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EXPERIMENTAL RESEARCH OF ROAD MAINTENANCE SALTS AND MOLASSES ("SAFECOTE") CORROSIVE IMPACT ON METALS

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Abstract. The purpose of this investigation is to assess the corrosive impact of de-icing salts and product "Safecote" on metals by performing immersion and spraying experiments. Metallic elements such as metallic bridges, road signs, and cars, situated near the road, are exposed to salts used for road maintenance in winter seasons. The salts, used to de-ice the road surface, can cause metal corrosion. NaCl, $CaCl_2$, also mixture of NaCl and $CaCl_2$ are most commonly used salts in Lithuania. Ions of chloride are the main agents which increase corrosion rate and the metal mass loss. This harmful effect could be mitigated by replacing the salts with organic de-icers, for instance, product "Safecote" based on molasses, which is a by-product of sugar production. The research of mass loss of metals and metal alloys was carried out with the help of two methods – immersion and spraying. In the first case tested metals were dipped into the solutions of NaCl, $CaCl_2$, NaCl:$CaCl_2$ and NaCl:Safecote, in the other – metals were sprayed with solutions of above mentioned metals. Results of the experimental research showed that $CaCl_2$ has the highest effect on metal corrosion. This solution caused mass loss of galvanized steel 301.71±4.2 mg, and carbon steel – 52.27±1.7 mg by immersion method. What is more, aluminium 1.37±0.13 mg, galvanized steel 51.79±0.9 mg, stainless steel 2.11±0.2 mg, and carbon steel 266.58±2.5 mg lost their mass by spraying method. The results of the experiment showed that salts, used for road maintenance in winter seasons, should be mixed with "Safecote", which mitigates corrosion of metals and minimizes their mass loss.

Keywords: road maintenance salts, sodium chloride, calcium chloride, molasses, metals, corrosion, mass loss.

1. Introduction

Road maintenance is connected with road safety, especially in winter time which lasts almost 5 months in Lithuania (Oškinis, Kasperovičius 2005). Snowy and ice covered roads have the lowest coefficient of grip between tires and pavement, that cause an increased risk of car accidents on roads (Žilionienė, Laurinavičius 2007). According to Ratkevičiūtė *et al.* (2007), the number of road accidents in Lithuania increased by 64% from 1995 till 2005. Winter road maintenance substances have been used to mitigate the slipperiness of road pavement. Almost 100 thousand tons of salts are sprayed on the road to de-ice road pavement every year in Lithuania (Rimkus 1999). NaCl, $CaCl_2$, and its mixture (NaCl:$CaCl_2$) are the main types of salts (chlorides) to de-ice the roads (Kazlauskienė, Baltrėnas 2004; Storpirštytė *et al.* 2004).

Road salts (NaCl, $CaCl_2$, and NaCl:$CaCl_2$) have been used very extensively because the price of these chemical substances is rather low and the appliance is quite easy. Chlorides have great ice melting properties, for instance, NaCl which melts ice from –10 °C, but the capability of this substance to melt ice decreases at a lower temperature. When the temperature is lower than –4 °C the capability decreases about 30%, then NaCl is mixed with $CaCl_2$ and the range of ice melting is expanded (Mangold 2000; Kasperovičius, Oškinis 2004).

The negative impacts of salt usage have become apparent over the past several decades. Salts negatively effect roadside vegetation, soil, water quality, vehicles and infrastructure. According to Zaveckytė and Ščupakas (2005), salts destroy physiologic properties of the plant by slowing photosynthesis, processes of water potential and evaporation. Increased sodium and chloride levels in soils bring osmotic imbalances in plants which inhibit water absorption and reduce root growth. Salt also blocks the uptake of plant nutrients and inhibits long-term growth (Baltrėnas *et al*. 2006; Kazlauskienė, Baltrėnas 2007). Hääl and Sürje (2006) carried out an investigation which showed that salts increase concentration of Zn in soil. Use of NaCl inhibits some soil bacteria at concentrations as low as 90 mg/*l*, which ultimately compromises soil structure and thereby inhibits erosion control (Jelisejevs, Urbanovichs 2007; Poszyler-Adamska, Czerniak 2007).

Salts also have an impact on man made structures, for instance, bridges, pavements, sidewalks, road signs. Mangold (2000) explains that annual nationwide damage to road infrastructure caused by highway de-icing ranges from $40–$90 per ton of applied salt. According to Zaki Ahmad (2006) the corrosion cost is estimated to be 4–5% of the GNP in UK, 5258 trillion yen per year in Japan, and USA has spent about 120 $ for maintenance of aging and deteriorated infrastructures. Over the years, serious

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salt damages have occurred to multi-level parking garages and bridges due to the road salt penetration into concrete and rusting of reinforcements (Mangold 2000). According to the Transportation Research Board Report, de-icing salts alone result in annual repair/maintenance costs estimated from \$50 to \$200 million for bridge decks in the USA (Smith, Virmani 2000; Sagues 2001).

Moreover, corrosion process itself affects the environment toxically by releasing heavy metals (Belghazi *et al.* 2002) on the soil or into water resources and contaminating them. Contamination of soil and water resources can cause bigger problems, especially when the metals get into food chain. Through food chain metals can move to plants, animals, and also human body by causing various damages. Wallinder *et al*. (2001) estimated that zinc based materials have the zinc runoff rate from 0.07 to 3.5 g/m^2 per year. Copper runoff varied between 1.1 and 1.4 g/m^2 in urban areas during the first year and between 1.4 and 1.7 g/m^2 after the second year (Wallinder and Leygraf 2001).

Nowadays scientists are seeking to mitigate salts' (chlorides) negative effect on environment by replacing them with less harmful substances such as organic de-icers. Product „Safecote", based on molasses which is a by-product of sugar production, is one of the alternatives to minimize the damage on vehicles and infrastructure as well. This product should be mixed with NaCl or $CaCl_2$ brines or solutions. This material cannot be used alone. The mixing rate depends on the country and used salts' type, for instance 9:1 ratio (NaCl solution:Safecote) is suggested to apply in Lithuania. By this ratio the average freezing point is –19.1 °C. The usage of "Safecote" with salts reduces application rates of salts from 30% to 50% (Burtwell and Wilson 2004). "Safecote" is a biodegradable organic substance and the main risk by using this material is increased BOD and COD in water sources near the roadside. What is more, it contains appreciable amount of various heavy metals and may have phosphorus. The product "Safecote" is called an inhibitor of corrosion, thus the compound of NaCl and "Safecote" used in Lithuania has about 40% lower corrosive effect compared with the corrosion caused just NaCl (Wilson *et al.* 2002).

The purpose of the experimental research was to assess the corrosive impact of de-icing salts and product "Safecote" on metals by performing immersion and spraying experiments.

2. Methodology of experiment

The experimental research was carried out in a chemical laboratory of the Environmental Protection Department of Vilnius Gediminas Technical University (VGTU). Duration of the experiment was 100 days. This timeframe was chosen because Lithuania has winter season which lasts for three months (that is roughly about 100 days). Experimental research was carried out under normal laboratory conditions (19–20 °C temperature with 38–40% relative humidity).

The following devices were used for the experiment: electronic weight "KERN-770" (which range of measurement is 0–210 g and accuracy 0,00001 g), pH-gauge "pH 538" (which range of measurement is –2–16 pH and accuracy ±0,01 pH), 100±0,1 and 500±0,25 ml measurement flasks to prepare solutions for experimental research.

Four different concentration solutions- (NaCl (p.a.), $CaCl_2$ (p.a.), NaCl:$CaCl_2$ and NaCl:Safecote), were chosen for the scientific test because those substances were actually used for winter road maintenance in Lithuania. All substances, except "Safecote", were mixed with de-ionized water to prepare solution for the experimental research. Technical salt (NaCl), used in brine media, was also applied as solution. Sodium chloride (NaCl) was mixed with de-ionized water to prepare 23% concentration of NaCl solution which had 7.6 pH. When temperature of environment increases to –4 °C, it is recommended to mix NaCl with $CaCl_2$ in mixing ratio 7.3:1, which is the solution of 8.0 pH. $CaCl_2$ solution with 8.5 pH is rarely used as de-icer but this opportunity is possible in order to keep road free of snow and ice. Concentration of calcium chloride ($CaCl_2$) solution was 30%. The last substance is "Safecote" which is a new de-icer in Lithuania so actually it hasn't been used on the roads and this product is on experimental stage in Lithuania. As it was presented, "Safecote" is an organic product from sugar production which is also called molasses. "Safecote" has good anti-corrosion characteristics, it prevents melting snow from freezing into ice, causes no harm to the environment and has binding of particles properties. For the experiment "Safecote" was mixed with NaCl solution in ratio 9:1 (NaCl:Safecote) where 900 ml of 23% NaCl solution was mixed with 100 ml of pure "Safecote". This mixing ratio is recommended to apply in Lithuania due to dominating weather conditions. The solution, presented in Table 1, was used for the experimental research and had 5.6 pH chemical composition of metals (wt, %).

Four types of metals such as carbon steel (S235JRG2), stainless steel (No. 1.4541), aluminium (ENAW5754H22) and galvanized steel (DX51D) were used for this investigation. All these metals are being used for production of road metallic elements such as bridges, crash barrier, road signs, and some parts of car body.

Table 1. Chemical composition of experimental metals (wt, %)

Composition	Carbon steel	Stainless steel	Aluminium	Galvanized steel
C	0.12	0.08	–	0.25
Si	0.02	0.75	0.15	–
Mn	0.42	2.00	0.23	–
S	0.14	0.015	–	0.04
P	0.09	0.045	–	0.10
Cr	–	18.00	0.05	–
Ni	–	10.00	–	–
Cu	–	–	0.02	–
Al	0.06	–	95.92	–
Mg	–	–	3.30	–
Ti	–	0.70	0.02	–
Fe	99.15	68.41	0.29	99.61
Zn	–	–	0.02	–

Immersion and spraying means were the two types of methods performed during the experimental research. Each metal was immersed into each solution as it is shown in Fig. 1A during the investigation period in the first experimental method. Second method was called spraying because each metal was sprayed with different solution every week during the experiment time (Fig. 1B). About 5 ml of experimental solution on metal surface were sprayed each time.

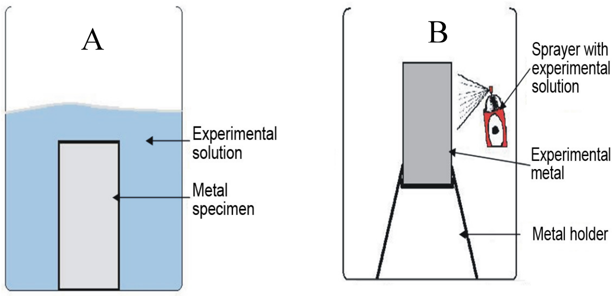

Fig. 1. Laboratory experiments. A – Immersion method; B – Spraying method

Every metal samples were cut into the size of 55×30 mm for the experimental research. Each metal had a different thickness, for instance, aluminium – 1 mm, galvanized steel – 1.5 mm, stainless steel – 4 mm, and carbon steel – 5 mm. The samples were mechanically polished with 400, 500 and 600 emery papers and lubricated by using de-ionized water before exposure. The polished samples were cleaned with acetone, washed by using de-ionized water (Rosliza *et al.* 2008; Cho *et al.* 2008) and then dried. Metals were weighted for the original weight (m_o), then immersed and sprayed with test solutions for 100 days after cleaning.

Corrosion rate may be expressed by calculating mass loss of metal (Vargel 2004; Glass and Buenfeld 2000). Mass loss (M_L) due to corrosion initiated by winter road maintenance substances, was evaluated by the following formula (Rosliza *et al*. 2008):

$$M_L = m_o - m_f, \quad (1)$$

where: M_L – mass loss of metal, mg; m_o – the weight before experiment, mg; m_f – the final weight after experiment, mg.

The corroded specimen were immersed into aqua fortis (HNO_3) for 2–3 minutes to eliminate corrosion products. Eventually, the metals were washed with de-ionized water, dried, and weighted in order to get the final weight (m_f).

Each metal was weighted 5 times in order to avoid inaccuracy. From that data an average value and confidence interval were calculated.

3. Results and discussion

"Corrosion" and "oxidation" are the terms of electrochemical reaction which occurs as corrosion of metals that is slow, although progress as rapid deterioration of metal properties under the influence of the aggressive surrounding environments such as temperature, relative humidity, pH and chlorides.

Intensive studies of aluminium corrosion were started by Richards in 1930s (Christian 2004). Aluminium is always covered by its natural oxide layer (Al_2O_3) so it is a very stable metal, especially in oxidised media (air, water). Corrosion pits of aluminium are always white pustules ($Al(OH)_3$), but they are not so intensive. The overall reaction of pitting corrosion on aluminium is

$$2Al + 3H_2O + \tfrac{3}{2}O_2 \rightarrow 2Al(OH)_3 . \quad (1)$$

The experimental research (Fig. 2) showed that NaCl and $CaCl_2$ solutions induce 0.61±0.09 mg and 0.58 ±0.04 mg mass losses respectively by immersing aluminium into those solutions. By immersing the experimental metal into NaCl and $CaCl_2$ mixed solution metal loss was 0.33±0.05 mg. The minimal mass loss was due to the influence of mixed solution of sodium chloride and product "Safecote" which caused 0.16±0,04 mg of mass loss. According to Vargel Christian (2004) aluminium resistance to corrosion depends on the pH of solution into which it is immersed. The poorest resistance is in the highly basic media. Solutions of NaCl, $CaCl_2$, and NaCl:$CaCl_2$ have basic pH which varies from 7.6 to 8.5. Consequently, the mass loss is the highest in those solutions as well. NaCl:Safecote solutions have 5.6 pH (light acidic) and the mass loss is minimal.

The investigation results of spray method about mass change of aluminium are presented in Fig. 3. $CaCl_2$ solution made the highest impact to this metal mass loss (1.37±0.13 mg). Solution of NaCl and $CaCl_2$ made 0.89±0.08 mg mass loss and NaCl solution entailed 0.7±0.07 mg mass loss. The same as in immersion method NaCl:Safecote solution made 5 times and 2.5 times lower mass loss compared to $CaCl_2$ and NaCl respectively that was 0.27±0.05 mg mass loss in spraying method. Aluminium mass loss is quite low that is determined by the natural oxide layer which forms when metal alloy reacts with oxygen.

Galvanized steel corrosion by immersion method after 100 days of the experiment (Fig. 4) showed that galvanized steel mass loss varied from 50.83±3.08 mg to 301.71±4.2 mg. The maximal loss, produced by $CaCl_2$ solution, made 6 times difference from the minimal loss which was induced by NaCl:Safecote solution. Aluminium immersed into NaCl solution lost about 129.04±2.65 mg of its mass. Mixed solution of NaCl and $CaCl_2$ induces 85.26±3.46 mg mass loss of aluminium and it is 1.7 times more than NaCl:Safecote solution induced mass loss.

The results of spraying method (Fig. 5) show that galvanized steel is sensitive to $CaCl_2$ solution as it was in the immersion method. By spraying $CaCl_2$ solution metal loss is 51.79±0.9 mg. Solutions of NaCl and NaCl:$CaCl_2$ cause 43±2.7 mg mass loss of galvanized steel. 27.67±1.1 mg mass loss of galvanized steel was made of NaCl:Safecote solution. The results show that galvanized steel is sensitive and very soluble by using immersion test since this metal loses the biggest amount of its mass (301.71 mg).

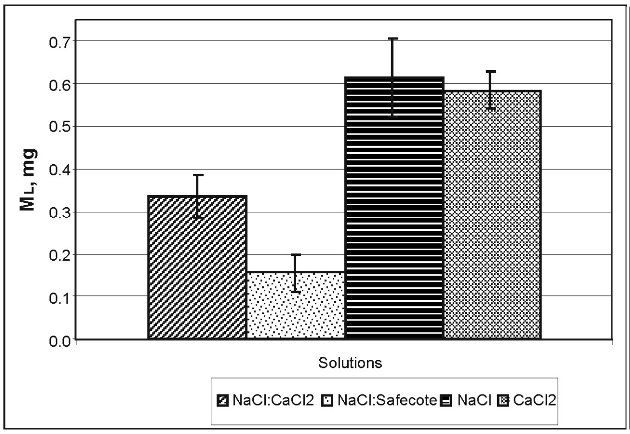

Fig. 2. Aluminium mass loss by immersion method

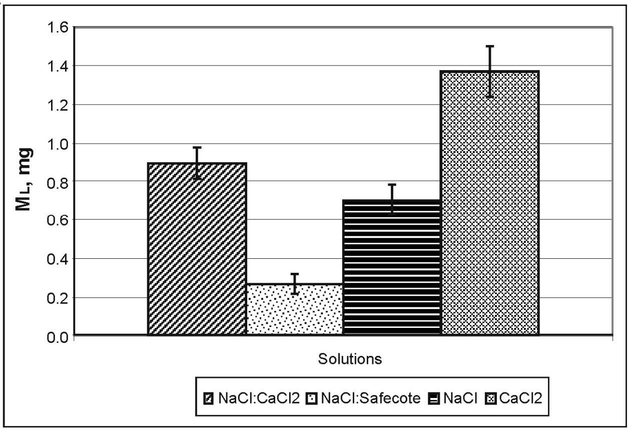

Fig. 3. Aluminium mass loss by spray method

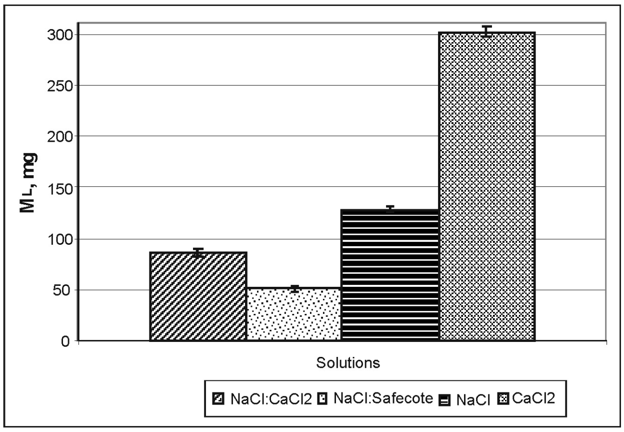

Fig. 4. Galvanized steel mass loss by immersion method

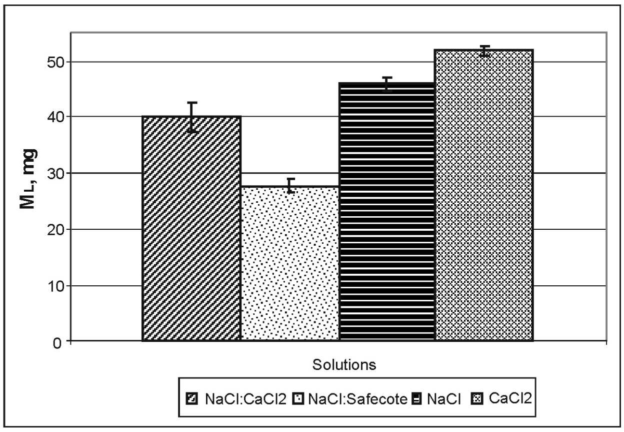

Fig. 5. Galvanized steel mass loss by spray method

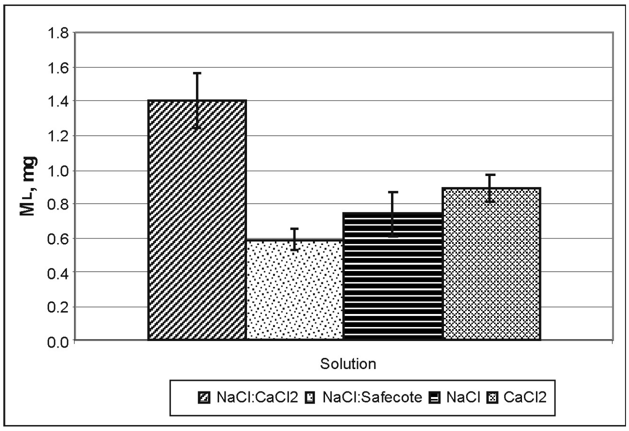

Fig. 6. Stainless steel mass loss by immersion method

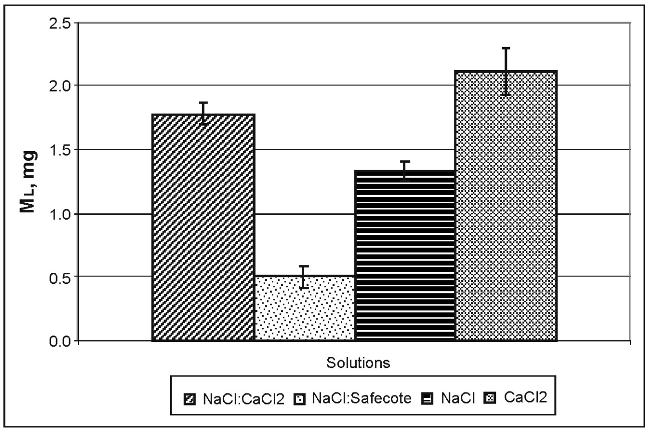

Fig. 7. Stainless steel mass loss by spray method

Stainless steel is widely used in process equipment as it is resistant to corrosion from a variety of media. However, this metal is vulnerable to certain types of attack, especially to chlorides, which cause pitting and crevice corrosion of metal (Dobrzański *et al.* 2007). According to L. A. Dobrzański *et al.* (2007) stainless steel resistance depends on the Chromium (Cr) content in the metal alloy at least by 11%, because Cr is a reactive element and it alloys passivity and exhibits excellent resistance to many environments. Nickel (Ni) is also the element which reduces risk of stress corrosion cracking (Leinartas *et al.* 2002).

Stainless steel with 18% content of chromium and 10% of nickel (Table 1) was used in our experimental research. Fig. 6–7 presents stainless steel corrosion rate which is determined by mass loss of experimental metal. The variation of mass change is from 0.58 mg to 1.40 mg in immersion method and from 0.497 mg to 2.11 mg in spraying method.

When stainless steel was immersed into NaCl:Safecote solution (Fig. 6) the minimal mass loss occurred ranging 0.58±0.06 mg. NaCl solution caused 0.74±0.13 mg mass loss and $CaCl_2$ – 0.89±0.08 mg. Mixed solution of sodium and calcium chlorides induced the maximal damage to stainless steel in the immersion method which was 1.40±0.2 mg.

Spraying method (Fig. 7) induced higher damage to stainless steel compared to immersion method. In this method average mass loss of experimental metal was 1.43 mg and in immersion method – 0.9 mg. It is 1.6 times stronger effect. 2.11±0.2 mg mass loss of stainless steel occurred by spraying with $CaCl_2$ solution which made the highest damage. NaCl and $CaCl_2$ solution made 1.78±0.09 mg mass change and NaCl solution – 1.33±0.08 mg. When product "Safecote" was blended with NaCl, the result of this solution had a lower corrosive impact on stainless steel (0.49±0.08 mg).

Carbon steel is the most unprotected steel from all the tested metals and metal alloys as it does not contain any percentage of chromium, nickel, or molybdenum, which give resistance to corrosion of metals (Mobin 2008). As showed in Fig. 8–9 mass loss of this alloy distributes differently from figures presented before. Sodium chloride solution mixed with organic de-icer "Safecote" induced the highest damage to carbon steel in immersion method where mass changes about 104.21 ±0.12 mg per 100 days of investigation. The loss is due to the metal's poor resistance to lower pH (acidic medium) (Christian 2004). NaCl:Safcote solution has a 5.6 pH which is light acidic medium. When carbon steel was immersed into $CaCl_2$ solution this alloy lost its mass twice (52.27± 1.7 mg). NaCl:$CaCl_2$ solution induced 19.28±0.80 mg mass loss. 16.47±0.90 mg mass change occurred when alloy was immersed into NaCl solution. The minimal mass loss was 6.3 times lower then maximal mass loss.

The same tendencies for tested metals and metal alloys occurred in spraying method as they had been registered in immersion method as well.

Spraying method (Fig. 9) had the highest mass loss which occurred when the carbon steel was sprayed with $CaCl_2$ solution that was 266.58±2.5 mg per 100 days (about 9.7 g/year). NaCl solution and NaCl:$CaCl_2$ solution effected carbon steel by causing the average 112.9±2.7 mg of mass loss. NaCl and "Safecote" solution made 5 times lower impact on metal mass loss as $CaCl_2$ solution (51.99±1.2 mg).

The empiric regression equation and correlation coefficient values were calculated in order to define statistically the mathematical reliability relation between chloride concentration in the solution and mass loss of metal due to corrosion induced by road maintenance substances by performing immersion and spray methods. Linear regression equation and correlation coefficient was calculated by given 95% probability. The linear regression equation was used as follows:

$$Y = ax + b, \quad (2)$$

where: Y – mass loss of metal, mg; x – Cl^- concentration in the solution, mg/l; a and b – coefficients.

Regression equations and their correlations coefficients are presented in Table 2. These regression equations described mathematical relationship between concentration of chloride in the solution and mass loss of metal (or metal alloys) due to corrosion.

Table 2. Regression equation and correlation coefficients

Metal/ Metal alloy	Method of investigation	Regression equation	R^2
Aluminum	Immersion	Y = 8302.5x + 11581	0.4
	Spray	Y = 5984.1x + 10236	0.9
Galvanaized steel	Immersion	Y = 24.87x + 11544	0.9
	Spray	Y = 27.85x + 5645,3	0.7
Stainless steel	Immersion	Y= 1834.4x + 13413	0.1
	Spray	Y = 3456.8x + 10128	0.7
Carbon steel	Immersion	Y = –14.87x + 15783	0.1
	Spray	Y = 30.58x + 10907	1.0

Correlation coefficient reliability is ranged when value of R^2 is up to 0.7 (when correlation between ratios is strong). If value of R^2 is between 0.5 and 0.7 correlation is average, but if R^2 is lower, 0.5 correlation is weak. If value of R^2 is about 0.1, it is very weak. Relation between Y and x was calculated with the help of least squares method.

Correlation between aluminium mass loss and chloride concentration in immersion method used solutions is quite weak (0.4), but in spray method this correlation is very strong (0.9). Galvanized steel mass loss has very

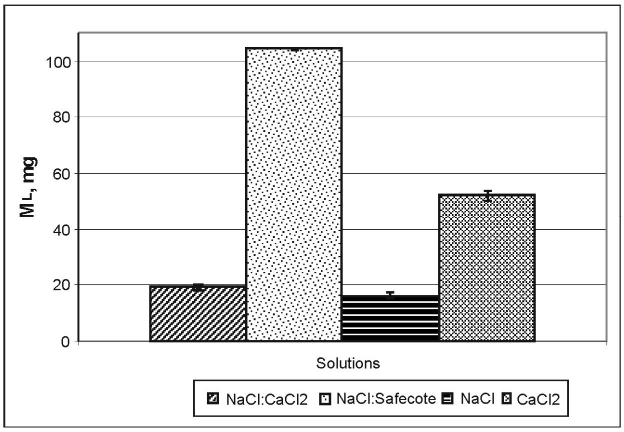

Fig. 8. Carbon steel mass loss by immersion method

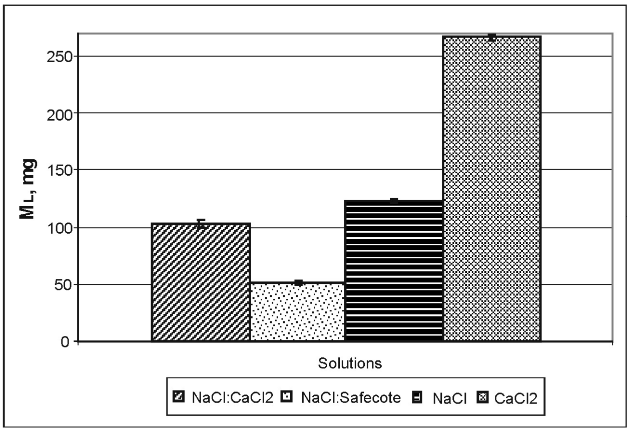

Fig. 9. Carbon steel mass loss by spray method

strong correlation with chloride concentration in used solutions in both methods (0.9 and 0.7 respectively). Stainless and carbon steels during immersion method mass losses had very weak correlation with chloride concentration of experimental solutions (0.1), but on the contrary in spray method mass losses of stainless and carbon steel had quite strong correlation (0.7 and 1.0 respectively).

4. Discussion

It is worth to notice that corrosion resistance mostly depends on metal type, its composition, and also impact of the substance. According to these properties, metals could be placed by resistance rate. By immersion method aluminium had the highest resistance to all solutions and NaCl induced the biggest damage to this metal by changing mass about 0.61±0.09 mg. The mass loss of stainless steel varied from 0.58±0.06 mg to 1.40±0.20 mg in the immersion method. This metal alloy has quite strong resistance to corrosion because it contains chromium, molybdenum, and nickel metals which protect it from rusting. Carbon steel has fairly low resistance to corrosion. For example, in the immersion method this experimental metal loss ranged from 16.47±0.9 mg to 104.21±0.12 mg of its mass. This was due to high content of carbon and iron which is soluble in the solutions. The worse metal alloy to use in salty solution is galvanized steel which can lose from 50.83±3.08 mg to 301.71±4.2 mg of its mass. This metal alloy has twice higher amount of carbon and 0.46% more of iron comparing with carbon steel.

Spraying method brought other metal resistant position as immersion method where aluminium and stainless steel had higher resistance to experimental solutions. They lost their mass ranging from 0.38 mg to 1.74 mg. Galvanized steel, which mass changed on an average 41.36 mg after 100 days, is in the third place according to corrosive resistance. Carbon steel is the most sensitive to corrosion by spraying method where the biggest loss occurs by spraying with $CaCl_2$ solution (266.58 mg).

The average mass loss of all experimental metals by immersion and spray methods depended on used solutions. Fig. 10 illustrates corrosive properties of experimental substances. The results show that $CaCl_2$ solution had a stronger damage to all metals and metal alloys when they were immersed into this solution. The average mass loss was 88.86 mg per 100 days. NaCl solution made the mean of 36.72 mg mass loss. Mixed solution of sodium and calcium chlorides effected metals by causing 26.57 mg mass loss on average. 23.43 mg was the mean minimal mass loss due to NaCl:Safecote solution induced corrosion.

The mean results of spraying method are quite similar to immersion method. The tendency of solutions corrosive impact on experimental metals is also the same. The biggest corrosive effect on metal had $CaCl_2$ solution (80.46 mg). When metals were sprayed with NaCl the average mass loss was 42.78 mg. By spraying with $NaCl:CaCl_2$ solution metals had 36.32 mg of the average mass loss. NaCl:Safecote solution made the lowest corrosion damage to metal mass change (20.11 mg).

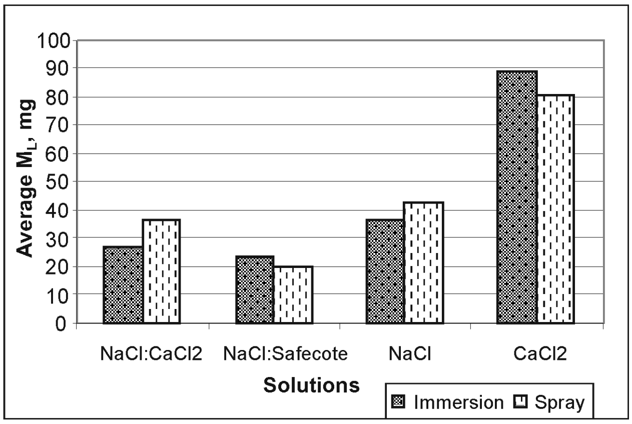

Fig. 10. Average mass loss by immersion and spray methods after 100 days of experiment

This situation of experimental solutions could have been the result of the usage of $CaCl_2$ which has good water preservation properties. As it has been mentioned above, humidity increases the corrosion rate of metals. NaCl:Safecote solution had the lowest impact on the tested metals and metal alloys. Due to good "Safecote" characteristics it helped to coat the metal with anticorrosion layer.

5. Conclusions

1. Metals could be serialized according to their resistance to corrosion by using spraying method: aluminium which losses average 0.8 mg mass, stainless steel – 1.4 mg, galvanized steel – 41.4 mg, carbon steel – 136.1 mg.
2. Metals could be serialized according to their resistance to corrosion by using immersion method: aluminium which losses average 0.42 mg mass, stainless steel – 0.92 mg, carbon steel – 48.1 mg, galvanized steel – 141.7 mg.
3. After the investigation of their corrosive impact on metals, chemical substances, used for road maintenance in winter season, could be placed into this order: $CaCl_2$ solution with the highest impact, NaCl, $NaCl:CaCl_2$, and NaCl:Safecote solution having the best anti-corrosive properties.
4. The most sensitive metal alloy to chloride attack is carbon steel. The second place takes galvanized steel. These two metal alloys have high amounts of carbon and iron which cause low resistance. Stainless steel and aluminium have the highest resistance to corrosion. Stainless steel contains 18 % of chromium and 10% of nickel which makes this metal alloy anti-corrosive. Aluminium has low iron amount (0.28%) and a trace of chromium (0.05 %) which also gives resistance to this metal.
5. According to the results of performed investigation, NaCl and "Safecote" mixed solution is recommended to use instead of NaCl, $CaCl_2$ and $NaCl:CaCl_2$ mixture solutions which have toxic effects on the environment since the "Safecote" mixture characterizes the lowest corrosive impact on experimental metal and metal alloys. What is more, this solution can minimize the concentration of released metal ions and prevent the soil and

water resources from contamination. In addition to this, it can prolong service time of road elements, increase safety and lower economic costs.

References

Ahmad, Z. 2006. *Principles of Corrosion Engineering and Corrosion Control*. Butterworth-Heinemann. 22 p. ISBN-13: 9780750659246.

Baltrėnas, P.; Kazlauskienė, A.; Zaveckytė, J. 2006. Experimental investigation into toxic impact of road maintenance salt on grass vegetation, *Journal of Environmental Engineering and Landscape Management* 14(2): 83–88.

Belghazi, A.; Bohm, S.; Sullivan, J. H.; Worsley, D. A. 2002. Zinc runoff from organically coated galvanised architectural steel, *Corrosion Science* 44: 1639–1653. doi:10.1016/S0010-938X(01)00176-7

Burtwell, M.; Wilson, M. 2004. *Safecote de-icer in UK Winter Maintenance*. Safeguarding winter travellers.

Cho, S. H.; Hur, J. M. Seo, C. S.; Park, S. W. 2008. High temperature corrosion of superalloys in a molten salt under an oxidizing atmosphere, *Journal of Alloys and Compounds* 452: 11–15. doi:10.1016/j.jallcom.2007.01.169

Christian, V. 2004. *Corrosion of Aluminum*. Elsevier Science. 177 p. ISBN-13: 9780080444956.

Dobrzański, L. A.; Brytan, Z.; Grande, M. A.; Rosso, M. 2007. Corrosion resistance of sintered duplex stainless steels in the salt fog spray test, *Journal of Materials Processing Technology* 192–193: 443–448. doi:10.1016/j.jmatprotec.2007.04.077

Glass, G. K.; Buenfeld, N. R. 2000. Chloride-induced corrosion of steel in concrete, *Prog. Struct. Engng Mater*. 2: 448–458. doi:10.1002/pse.54

Hääl, M.-L.; Sürje, P. 2006. Environmental problems related to winter traffic safety conditions, *The Baltic Journal of Road and Bridge Engineering* I(1): 45–53.

Jelisejevs, B.; Urbanovichs, V. 2007. *Environmental Aspects of Road de-icing Technologies*. Latvia. 11p.

Kasperovičius, V.; Oškinis, V. 2004. Žiemos metu kelių slidimui mažinti naudojamų cheminių medžiagų vertinimas, iš *7-osios Lietuvos jaunųjų mokslininkų konferencijos „Lietuva be mokslo – Lietuva be ateities", įvykusios Vilniuje 2004 m. kovo 25 d., pranešimų medžiaga.* Vilnius: Technika, 396–402.

Kazlauskienė, A.; Baltrėnas, P. 2004. Chloridų koncentracijos tyrimai sniego dangoje magistralės Kaunas–Zarasai pakelėse, iš *7-osios Lietuvos jaunųjų mokslininkų konferencijos „Lietuva be mokslo – Lietuva be ateities", įvykusios Vilniuje 2004 m. kovo 25 d., pranešimų medžiaga*. Vilnius: Technika, 347–354.

Kazlauskienė, A.; Baltrėnas, P. 2007. Trumpalaikiai kelių priežiūros druskos tirpalų ūminio toksiškumo vaivorykštiniam upėtakiui (Oncorhynchus Mykiss) tyrimai, iš *10-osios Lietuvos jaunųjų mokslininkų konferencijos „Mokslas – Lietuvos ateitis" medžiaga*, 2007 03 29. Vilnius: Technika, 130–134.

Mangold, T. 2000. *Road Salt Use for Winter Maintenance. A Review of Impacts, Alternatives, and Recommendations for the St. Paul Campus Stormwater Management Plan.* December 8. 19 p.

Mobin, M. 2008. Electrochemical studies on the corrosion behaviour of carbon steel in presence of Cu and Ni, *Portugaliae Electrochimica Acta* 26/5: 449–457.

Leinartas, K.; Gladkovas, M.; Valotkienė, R.; Virbalytė, D.; Juzeliūnas, E. 2002. Regularities of galvanic corrosion of the copper/stainless steel couple in Fe(III) environment, *Chemija* 13(4): 203–207

Oškinis, V.; Kasperovičius, T. 2005. Impact of road maintenance salts on water ecosystems according to Diatom flora investigation, *Journal of Environmental Engineering and Landscape Management* 13(1): 51–55.

Poszyler-Adamska, A.; Czerniak, A. 2007. Biological and chemical indication of roadside ecotone zones, *Journal of Environmental Engineering and Landscape Management* 15(2): 113a–118a.

Ratkevičiūtė, K.; Čygas, D.; Laurinavičius, A.; Mačiulis, A. 2007. Analysis and evaluation of the efficiency of road safety measures applied to Lithuanian roads, *The Baltic Journal of Road and Bridge Engineering* 2(2): 81–87.

Rimkus, A. 1999. Chloridų, naudojamų kelių dangų apledėjimui tirpinti, neigiamas poveikis. Inhibicija, *Aplinkos inžinerija* (Environmental Engineering) 7(2): 99–103.

Rosliza, R.; Wan Nik, W. B.; Senin, H. B. 2008. The effect of inhibitor on the corrosion of aluminum alloys in acidic solutions, *Materials Chemistry and Physics* 107: 281–288. doi:10.1016/j.matchemphys.2007.07.013

Sagues, A. 2001. *Metallurgical Effects on Chloride Ion Corrosion Threshold of Steel in Concrete*. Summary of Final Report, WPI#0510806, November 2001. 3 p.

Smith, J. L.; Virmani, Y. P. 2000. *Materials and Methods for Corrosion Control of Reinforced and Prestressed Concrete Structures in New Construction.* Reposrt No FHWA-RD-00-081, August 2000. 76 p.

Storpirštytė, I.; Kazlauskienė, A.; Ščupakas, D. 2004. Chloridų koncentracijos sniego dangoje intensyvaus eismo Lietuvos kelių pakelėse tyrimai, *Journal of Environmental Engineering and Landscape Management* 12(2): 60–66.

Zaveckytė, J.; Ščupakas, D. 2005. Druskų, skirtų kelių priežiūrai, poveikio augalijai analizė, iš *8-osios Lietuvos jaunųjų mokslininkų konferencijos „Lietuva be mokslo – Lietuva be ateities", įvykusios Vilniuje 2005 03 24, pranešimų medžiaga.* Vilnius: Technika, 303–308.

Žilionienė, D.; Laurinavičius, A. 2007. De-icing expierence in Lithuania, *The Baltic Journal of Road and Bridge Engineering* 2(2): 73–79.

Wilson, M. I.; Burtwell, M. H.; Zohrabi, A. 2002. *Assessment of Safecote de-icer Product: Phase 2.* PR/IS/13/02. 77 p.

Wallinder, I. O.; Leygraf, C. 2001. Seasonal variations in corrosion rate and runoff rate of copper roofs in an urban and a rural atmospheric environment, *Corrosion Science* 43: 2379–2396. doi:10.1016/S0010-938X(01)00021-X

Wallinder, I. O.; Leygraf, C.; Karlén, C.; Heijerick, D.; Janssen, C. R. 2001. Atmospheric corrosion of zinc-based materials: runoff rates, chemical speciation and ecotoxicity effects, *Corrosion Science* 43: 809–816. doi:10.1016/S0010-938X(00)00136-0

KELIŲ PRIEŽIŪRAI NAUDOJAMŲ DRUSKŲ IR MELASOS („*SAFECOTE*“) POVEIKIO METALŲ KOROZIJAI EKSPERIMENTINIAI TYRIMAI

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Santrauka

Tyrimų tikslas – taikant įmerkimo ir purškimo metodus įvertinti kelių priežiūrai žiemą naudojamų druskų ir melasos įtaką metalų korozijai. Metalinius tiltus, kelio ženklus, kitus metalinius kelio elementus bei mašinas žiemą veikia kelio priežiūrai (slydimui sumažinti) naudojamos druskos, vyksta korozija. NaCl, $CaCl_2$ bei NaCl ir $CaCl_2$ mišinys – dažniausiai Lietuvoje naudojamos druskos. Chloridai yra pagrindiniai koroziją sukeliantys ir metalų masę mažinantys jonai. Šis negatyvus chloridų poveikis gali būti sumažintas pakeitus kelių priežiūrai naudojamas druskas organinėmis cheminėmis medžiagomis ledui tirpinti, pvz., „Safecote“. Tai antrinis žemės ūkio produktas, gaunamas iš cukraus pramonės atliekų, dar vadinamas melasa.

Metalų ir jų lydinių masės mažėjimo tyrimas buvo atliekamas dviem būdais – įmerkimo ir purškimo. Pirmuoju atveju tiriamieji metalai įmerkiami į NaCl, $CaCl_2$, NaCl:$CaCl_2$ ir NaCl: „Safecote“ tirpalus, o antruoju atveju – metalai šiais tirpalais purškiami. Pagal eksperimentinių tyrimų rezultatus įrodyta, kad $CaCl_2$ tirpalas sukėlė didžiausią metalų koroziją, t. y. cinkuotoji skarda neteko 301,71±4,2 mg, anglinis plienas – 52,27±1,7 mg masės taikant įmerkimo metodą, o purškimo atveju aliuminis neteko 1,37±0,13 mg, cinkuotoji skarda – 51,79±0,9 mg, nerūdijantis plienas – 2,11±0,2 mg, o anglinis plienas – 266,58±2,5 mg masės. Remiantis atliktų eksperimentinių tyrimų rezultatais siūloma su kelių priežiūrai naudojamomis druskomis naudoti „Safecote“ tirpalą, kuris sumažina metalų koroziją.

Reikšminiai žodžiai: kelio priežiūra, druskos, natrio chloridas, kalcio chloridas, melasa, metalai, korozija, masės netekimas.

ЭКСПЕРИМЕНТАЛЬНОЕ ИССЛЕДОВАНИЕ КОРРОЗИОННОГО ВОЗДЕЙСТВИЯ НА МЕТАЛЛЫ СОЛЕЙ И МЕЛАССЫ (“SAFECOTE”), ПРИМЕНЯЕМЫХ ДЛЯ СОДЕРЖАНИЯ ДОРОГ

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Резюме

Целью исследования была оценка коррозионного воздействия солей и продукта “Safecote”, применяемых для содержания дорог в зимний период, на металлы.

Металлические мосты, дорожные знаки и другие металлические элементы, а также автомобили подвергаются воздействию солей, используемых для уменьшения скользкости дорог в зимний сезон. Чаще всего в Литве используются соли NaCl, $CaCl_2$, а также смесь NaCl и $CaCl_2$. Ионы хлорида являются основными агентами, способствующими коррозии металла и потерям их массы. Это вредное воздействие хлоридов может быть уменьшено путем замены солей, используемых для содержания дорог, органическими веществами для удаления льда, например, продуктом “Safecote” на основе мелассы, которая является побочным продуктом производства сахара.

Исследование потери массы металлов и их сплавов осуществлялось двумя методами – методом погружения и распыления. В первом случае исследуемые металлы погружались в растворы NaCl, $CaCl_2$, NaCl: $CaCl_2$ и NaCl:Safecote, а во втором – металлы подвергались распылению этими растворами.

Результаты эксперимента показали, что раствор $CaCl_2$ оказывает наибольший эффект на коррозию металлов. В случае применения метода погружения потеря массы из оцинкованной стали составила 301,71±4,2 мг, а массы из углеродистой стали – 52,27±1,7 мг. В случае применения метода распыления металлы также лишились массы: алюминий – 1,37±0,13 мг, оцинкованная сталь – 51,79±0,9 мг, нержавеющая сталь – 2,11±0,2 мг и углеродистая сталь – 266,58±2,5 мг. Результаты эксперимента показали, что соль, используемую для содержания дорог в зимний период, следует смешивать с продуктом “Safecote”, который уменьшает коррозию металлов.

Ключевые слова: соли для содержания дорог, хлорид натрия, хлорид кальция, меласса, металлы, коррозия, потеря массы.

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