icy surface. The skid resistance of icy surface recovered to original condition in 30 minutes after deicer spreading. Instead of the dropping of freezing point, the separation of interface between ice and pavement surface after deicer penetration into the ice increase the skid resistance on this condition. The physical action such as vehicle passage also helped to increase the skid number of PFT. The second test was conducted on 2~3mm of packed snow surface. It is found from the test results that the effect of de-snow at early stage of deicer spreading and freezing point dropping affects the increase of skid resistance. Field test results and weather condition during the test were summarized in Table 4.

Table 4 - Results for Field Skid Resistance Test

| Measured Content | | 1st | | 2nd | |
|---|---|---|---|---|---|
| | | EFD | PWS | EFD | PWS |
| Skid Resistance (SN) | Before Spray | 15 | 15 | 15 | 17 |
| | 15 min | 42 | 48 | 19 | 18 |
| | 30 min | 58 | 57 | 29 | 34 |
| | 45 min | - | - | 46 | 51 |
| | 60 min | 61 | 60 | 57 | 58 |
| PFT Speed | | 40mph | | | |
| Surface Condition | | Icy surface 2~4mm | | Compacted Snow 2~3cm | |
| Air Temperature | | -2~-4℃ | | 5~6℃ | |
| Relative Humidity | | 60% | | 77% | |
| Surface Temperature | | 0~-4℃ | | 1~-3℃ | |
| Wind Speed | | 7m/s | | 2.8m/s | |

Figure 9 shows the change of skid number with elapsed time after deicer spreading for comparing the melting performance between EFD and PWS chemicals. Although the time to improve the skid resistance of PWS is slightly faster than EFD, there is not much difference in melting performance for two deicers. The SN40 value tends not to be increased after 60 which indicates about 60 values of wet condition is equal to SN40 value. Regardless of deicer type, the time to recover the skid resistance to wet condition is about 30 minutes in the first test and 60 minutes in the second test, respectively. In case of highway with 80km of design speed, the minimum SN40 value is 37. PWS has three minutes faster than EFD in recovering the skid number to the minimum requirement.

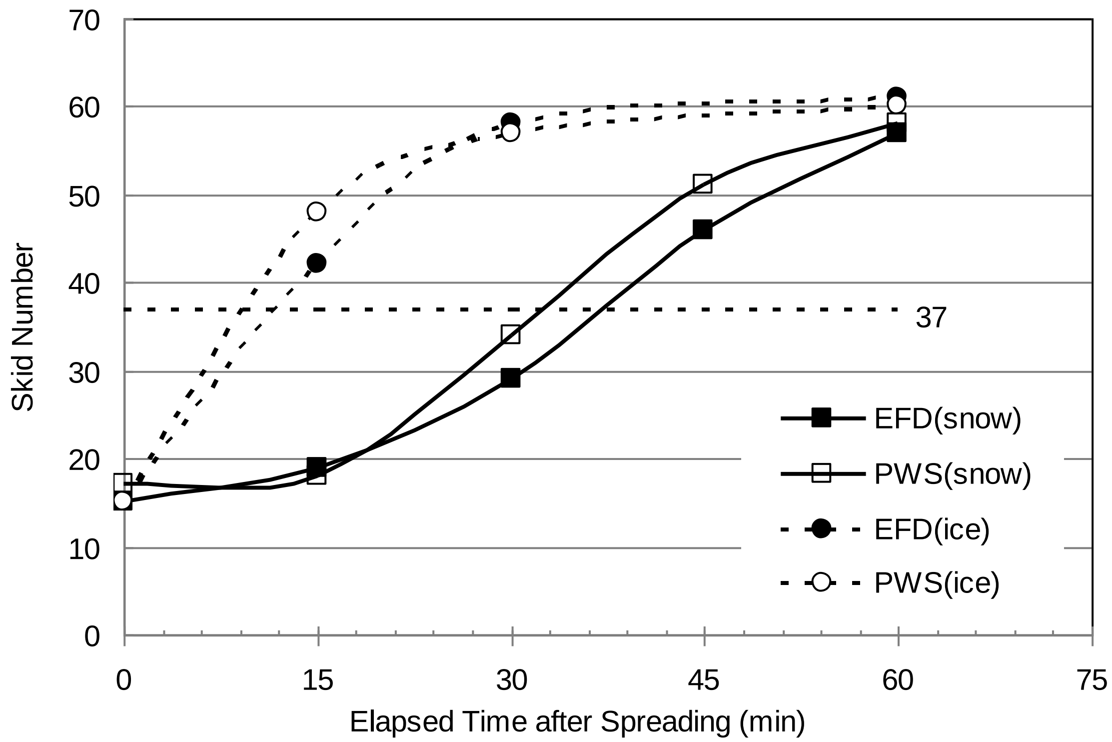


Figure 9 - Change of Skid number with Elapsed time after Deicer Spreading.

## 3. CONCLUSIONS

The melting performance of EFD developed by our research team has been evaluated in this study. Various laboratory tests have been conducted to evaluate the melting performance of EFD and select the optimum concentration of EFD for maximizing the melting performance. Field skid resistance test for two different surface conditions was performed to examine the feasibility of EFD field application.

As a result of freezing and eutectic point tests, the reduction trend of freezing point for EFD and PWS tends to be similar. However, the eutectic point of EFD is about 17$^{o}$C lower than PWS indicating that the EFD can be used in wider range of temperature. Based on the ice melting and penetration test results, the melting performance of PWS is slightly better than that of EFD. It is also observed that the higher concentration shows the better melting performance in the EFD. The melting performance of EFD is almost equal to PWS in the early stage of spreading indicating that the liquid spreading of EFD is capable of improving the melting performance. Based on the test results, the optimum concentration of EFD was found to be 45wt%. Field skid resistance test results showed that the time from snowed and icy surface to the original condition are almost same in both EFD and PWS. The melting performance of EFD in de-icing actions has been validated in this study.

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