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Research Article

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The Environmental Impact of Anti-Icing Materials on Asphalt Surfaces (Commonly Used Anti-Icing Agents)

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Keywords

Anti-icing materials, Environmental impact, Sodium chloride, Calcium magnesium acetate, Potassium acetate.

Abstract

This article investigates the effects of anti-icing materials on the environmental properties of asphalt mixtures. The studied materials include sodium chloride (NaCl), calcium magnesium acetate (CMA), and potassium acetate (PA). The Topsis method was employed to assess the environmental impacts of different anti-icing agents, focusing on their effects on soils, groundwater, surface water, vegetation, animal corrosion, particularly birds, as well as their detrimental effects on vehicles and surrounding structures. The results demonstrate that the optimal use of these materials can mitigate their negative environmental effects. Among the anti-icing agents, calcium magnesium acetate exhibits the highest environmental performance. It has the ability to reduce metal corrosion, concrete deterioration, and water pH changes. Therefore, a smart and careful utilization of anti-icing materials, especially calcium magnesium acetate, requires precise concentration adjustment and appropriate usage. On the other hand, increasing the concentration of anti-icing agents, particularly potassium acetate, is not recommended as it may exacerbate the negative environmental impacts and lead to moisture damage and fatigue in asphalt. Hence, responsible and optimal utilization of anti-icing materials can improve environmental properties and enhance economic efficiency.

1. Introduction

The use of anti-icing materials on roads is a crucial solution for increasing safety and reducing damages caused by adverse weather conditions. Snow and ice can significantly disrupt traffic and transportation. Unfavorable road conditions can lead to increased road deterioration, accidents, and higher transportation costs and personal injuries. In this context, winter maintenance systems play a vital role as they can have significant effects on transportation economics and road safety and environmental impacts [1, 2].

One of the problems that may occur during winter is the formation of a frozen road surface. This phenomenon eliminates the contact between tires and the road surface, resulting in a severe reduction in friction coefficient and vehicle control. Frozen road surfaces increase road accidents, making their management a crucial task for road authorities. One of the primary reasons for using anti-icing materials is to enhance road safety since poor road surface conditions can intensify road deterioration [3, 4].

While the use of anti-icing materials can be effective in controlling road icing, it may also have various environmental effects. The use of these materials can lead to increased corrosion of metals in structures near roads,

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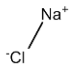
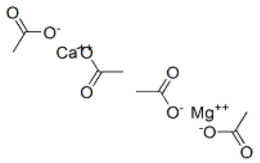
asphalt damage, elimination of vegetation cover along roads, and even harm and disturbance to animals, especially eye irritation and burning in animals and birds [5].

2. Materials and Methods

Typically, all anti-icing agents work in a similar manner. They lower the freezing point and convert snow and ice into a semi-liquid or liquid state. Anti-icers penetrate and dissolve snow and ice, forming a thick water layer that is spread beneath the ice or hard layers of snow, separating them from the road surface [6]. Table 1 presents the engineering specifications of the anti-icing materials used in this study [7]. The molecular structure of the studied anti-icing materials is depicted in Figure 1. These materials are entirely manufactured in Iran and tailored to the climatic conditions of Iran, differing from the foreign samples in terms of concentration percentage and freezing point. For example, in foreign samples, calcium magnesium acetate and potassium acetate are produced with concentration percentages of 44 and 50, respectively, to achieve higher freezing temperatures.



(A)



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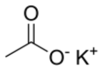

(C)

Figure 1. Molecular Structures of the Studied Anti-Icing Materials: A: NaCl, B: CMA, C: PA

Salt (NaCl) is one of the most commonly used deicing materials on roads due to its cost-effectiveness and widespread availability. However, in mountainous regions with lower temperatures, alternative anti-icing materials are recommended. Calcium magnesium acetate (CMA) and potassium acetate (PA) are among these suggested alternatives [8].

Table 1. Engineering Specifications of Anti-Icing Materials Used in this Study.

Anti-Icing Materials	Chemical Formula	Eutectic Point (°C)	Concentration (%)	Molar Mass (g/mol)
Sodium Chloride	NaCl	-21	23	58.44
Calcium Magnesium Acetate	CMA	-30	31	300.55
Potassium Acetate	PA (CH_3CO_2K)	-30.5	20	98.15

CMA refers to the compound calcium magnesium acetate. Initially, this chemical substance emerged as an excellent option for roads. Its use began in the late 1970s by the National Cooperative Highway Research Program in the United States. Since then, it has been commercially tested and developed. CMA is currently a global response to environmental concerns and a solution to the corrosion issues caused by other similar substances. CMA is typically in solid form and is applied to surfaces. However, CMA has a temperature dependency similar to salt and has its own specific performance characteristics. Liquid CMA with a concentration of around 31% is suitable for deicing roads and bridges. The liquid product prevents snow and ice from adhering to road surfaces during storms [9].

PA is an effective deicer that is completely soluble in water. It has high safety standards for various applications and complies with the ASTM D1435 standard for road and runway use. It is considered one of the best deicing materials due to its ability to work at very low temperatures and provide lower slipperiness compared to glycol-based compounds. PA has the capability to decompose at low temperatures without urea, chlorine, sodium, and without harming fish, animals, and plants. It is used for melting ice and snow. By solid and liquid application of PA on road surfaces, it prevents the adhesion of snow and ice. This substance can be used for deicing and removing snow and ice on all road surfaces, bridges, streets, and sidewalks.

To ensure responsible and optimal use of anti-icing materials, it is necessary to thoroughly examine their environmental impacts. In this article, we investigate the effects of three types of anti-icing agents, namely sodium chloride (NaCl), calcium magnesium acetate (CMA), and potassium acetate (PA), on asphalt and their environmental properties using by TOPSIS model.

3. Result and Discussion

Table 2 presents the environmental specifications of the studied deicing materials. The information provided in this section is extracted from reference [10], which is categorized and organized here. The table examines the effects of deicing materials, including NaCl, PA, and CMA, on soils, groundwater, surface water, plants, animal irritation, and metal corrosion. The results indicate that, relatively among the deicing materials, CMA has the least negative impact on environmental characteristics. Additionally, in Table 2, attempts have been made to assess its environmental effects. However, these results are not applicable to the environmental effects of composite deicers and should be considered as a prediction of the behavior of such deicers. It is recommended to conduct further studies on the negative effects of these deicers in future research.

Since quantitative comparison of anti-icing materials based on Table 2 is not feasible, various studies have been reviewed to collect numerical values of the environmental impact associated with these materials from different sources. These values, obtained based on laboratory experiments reported by the aforementioned references, are presented in Table 3, with the units of each parameter specified in the first column. Subsequently, using the TOPSIS method [11], the weights of different parameters were determined according to Figure 2. According to this figure, metal corrosion and the acidity or alkalinity level of the anti-icing materials have the highest weights. By employing Shannon's entropy weight coefficients, the overall scores of each anti-icing material were calculated, considering all the weight coefficients as shown in Figure 3. Accordingly, calcium magnesium acetate (CMA), potassium acetate (PA), and sodium chloride (NaCl) rank first, second, and third, respectively, in terms of environmental compatibility. Therefore, the results of Table 3 demonstrate that calcium magnesium acetate (CMA) exhibits the best environmental performance among the examined anti-icing materials.

Based on the results in Figure 3, quantitative values related to the environmental characteristics of the studied anti-icing materials were extracted. Then, using TOPSIS analysis, weight coefficients for various parameters such as metal corrosion, concrete corrosion, water pH, and other parameters were determined. Finally, among the anti-icing materials, CMA with a score of 0.96 has the least negative impact on environmental specifications. Additionally, regarding the PA anti-icing material, increasing its concentration percentage is not economically feasible considering the coldest regions of Iran, and increasing the percentage of this material will lead to increased moisture damage and fatigue [12].

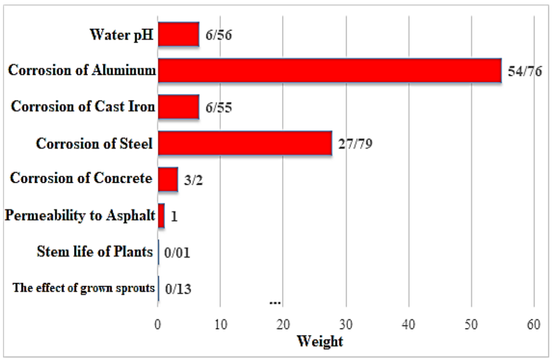

Figure 2. The weights obtained from TOPSIS analysis according to the initial values.

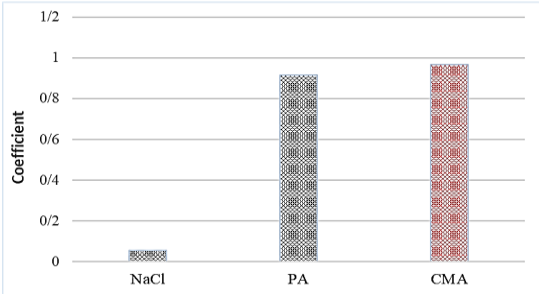

Figure 3. Molecular Structures of the Studied Anti-Icing Materials: A: NaCl, B: CMA, C: PA

Table 2. Comparison of Environmental Specifications of Anti-Icing Materials

Anti-Icing Material	CMA	PA	NaCl	Environmental Effects
Soil Conditions	Highly desirable compared to NaCl and PA. Potential for Ca and Mg to exchange with heavy metals in the soil and release them into the environment, improving soil structure.	Potassium may form complexes with heavy metals and increase their mobility.	Na can adhere to soil particles, disrupt soil structure, and reduce permeability.	Soils
Groundwater	Similar to all anti-icing materials, not suitable for groundwater.	Potential for separation of heavy metals from soil and their entry into groundwater.	Acts similarly to NaCl.	Increase in Cl concentration may occur in groundwater during low water flow or spring heat, affecting drinking water near roads.
Small Water Bodies	Similar conditions to CMA and PA. Biological oxygen demand associated with acetate leaching can deplete oxygen in small water bodies.	Causes oxygen depletion in the depths of small water bodies.	Causes oxygen depletion in the depths of small water bodies.	Surface Water Bodies
Marginal Roadside Vegetation	Negligible to zero negative effects.	Acts similarly to NaCl.	Negative effects up to 120 meters along high-traffic roadways.	Vegetation
Wildlife	Negligible to very minimal negative effects compared to NaCl.	Negligible to very minimal negative effects compared to NaCl.	Negligible to very minimal negative effects compared to NaCl.	Negative effects on birds and mammals, leading to collisions with vehicles.
Corrosion	Very minimal negative effects compared to NaCl.	Very minimal negative effects compared to NaCl.	Very minimal negative effects compared to NaCl.	Initiates and accelerates corrosion in metals and rebar in concrete pavement.

Table 3. Calculation results for window 1 in example building in June

Influential Parameters	The studied anti icing materials			References
	NaCl	PA	CMA	
Effect of Plants: Germinated shoots (ep)	1.67	1.67	1.87	13
Effect of Plants: Stem lifespan	2.53	2.53	2.60	13
Permeability to Asphalt (um/sec)	414.62	417.70	415.56	12
Volume of Corrosion in Concrete Blocks (mv)	547.0	488.0	254.0	14
Corrosion Rate of Steel (A36) (millimeters per year)	6.6	1.0	0.9	15
Corrosion Rate of Iron (millimeters per year)	4.1	1.0	2.0	16
Corrosion Rate of Aluminum (millimeters per year)	1.3	0.1	0.1	16
Difference in Acidity or Alkalinity with the pH of Pure Water	0.66	1.80	1.29	12

4. Conclusions

Based on the results of this study, it appears that using anti-icing materials on asphalt during winter maintenance can be suitable for preserving environmental properties, but attention to details of usage and necessary adjustments is essential. Specifically, the use of calcium magnesium acetate as an anti-icing material is recommended because it has shown the ability to reduce metal corrosion, concrete corrosion, and changes in water pH. However, it is important to refrain from increasing the concentration of the PA anti-icing material as it may lead to moisture-related issues and fatigue in the asphalt, while also lacking economic advantages. Overall, this study demonstrates that the optimal and environmentally compatible use of anti-icing materials, especially calcium magnesium acetate, can contribute to environmental improvements in asphalt properties and increase economic efficiency. However, achieving these outcomes requires careful attention and consideration in adjusting the concentration and use of these materials. Optimal use of the mentioned anti-icing materials, following the recommended values, can help protect the environment, enhance mechanical properties and durability of asphalt, and reduce maintenance and repair costs throughout its lifespan. Additionally, considering the environmental aspects in the selection and use of anti-icing materials holds great importance. Improving environmental quality and reducing detrimental effects on groundwater and natural ecosystems are among the benefits of appropriate utilization of these materials.

Conflict of Interest Statement

The authors declare no conflict of interest.

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