СТРОИТЕЛЬСТВО И АРХИТЕКТУРА

DOI: 10.34031/2071-7318-2021-7-3-8-15

[1]Kozhukhova M.I., [1]Sobolev K.G., [2]Strokova V.V., [2,]*Kozhukhova N.I.
[1]University of Wisconsin-Milwaukee
[2]Belgorod State Technological University named after V.G. Shukhov
**E-mail: kozhuhovanata@yandex.ru*

USE OF PMHS-BASED HYDROPHOBIC COATINGS TO FIGHT SLIPPERY CONCRETE TRANSPORTATION INFRASTRUCTURE

Abstract. *The developed hydrophobic complex protective layer based on polymethylhydrosiloxane (PMHS) organosilicons on the top layer of the concrete surface along with hydrophobic characteristics and low ice adhesion strength enable to provide a developed surface roughness that is a direct measure of high traction forces between vehicle tires and road surface pavement, and its applicability in transport infrastructure as one of the inti-icing methods.*

Portland cement mortar samples treated with PMHS-based hydrophobic emulsion demonstrated very apparent hydrophobic and icephobic characteristics. The majority of the coated mortar samples reveal over- and superhydrophobicity.

Ice adhesion of the mortars with hydrophobic coatings was 10 times lower in comparison with the reference non-treated hydrophilic samples.

Keywords: *anti-icing methods, hydrophobic and icephobic characteristics, ice adhesion, concrete surface roughness.*

Introduction. According to statistical reports, the level of road traffic injuries in Russia exceeds all acceptable limits, and the fatality risk as a result of road traffic accidents on the territory of the Russian Federation is one of the highest in the world. About one hundred people die in Russia every day due to road traffic accidents. This is a high rate of accidents giving a relatively low car dependency in the country where the average number of cars per thousand people in Russia is three times less than in Europe and almost four times less than in the United States [1].

At the same time, the annual average number of road accidents with fatality cases due to icy conditions of roads in Russia reaches ten thousand, while in the United States this number would not exceed 480 deaths [2]. Plus, the number of those accidents that resulted in people's physical injuries and material damage is due to the car's loss of control on icy roads. Car accidents are caused due to multiple factors such as exceeding speed limits above 70 km/h on highways and two-lane roads in residential areas, a thin layer of invisible ice as well as intermittent areas of icing on the road pavements, winter precipitation such as snow, freezing rain, drizzle, fog, etc. Most of the road traffic fatalities and serious injuries occur in these conditions especially in the high-risk areas as depicted in Figure 1.

In search of the way to solve this problem on a global scale, many research studies have been conducted for more than a decade and resulted in various methods, materials, and technologies that are proposed to mitigate the issues related to icy slippery roads. The research studies focused on improving the anti-icing properties of a road surface have been conducted since the 70s of the XX century. Now, there established two fundamental methods for ice control, are physical and physical, and chemical methods. The physical method is based on the increase of anti-icing properties of a surface due to its treatment with various anti-icing compounds. The physical-and-chemical method considers the design of materials with anti-icing properties for building top protective layers of the road surface. Depending on the chosen approach to solve the problem, the research studies are being performed in the frame of one of the methods.

Among the most commonly applied solutions are the following:

Melting ice using heating devices. Despite the cost-effective benefits over mechanical deicing such as chopping off and breaking of ice crust, the method is very energy-intensive. This method of anti-ice control is actively used in factory areas, access roads, and residential areas [3, 4].

Introduction of chemical additives. Among the most common and effective methods of permanent action is the internal introduction of chemical additives which enable the increase of protective characteristics of portland cement concrete and other road surfaces, such as water repellence, frost resistance, and steel reinforcement corrosion control. These additives can be classified as follows:

- finely ground with hydraulic properties or properties of colloidal systems;

- salts of inorganic acids which accelerate the processes of hydration and structure formation of cement concrete;

- additives that increase the hydrophobicity of concrete road surfaces;

- polymer additives that polymerize in concrete [5].

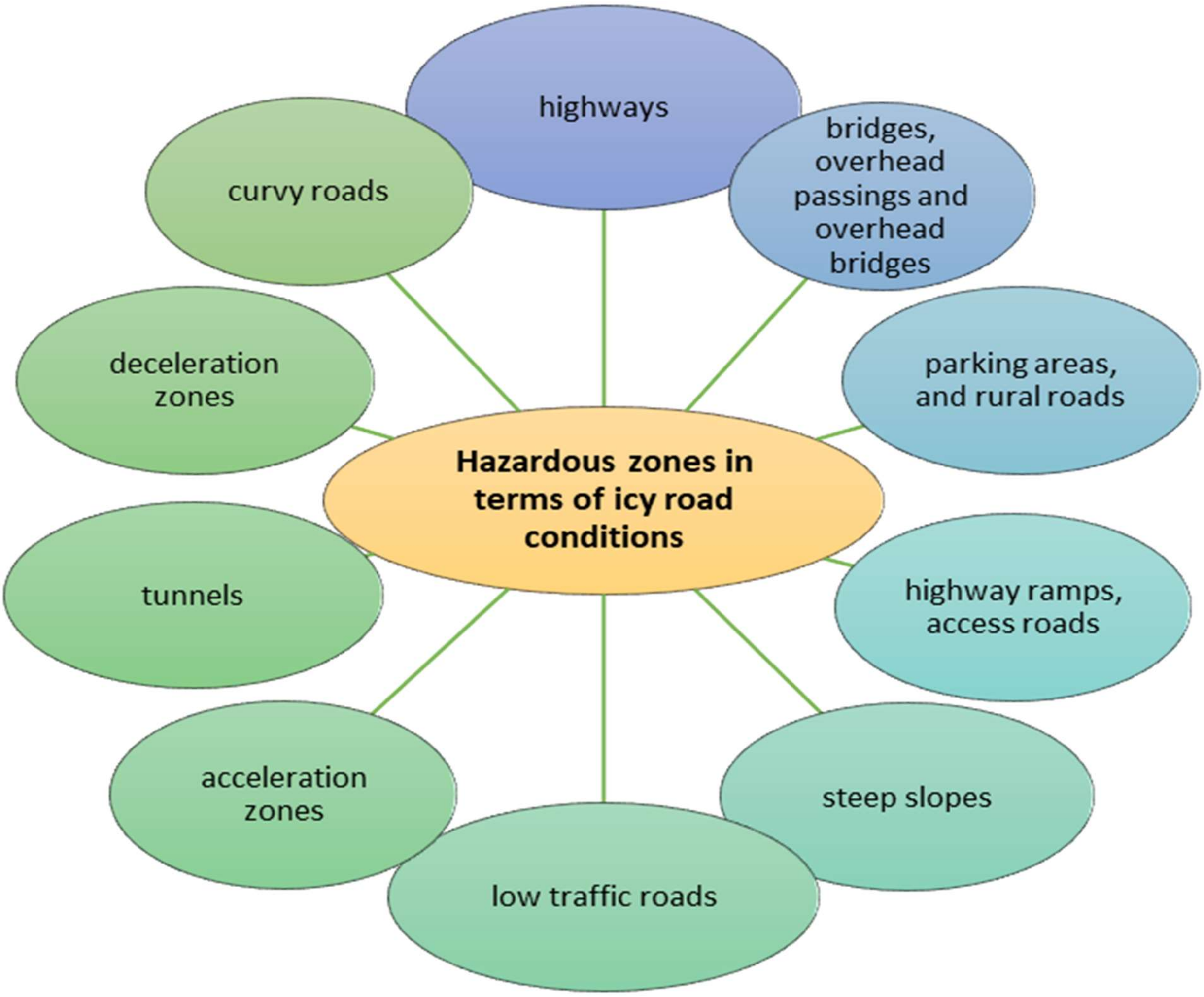

Fig. 1. The high-risk areas with icy road conditions

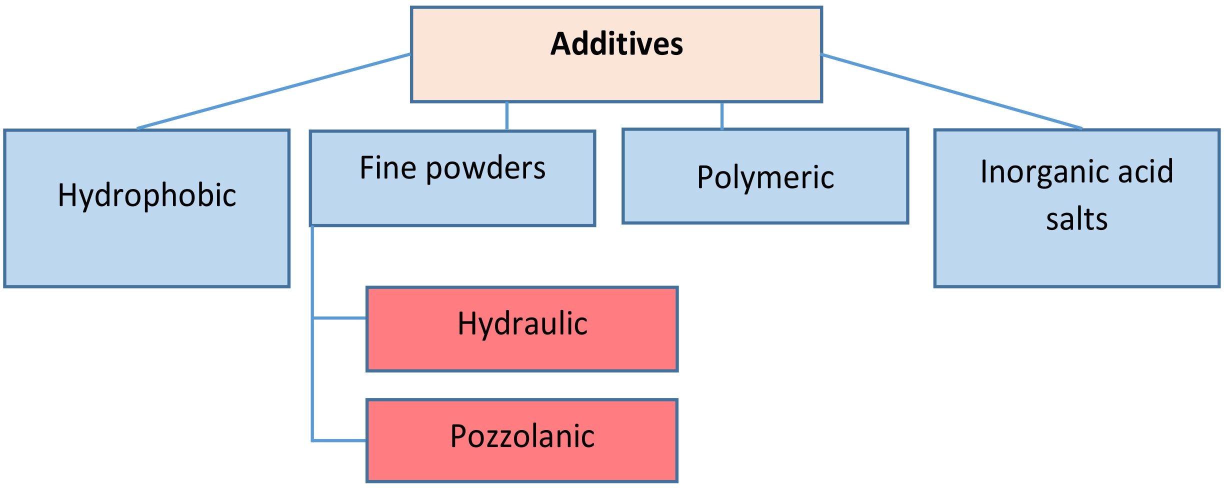

Fig. 2. Types of anti-icing additives

Use of anti-icing coatings. A group of scientists led by Sture Persson and Lars-Orff Anderson [6] suggested the application of vulcanized non-polar rubbers as anti-icing coatings, where the vulcanization agent consists of sulfur and/or components derived from sulfur or metal oxides. In this case, the anti-icing effect is achieved due to the high deformability of rubbers which do not allow the formation of ice crust when vehicles are in motion.

The application of pervious asphalt concrete which intended to quickly remove moisture from the pavement and, so reduce the chance for ice formation was one of the proposed technologies [7]. However, the European practice of 1995–96 showed that the technology did not perform as well as was hoped. On the contrary, the field demonstrations with pervious asphalt concrete resulted in the increase of maintenance costs during the winter season by 10–20 %, mainly due to the rapid removal of salts from the asphalt top layer and so, the increased demand for anti-icing agents.

Nowadays, physical-and-chemical method to prevent or remove ice formation has become more widely used. The method suggests making a hydrophobic coating on the surface of a material by introducing chemical additives which reveal water-repelling or hydrophobic properties.

In Switzerland, since 1974, field demonstrations have been carried out when in the composition of the top layer of fine-grained asphalt-concrete pavement was added 5 % of a special multicomponent anti-icing additive "Verglimit". The additive was composed of 80 % calcium chloride and 5 % sodium hydroxide as active agents [8, 9]. These pilot concrete pavements were placed in two areas, the carriageways and bridges in Switzerland, Austria, Germany, the USA, and France. The test results demonstrated significant benefits associated with maintenance labor and costs compared to conventional coatings. The pilot pavements had a reduced adhesion of snow and ice deposits to the applied anti-icing coating.

Earlier, the authors of this article proposed a complex coating based on PMHS compound applied over a specially engineered Portland cement concrete top layer that is enabled to provide superior hydrophobic properties to concrete surfaces [10–12]. Some wetting properties of the proposed complex hydrophobic coating such as contact angle and roll-off angle have been studied [12, 13].

The ice adhesion properties of the developed complex hydrophobic coatings were studied in this research work to evaluate icephobicity of the level of traction between vehicle tire and surface of concrete pavement as a factor of applicability of the proposed anti-icing method in concrete transportation infrastructure.

Materials and methods. Portland cement Type I supplied by LafargeHolcim (USA), as well as CEM I 42.5 N (Russia) were used to produce cement mortars as a top protective layer. Standard fractionated quartz sand with an average particle size of 425 microns and quartz sand from the Vyazemskoye deposit (Russia) was used as a fine aggregate to produce cement mortar samples. Polyvinyl alcohol (PVA) fibers with a diameter of 1 micron and length of 12 mm were used as a fibrous fine component to provide additional roughness on the surface of the cement mortars.

Polyvinyl alcohol in powder form (PVA) was used as an emulsifier for the production of hydrophobic oil in water emulsion. The procedure for emulsion preparation has been described in [10, 12].

Two analogous organosilicon compounds Polymethylhydrosiloxane produced by Dow Corning in the USA and by SIlan in Russia were used as active hydrophobic agents. Also, silica fume and metakaolin were used as fine mineral fillers in the hydrophobic emulsion. Wetting properties as well as icephobic (anti-icing) characteristics of the prepared mortar samples treated with the complex hydrophobic PMHS emulsion were evaluated by measuring contact angle and roll-off angle in the "water-solid-air" interface and the adhesion shear strength within the contact area of hydrophobic coating and ice using the goniometric system (Kruss DSA-100) and the force sensor PASCO CI-6746, respectively.

Experimental Results. In order to evaluate adhesion properties of a hydrophobic coating on the mortars surface to ice layer, the mortar samples treated with the developed complex hydrophobic PMHS emulsion were prepared, determined as optimal compositions based on the contact angle (CA) and the roll-off angle (ROA) test results [12–14]. To estimate the effectiveness of the complex hydrophobic PMHS coatings in assessing wetting properties, 30 mortar compositions were prepared with and without PVA fiber in the matrix as depicted in Table 1. The samples were divided into 3 series for further testing. Mortar samples from the first set were reference mortars (M1-M10). The second set of the samples was treated with the hydrophobic complex emulsion that contained 5 % PMHS as an active hydrophobic component (M1/5-M10/5) and the third set of the samples were treated with the emulsion containing 25 % of PMHS compound (M1/25-M10/25).

According to the previously obtained data [12, 13], the highest values of hydrophobicity were revealed by the mortars treated with a siloxane emulsion containing 5 % of the active PMHS hydrophobic component.

The contact angle values of water droplets on the surface of the mortar samples were in the range of 140–156° and that indicated over- and superhydrophobicity of the studied coatings.

Correlation between the wettability characteristics and the strength of ice adhesion on the surface of hydrophobic mortar samples.

To assess the icephobic characteristics of the developed hydrophobic protective layer of cement mortars, ten mixes of mortar compositions with and without PVA fibers were tested for ice adhesion strength to the surface of mortar samples by applying shear stress to an ice layer using the force sensor PASCO CI-67461 device, according to the method described in [15, 16]. The tests were performed for reference mortar samples, as well as those treated with 5 % and 25 % hydrophobic PMHS emulsion. The test results are graphically presented in Figure 3.

The shear stress data demonstrate a significant decrease in ice adhesion strength relative to the surface of mortar samples treated hydrophobic coating regardless of whether the samples contain PVA fibers or not. The ice strength adhesion for the mortar samples with coatings was 10 times lower than untreated reference mortar samples.

It should be noted that in the series of mortar samples treated with hydrophobic PMHS emulsion, the shear strength values were higher for the fiber-reinforced mortars in comparison with the non-reinforced samples and the difference between the values was 28 % and 2 % for the mortar samples treated with the emulsions containing 5 % and 25 % PMHS component, respectively. The higher values of ice adhesion observed for the fiber-reinforced mortars are justified by the greater roughness that PVA fibers have created on the surface of the mortar samples, with this creating topographical obstacle that requires greater stress to apply for ice to slide over the surface.

Table 1

Mix design and wetting properties of the mortars

Mortars ID	W/C ratio	C/S ratio	PVC fiber, %	Contact angle, degree	Roll-off angle, degree
M1	0.25	–	1	9	–
M2		1	1	12	–
M3		0.5	1	0	–
M4		0.4	1	0	–
M5		0.33	1	25	–
M6		–	–	13	–
M7		1	–	15	–
M8		0.5	–	1	–
M9		0.4	–	0	–
M10		0.33	–	0	–
M1/5		–	1	146	3
M2/5		1	1	148	2
M3/5		0.5	1	156	5
M4/5		0.4	1	131	8
M5/5		0.33	1	127	14
M6-5		–	–	146	8
M7/5		1	–	144	15
M8/5		0.5	–	146	21
M9/5		0.4	–	141	27
M10/5		0.33	–	139	35
M1/25		–	1	123	–
M2/25		1	1	119	–
M3/25		0.5	1	122	74
M4/25		0.4	1	121	57
M5/25		0.33	1	120	66
M6/25		–	–	116	61
M7/25		1	–	119	60
M8/25		0.5	–	125	62
M9/25		0.4	–	123	64
M10/25		0.33	–	122	68

For the mortar samples treated with the emulsion containing 25 % PMHS component, the ice adhesion values were lower by an average of 27 % vs the mortar samples coated with an emulsion containing 5 % PMHS.

Reduced ice adhesion to the coated top layer of the mortars, in this case, was the result of the thicker hydrophobic layer that the 25 % PMHS emulsion was enabled to create on the surface of mortar samples, thus covering and reducing it's natural and impregnated with PVA fibers roughness of the top mortar layer. This is a similar adhesion effect under shear forces as was observed earlier in this study for the fiber-reinforced and non-reinforced mortar samples, when the roughness of surfaces is much lower, that enables ice to slide much easier over the smooth hydrophobic surface under shear loading due to the minimal surface roughness. The less the surface roughness, the lower the traction forces between surfaces that arise under horizontal shear loads. Taking into account the applicability of these protective hydrophobic coatings for concrete in road construction, the surface roughness is a fundamental factor as it has a direct correlation to the degree of traction forces of a vehicle tire to the road surface in motion [13, 14]. In this regard, the lower roughness characteristics and lower ice adhesion strength values of the mortar samples treated with 25 % PMHS emulsion, having a smoother surface, will indicate lower traction forces of a vehicle tire against the road surface pavement.

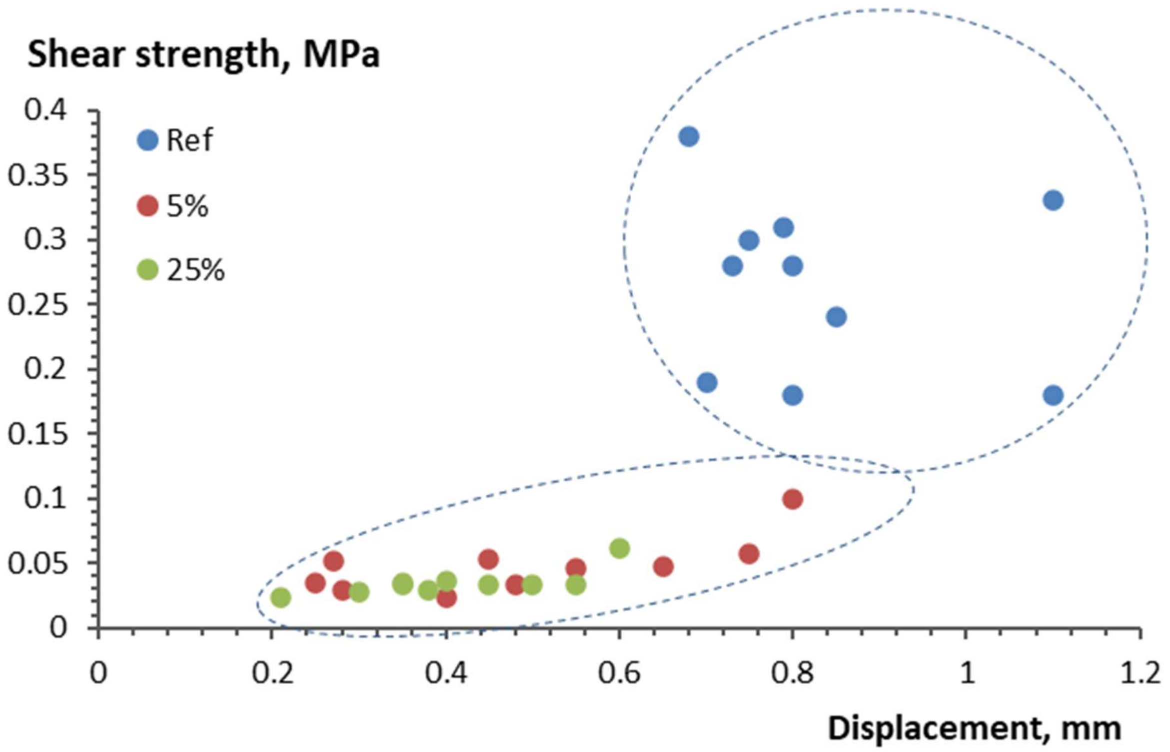

Fig. 3. Correlation between horizontal ice displacement over the surface of mortar samples and ice shear strength

At the same time, hydrophobic coatings produced by treatment of the mortar surface layer with 5 % PMHS emulsion provides low adhesion of ice crust on the protective hydrophobic surface of mortar samples, which enables an anti-icing (ice-phobic) effect. The developed complex hydrophobic coatings also retain a highly developed surface roughness and, so the higher traction forces between vehicle tires and road surface pavement, which defined their applicability in concrete transport infrastructure as one of the inti-icing methods.

Conclusions. The developed protective complex hydrophobic coating based on PMHS compounds for concrete surface application demonstrated the effectiveness in mitigating ice adhesion, which is a critical factor when applied to the safety of roadways in the winter season.

Mortar samples treated with hydrophobic PMHS emulsion demonstrated very apparent hydrophobic and icephobic characteristics. The majority of the coated mortar samples reveal over- and superhydrophobicity.

Ice adhesion of the mortars with hydrophobic coatings was 10 times lower in comparison with the reference non-treated hydrophilic mortar samples.

Samples reinforced with PVA fibers and treated with 5 % PMHS hydrophobic coatings demonstrated a good balance of high hydrophobicity and low ice adhesion to the mortar surface layer while retaining moderate traction forces when horizontal shear loads were applied.

Mortar samples, with and without PVA fiber-reinforcement treated with 25 % PMHS hydrophobic emulsion showed minimal ice adhesion values and minimal traction effect, while the hydrophobic characteristics were 15–20 % lower than those for the mortar samples treated with 5 % PMHS emulsion.

Funding. *This work was realized in the framework of the implementation of the Scholarship of the President of the Russian Federation. The work was realized using equipment of High Technology Center at BSTU named after V. G. Shukhov.*

REFERENCES

1. Analytical review "Comparative analysis of accidents on the roads of Russia and the United States." [Analiticheskiy obzor «Sravnitel'nyy analiz proisshestviy na dorogakh Rossii i SSHA»]. Moscow: Interregional Community Center 2007. 12 p.
2. Icy Road Safety. URL: www.icyroad-safety.com (date of treatment: 03/15/2014).
3. Methods for protecting roads from icing [Metody zashchity dorog ot obledeneniya]. URL: http //www.vinokna.ru/stat/1766_stat.html. (date of treatment: 20.02.2014). (rus)
4. Blackburn R.R., Bauer K.M., Amsler D.E., Boselly S.E., McElroy A.D. Snow and Ice Control: Guidelines for Materials and Methods. NCHRP REPORT 526. Transportation Research Board, 2004.
5. Doroshenko Yu.M., Doroshenko A.Yu. Organosilicon additives - effective modifiers of cement concrete for road surfacing [Kremniyorganicheskiye dobavki - effektivnyye modifikatory tsementobetona dlya dorozhnykh pokrytiy]. Concrete and reinforced concrete. 2013. No. 1(8). Pp. 56–60. (rus)
6. Sture Persson, Lars – Orff Anderson. Anti-icing coating. Patent No 2086601. MPK C 09 K 3/18, 1997. No. 22.
7. Verburg D.J. Voorkomen is beter dan gemzen. Otar. 1997. Vol. 82. No. 9. Pp. 322–323.
8. Anti-icing of road surfaces in winter. Construction and operation of roads: Foreign experience [Bor'ba s obledeneniyem pokrytiya dorog v zimneye vremya. Stroitel'stvo i ekspluatatsiya dorog: Zarubezhnyy opyt]. Moscow: Express information TsBNTI of the Ministry of Avtodor of the RSFSR, 1981. Issue No 2. Pp. 8–10. (rus)
9. Dupuis I., Hussain N. Glatteishemmender Strassenbelag anf der Umfahrungsstrasse von Valangin. Strasse und Verkehr. 1977. Vol. 63. No 4.
10. Kozhukhova M.I., Flores-Vivian I., Rao S., Strokova V.V., Sobolev K.G. Complex siloxane coating for superhydrophobization of concrete surfaces [Kompleksnoye siloksanovoye pokrytiye dlya supergidrofobizatsii betonnykh poverkhnostey]. Stroitel`nye Materialy. 2014. No. 3. Pp. 26–30. (rus)
11. Hejazi V., Sobolev K., Nosonovsky M. From superhydrophobicity to icephobicity: forces and interaction analysis. Scientific reports. 2013.Vol. 3(1). Pp 1-6.
12. Flores-Vivian I., Hejazi V., Kozhukhova M.I, Nosonovsky M., Sobolev K. Self-assembling particle-siloxane coatings for superhydrophobic concrete. ACS Applied Materials & Interfaces. 2013.Vol. 5(24). Pp 13284-13294.
13. Kozhukhova M.I., Strokova V.V., Sobolev K.S. Features of hydrophobization of fine-grained concrete surfaces [Osobennosti gidrofobizatsii melkozernistykh betonnykh poverkhnostey]. Bulletin of STU named after V.G. Shukhov. 2014. No 4. Pp. 33-35.
14. Sobolev K., Nosonovsky M., Krupenkin T., Flores-Vivian I., Rao S., Kozhukhova M., Hejazi V., Muzenski S., Bosch B., Rivero R. Anti-Icing and De-Icing Superhydrophobic Concrete to Improve the Safety on Critical Elements on Roadway Pavements. CFIRE report, 2013. 54 p.
15. Lanka S., Alexandrova E., Kozhukhova M., Hasan M.S., Nosonovsky M., Sobolev K. Tribological and wetting properties of TiO_2 based hydrophobic coatings for ceramics. Journal of Tribology. 2019.Vol. 141(10) No. 101301 https://doi.org/10.1115/1.4044178
16. Ramachandran R., Kozhukhova M., Sobolev K., Nosonovsky M. Anti-icing superhydrophobic surfaces: Controlling entropic molecular interactions to design novel icephobic concrete. Entropy. 2016. Vol. 18(4). No 132. https://doi.org/10.3390/e18040132

Информация об авторах

Kozhukhova, Marina I. PhD, Adjunct Professor at University of Wisconsin-Milwaukee, Department of Civil&Environmental Engineering. E-mail: kozhuhovamarina@yandex.ru. University of Wisconsin-Milwaukee. 3200 N Cramer Street, Milwaukee, WI 53211, USA.

Sobolev, Konstantin G. PhD, Professor at University of Wisconsin-Milwaukee, Department of Civil&Environmental Engineering. E-mail: k.sobolev@gmail.com. University of Wisconsin-Milwaukee. 3200 N Cramer Street, Milwaukee, WI 53211, USA.

Strokova, Valeria V. PhD, Professor, Department of Material Science and Material Technology. E-mail: vvstrokova@gmail.com. Belgorod State Technological University named after V.G. Shukhov. Russia, 308012, Belgorod, Kostukov St., 46.

Kozhukhova, Natalia I. PhD, assistant professor, Department of Material Science and Material Technology. E-mail: kozhuhovanata@yandex.ru. Belgorod State Technological University named after V.G. Shukhov. Russia, 308012, Belgorod, Kostukov St., 46.

Received 16.12.2021

[1]Кожухова М.И., [1]Соболев К.Г., [2]Строкова В.В., [2,]*Кожухова Н.И.
[1]Университет Висконсин-Милуоки
[2]Белгородский государственный технологический университет им. В.Г. Шухова
**E-mail: kozhuhovanata@yandex.ru*

ПРИМЕНЕНИЕ ГИДРОФОБНЫХ ПОКРЫТИЙ НА ОСНОВЕ ПМГС ДЛЯ БЕТОНА ПРИ БОРЬБЕ С ОБЛЕДЕНЕНИЕМ В ДОРОЖНО-ТРАНСПОРТНОЙ ИНФРАСТРУКТУРЕ

Аннотация. *Разработанное гидрофобное комплексное защитное покрытие на основе кремнийорганических соединений полиметилгидросилоксана (ПМГС), используемое в качестве поверхностного слоя для цементобетона обладает не только гидрофобными и льдофобными характеристиками, но также позволяет обеспечить развитую шероховатость поверхности, которая является основным показателем высоких значений силы сцепления между шинами автомобиля и верхним слоем дорожного покрытия. Это объясняет эффективность его применения в транспортной инфраструктуре как один из методов борьбы с обледенением. Образцы цементобетонной растворной смеси, обработанные гидрофобной эмульсией на основе ПМГС, продемонстрировали довольно высокие гидрофобные и льдофобные характеристики. Большинство образцов цементобетонных растворов с защитным покрытием проявляют сверх- и супергидрофобность.*

Выявлено, что адгезия льда к цементобетонной поверхности с гидрофобным покрытием демонстрирует показатели в 10 раз ниже по сравнению с аналогичными значениями для эталонных необработанных образцов с гидрофильными свойствами.

Ключевые слова*: методы защиты от обледенения, гидрофобные и льдофобные характеристики, ледяная адгезия, шероховатость бетонной поверхности*

БИБЛИОГРАФИЧЕСКИЙ СПИСОК

1. Аналитический обзор «Сравнительный анализ происшествий на дорогах России и США». Москва: Межрегиональный общественный Центр, 2007. 12 с.
2. Icy Road Safety [Электронный ресурс]. URL: www.icyroadsafety.com (дата обращения:15.03.2014)
3. Методы защиты дорог от обледенения [Электронный ресурс]. URL: http //www.vinokna.ru/stat/1766_stat.html. (дата обращения: 20.02.2014).
4. Robert R. Blackburn, Karin M. Bauer, Duane E. Amsler, S. Edward Boselly, Dean McElroy A. Snow and Ice Control: Guidelines for Materials and Methods. NCHRP REPORT 526. Transportation Research Board, 2004.
5. Дорошенко Ю.М., Дорошенко А.Ю., Кремнийорганические добавки – эффективные модификаторы цементного бетона покрытия дорог // Бетон и железобетон. 2013. № 1(8). С. 56–60
6. Пат. 2086601, ФРГ, МПК C 09 K 3/18. Противообледенительное покрытие / Стуре Перссон, Ларс–Орф Андерсон; заявитель и патентобладатель Скега Актиеболаг. № 5052955/04; заявл. 1991.11.15; опубл. 1997.08.10, № 22
7. Verburg D.J. Voorkomen is beter dan gemzen // Otar. 1997. Vol. 82. № 9. Pp. 322–323.
8. Борьба с обледенением покрытия дорог в зимнее время. Строительство и эксплуатация дорог: Зарубежный опыт. М.: Экспресс информация ЦБНТИ Минавтодора РСФСР.1981. Вып. № 2. С. 8–10.
9. Dupuis I., Hussain N. Glatteishemmender Strassenbelag anf der Umfahrungsstrasse von Valangin // Strasse und Verkehr. 1977. Vol. 63. № 4.
10. Кожухова М.И., Флорес-Вивиан И., Рао С., Строкова В.В., Соболев К.Г. Комплексное силоксановое покрытие для супергидрофобизации бетонных поверхностей // Строительные материалы. 2014. № 3. С. 26–30.
11. Hejazi V., Sobolev K., Nosonovsky M. From superhydrophobicity to icephobicity: forces and interaction analysis // Scientific reports. 2013. Vol 3(1). Pp. 1–6.
12. Flores-Vivian I., Hejazi V., Kozhukhova M.I, Nosonovsky M., Sobolev K. Self-assembling particle-siloxane coatings for superhydrophobic concrete // ACS Applied Materials & Interfaces. 2013. Vol 5(24). Pp. 13284–13294.
13. Кожухова М.И., Строкова В.В., Соболев К.С. Особенности гидрофобизации мелкозернистых бетонных поверхностей // БГТУ им. В.Г. Шухова. 2014. № 4. С. 33–35.
14. Sobolev K., Nosonovsky M., Krupenkin T., Flores-Vivian I., Rao S., Kozhukhova M., Hejazi V., Muzenski S., Bosch B., Rivero R. Anti-Icing and De-Icing Superhydrophobic Concrete to Improve the Safety on Critical Elements on Roadway Pavements. CFIRE report, 2013. 54 pp.

15. Lanka S., Alexandrova E., Kozhukhova M., Hasan M.S., Nosonovsky M., Sobolev K. Tribological and wetting properties of TiO_2 based hydrophobic coatings for ceramics // Journal of Tribology. 2019. Vol. 141(10). № 101301 https://doi.org/10.1115/1.4044178

16. Ramachandran R., Kozhukhova M., Sobolev K., Nosonovsky M. Anti-icing superhydrophobic surfaces: Controlling entropic molecular interactions to design novel icephobic concrete // Entropy. 2016. Vol. 18(4). № 132 https://doi.org/10.3390/e18040132

Information about the authors
Кожухова Марина Ивановна, кандидат технических наук, адьюнкт профессор Университета Висконсин-Милуоки; кафедра гражданского строительства и охраны окружающей среды; кафедра инжиниринга и математических наук. E-mail: kozhuhovamarina@yandex.ru. Университет Висконсин-Милуоки, штат Висконсин. P.O. Box 413, Милуоки, WI 53201, США.

Соболев Константин Геннадьевич, PhD, профессор, Университет Висконсин-Милуоки; кафедра гражданского строительства и охраны окружающей среды; Университет Висконсин-Милуоки, штат Висконсин, США. E-mail: k.sobolev@gmail.com. Университет Висконсин-Милуоки, штат Висконсин. P.O. Box 413, Милуоки, WI 53201, США.

Строкова Валерия Валерьевна, доктор технических наук, профессор, кафедра материаловедения и технологии материалов. E-mail: vvstrokova@gmail.com. Белгородский государственный технологический университет им. В.Г. Шухова. Россия, 308012, Белгород, ул. Костюкова, д. 46.

Кожухова Наталья Ивановна, кандидат технических наук, доцент, кафедра материаловедения и технологии материалов. E-mail: kozhuhovanata@yandex.ru. Белгородский государственный технологический университет им. В.Г. Шухова. Россия, 308012, Белгород, ул. Костюкова, д. 46.

Поступила 16.12.2021 г.

Для цитирования:
Кожухова М.И., Соболев К.Г., Строкова В.В., Кожухова Н.И. Применение гидрофобных покрытий на основе ПМГС для бетона при борьбе с обледенением в дорожно-транспортной инфраструктуре // Вестник БГТУ им. В.Г. Шухова. 2022. № 3. С. 8–15. DOI: 10.34031/2071-7318-2021-7-3-8-15

For citation:
Kozhukhova M.I., Sobolev K.G., Strokova V.V., Kozhukhova N.I. Use of PMHS-based hydrophobic coatings to fight slippery concrete transportation infrastructure. Bulletin of BSTU named after V.G. Shukhov. 2022. No. 2. Pp. 8–15. DOI: 10.34031/2071-7318-2021-7-3-8-15