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EVALUATION OF THE FUNCTIONALITY OF MINERAL-RESIN PAVEMENT

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Abstract. Due to climate change and the recent increase in the number of floods in urbanized areas, there is a growing need for the introduction of new technologies into the road material market. One such technology is water-permeable mineral-resin surfaces, which are becoming increasingly popular. However, due to a lack of clear requirements and solution approval procedures, they are not commonly used in public investments. This paper first describes the materials used for preparing surface samples, including bulk density and granulometric aggregate tests, consistency, colour, and density at 20 °C testing of the hardener and resin. It then outlines the process of sample preparation and provides a brief description of the materials used. The tests conducted on the prepared material samples included flexural and compressive strength tests, frost resistance tests under normal conditions and in the presence of salts, and skid resistance tests. Based on the results obtained, it can be generally concluded that, in the case of permeable surfaces, the type of aggregate is an important factor, as evidenced by the results of the strength tests. The same can be stated about the influence of atmospheric factors. Tests conducted with granite aggregate proved to be more resistant to cyclically changing temperatures, even in the presence of salt.

Keywords: aggregate, compressive strength, flexural strength, frost resistance, mineral-resin pavement, skid resistance, water permeable surfaces.

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Introduction

Sealing of spaces in cities and the resulting limitation of green areas lead to recurrent flooding from rainwater and snowmelt in urbanized regions, particularly affecting housing estates and communication routes. Impermeable surfaces obstruct natural infiltration, necessitating the redirection of rainwater to sewage systems or artificial receivers (Siedlecka & Suchocka, 2017). With advancements in technology, road construction is introducing innovative materials designed to enhance rainwater drainage systems by prioritizing sustainability and environmental protection (Cai et al., 2020; Radziszewski et al., 2016; Sha et al., 2021).

The hardening and sealing of urban surfaces, coupled with the gradual reduction of green spaces, have led to issues regarding rainwater and snowmelt accumulation (Kriech & Osborn, 2022). It is evident that conventional rainwater and combined sewer systems struggle to manage periodic high water volumes, resulting in flooding of roads, buildings, or entire sections of towns and cities. Additionally, increased surface runoff and the removal of rainwater from urban spaces hinder groundwater replenishment and contribute to the desiccation of these areas, disrupting the natural water circulation balance in the environment. Transforming or replacing conventional road surface construction methods with solutions enabling sustainable rainwater management appears to be an effective strategy (Ciriminna et al., 2022; Diyora et al., 2019). This research discusses some of the most popular innovative technical solutions for this purpose, including water-permeable surfaces suitable for pedestrian and cycle paths, streets, and squares, aimed at improving water management systems in urban areas (Eisenberg et al., 2015; Scholz & Grabowiecki, 2007).

One example of such technology is porous asphalt, known for its high water flow rate and better resistance to weather conditions, albeit with lower strength suitable only for light-duty facilities (Hashim et al., 2021; Zhang & Kevern, 2021). Studies often focus on enhancing porous asphalt properties by adding polymers, fly ash, hydrated clay, or various fibres to the asphalt mixture, with promising results particularly in strength improvement when fly ash is added (Pradoto et al., 2019; Slebi-Acevedo et al., 2023). However, the aesthetic impact of black asphalt may not be suitable for parks or recreational areas. Porous concrete, another permeable pavement material, addresses environmental concerns such as limiting runoff, improving groundwater quality, mitigating the heat island effect, reducing noise, and enhancing slip resistance (Xie et al., 2019). Though the high porosity of concrete reduces its mechanical properties, the use of appropriate aggregate sizes can improve drainage and resistance to freezing and thawing cycles (Adresi et al., 2023). Recycled glass, as an innovative material for permeable surfaces, demonstrates environmental benefits without negative impacts (Perera et al., 2021). Recycled glass porous pavement, apart from being recycled, does not have a negative impact on the environment (Disfani et al., 2012). Yet another example is permeable concrete, but made of recycled concrete aggregate and the addition of waste glass cullet (Lu et al., 2019).

Another innovative system is mineral-resin pavement, which effectively absorbs rainwater, preventing uncontrolled floods, while blending naturally with green areas. Utilising high-quality natural materials renders mineral-resin surfaces environmentally friendly, weather-resistant, non-crumbly, and abrasion-resistant, providing a smooth, stable surface with low slip risk and minimal maintenance requirements, thus reducing implementation costs (Xiang & Xiao, 2020). These solutions can also be effectively employed in the adaptation and replacement of surfaces in historic parks and public gardens, aligning with modern requirements while preserving historical characteristics (Kimic, 2017). Examples include their successful integration in the revitalization of various public gardens with a rich heritage, such as Public Park Ujazdowki and Krasinskich garden in Warsaw, and Saski garden, among others.

Furthermore, there is significant potential in utilising various types of aggregate for the preparation of mineral-resin pavements. One aspect involves the utilization of leftovers from road works and construction waste, such as stones or tiles, which can be crushed into the required fraction, tested, and, if results are positive, used for further production. This practice helps reduce environmental pollution stemming from the civil industry (Krzywiński et al., 2021).

However, the lack of official requirements for the properties of road wear layers or specifications for materials used in the production of such pavement elements has hindered the widespread adoption of this new material, despite its valuable features. Developing a detailed and straightforward plan for testing the materials used in preparation, as well as a research strategy for the final product, could lead to broader adoption of these innovative technologies in the market. This, in turn, could enhance the level of infrastructure comfort and overall quality (Bin et al., 2021; Muttuvelu et al., 2022).

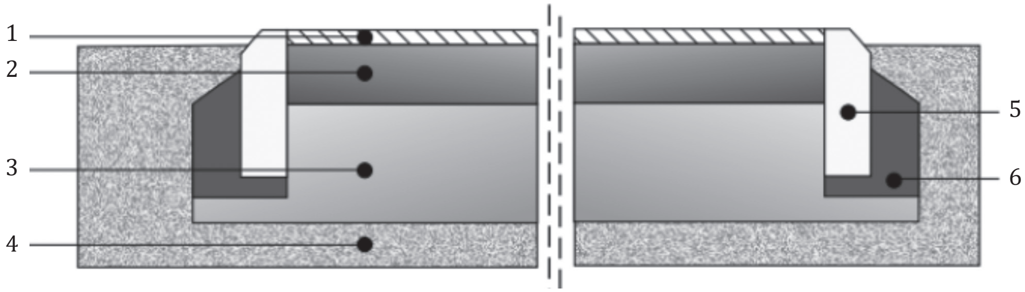
This research paper aims to formulate such a testing plan, making it easy and straightforward to assess whether aggregate can be used for the production of mineral-resin pavements by evaluating its basic parameters and the qualities of samples derived from it.

1. Mineral – resin water permeable surfaces

A well-constructed road can serve for many years, consisting of multiple layers with the primary task of absorbing stresses to provide road users with a comfortable ride. Depending on the type of road, various materials are used for these layers, including soil, aggregate, binder-enhanced materials, paved surfaces, bituminous materials, and concrete (Bean et al., 2019).

Mineral-resin water-permeable surfaces resemble smooth gravel road finishes, composed of natural aggregate such as grit or gravel bound together with a small amount of epoxy resin. This polyurethane binder, stored in two components, is mixed proportionally using a mechanical mixer, resulting in solidification. The mixture is then combined with selected aggregate and poured onto a prepared substrate. The setting time, approximately 8 h at an ambient temperature of at least 15 °C, allows the surface to be fully loaded after 1–3 days. Rare damage can be repaired by cutting out the damaged section with a diamond blade cutter and filling it with a new mixture. Epoxy resin is non-toxic and recyclable (Siedlecka & Suchocka, 2017).

Mineral-resin surfacing exhibits exceptional usage characteristics and high water permeability, allowing rainwater to flow freely through subsequent layers to the ground, aiding flood protection during inundation events. Additionally, its production uses natural materials, reducing transport pollution, and its natural appearance blends well with green and monumental areas, adaptable to different shapes and slopes to accommodate existing topography.



1 – Mineral-resin stonne water permeable surface 2.5 mm
2 – Srushed aggregate min 10 cm
3 – Sand (drainage layer) 10–20 cm
4 – Native ground
5 – Concrete edging 6×25×100 cm laid with bevel outside
6 – Concrete C12/15

Figure 1. Cross section of typical pavement layers solution for mineral – resin surface application (Krajewski-Wieczorek, 2020)

Suitable for light traffic, such as scooters, cars, and bikes, mineral-resin surfaces find application in urban parks, leisure and recreation areas, parking spaces, and more, due to their high load-bearing capacity and resistance to shear forces, ensuring functionality, durability, and resistance to mechanical damage.

Additional advantages of the surface include UV stability, non-yellowing resin, resistance to water, oil, acid, heat, and cold, a natural appearance due to the usage of stone materials, potential use of recycled aggregates to reduce construction waste, high slip resistance, low maintenance requiring only occasional washing with water, and a wide range of available colours due to the variety of aggregates that can be used (Gardziejczyk, 2018).

Despite these advantages, the production technology for mineral-resin surfaces is relatively complex, requiring precise measurement of ingredients to avoid poor-quality results. Additionally, production is limited to summer due to temperature requirements and cannot proceed during rainy days, necessitating additional costs for site covering and protection from humidity.

Architectural solutions using this technology, such as park paths, cycle paths, and driveways for the disabled, do not require longitudinal or transverse inclination, as the surface itself allows water to flow easily in all directions. To facilitate water permeation into the ground, a minimum of two layers of substructure in a specific order and thickness is required, with the first layer comprising compacted excavated sand (a drainage layer) and the second layer comprising clinker (crushed stone) of specific grain sizes, also compacted (Figure 1).

2. Materials used to prepare samples of mineral-resin surfaces and research methods

For the research, two types of aggregate were selected:

- Aggregate no. 1: Grey granite with a fraction of 2–5 mm;
- Aggregate no. 2: Coarse marble gravel (white grit) with a fraction of 2–4 mm.

The results of the granulometric analysis allowed us to determine if the chosen aggregate fractions were suitable for use in the production of mineral-resin surfaces. In both cases, the aggregate grain size fell within the range of 2 to 5 mm, indicating their suitability for further research. Aggregate no. 1 had a fraction range of 2 to 5 mm, while aggregate no. 2 was mostly within the 2–4 mm range (Figure 2). Granulometric analysis also provided information about the presence of silt fraction in the aggregate. In both cases, the silt fraction was less than 0.01%, indicating that the aggregates could be used (Table 1).

The maximum grain size of the aggregate incorporated into the wearing course significantly affects the rolling noise of motor vehicles. This applies to both compact and semi-open textured layers, as well as porous pavements. Studies have shown that increasing the maximum aggregate grain size by 1 mm increases the noise level by between 0.25 dB and 1.03 dB. Furthermore, this effect depends on the technology used to construct the wearing course, the length of service life, and the technical condition of the pavement (Gardziejczyk, 2018; Jaskula et al., 2020).

The determination of bulk density in the loose and compacted states is applicable to construction aggregates with grain sizes up to 63 mm and is conducted according to PN - EN 1097-6 (2022). Checking

Table 1. Granulometric test results

	Aggregate no. 1	**Aggregate no. 2**
Granularity of the stone fraction, %	0.0%	0.0%
Granularity of the gravel fraction, %	95.8%	93.8%
Granularity of the sand fraction, %	4.2%	6.2%
Granularity of the silt - clay fraction, %	0.0%	0.0%
The uniformity coefficient, U	1.85	1.78

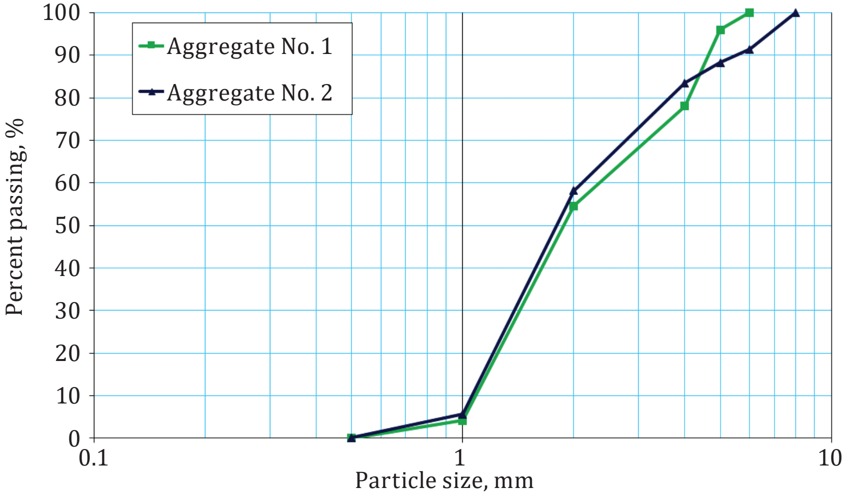


Figure 2. The curves of grain composition

the density of the aggregate is crucial as the obtained information is necessary for selecting the right proportions of ingredients for the surface material mixture. In this research, the bulk density in the loose and compacted states is presented as the arithmetic mean of three values rounded off to two decimal places. The results of the conducted tests are outlined in Table 2. The producer of epoxy resin recommends using aggregate with a compact bulk density of at least 1.4 g/cm^3, as those below this limit may not achieve the required strength parameters. After the tests conducted, it can be confirmed that both chosen aggregates are suitable for the preparation of mineral-resin surfaces.

Before mixing the liquid ingredients of the mixture (resin and hardener), they should be visually inspected for the presence of air voids, any solid pieces inside the bottles, and the colour of the extracts themselves. According to the manufacturer's description, the resin should have a light yellow colour, and the hardener should be transparent; both should be in a liquid state to permit easy mixing (Table 2). For resin and hardener, density should be checked according to PN - EN ISO 2811-1 (2023). This part of ISO outlines the method for determining the density of paints, varnishes, and similar products using the Gay-Lussac metal pycnometer. The application of this method is limited to products with low or medium viscosity at the test temperature.

A mineral-resin mixture comprises resin (component A), hardener (component B), and aggregate (component C). The mortar is prepared by blending these components in precise proportions. Initially, components A and B should be mixed together using a hand-held ribbon mixer for 3 min. It is important to avoid introducing air into the product by mixing too vigorously. In the subsequent step, component C should be added. The final surface quality depends on thorough mixing of the binder with the aggregate. Once mixing is complete, the ready material should be placed in prepared sample moulds. For the research, sample moulds measuring 160×40×40 mm were utilised (Figure 3).

Table 2. Results of all the tests of surface ingredients

	Resin	Hardener	Aggregate no. 1	Aggregate no. 2
Colour	yellow	transparent	grey	white
Consistency	liquid	liquid	loose	loose
Density at 20 °C, g/cm^3	1.15	1.02	–	–
Loose bulk density, g/cm^3	–	–	1.35	1.18
Compact bulk density, g/cm^3	–	–	2.32	1.40

It is crucial to maintain all the specified conditions unchanged throughout the entire process of sample hardening, as any changes in temperature or air humidity can result in failure during sample preparation.

The following laboratory tests were carried out on the samples:

– Flexural and compressive strength tests;
– Frost resistance test in normal conditions;
– Frost resistance test in the presence of salt;
– Skid resistance test.

Flexural and compressive strength of the prepared samples should be determined according to PN - EN 1015-11 (2020). The bending strength of the beams was determined by loading them at three points until failure. Before placing the specimens in the testing machine, the surface was cleaned of any loose grains and dust. The specimens were then positioned in the testing machine on two supports (100 mm apart) in a simply supported beam configuration and loaded until failure with a concentrated force applied symmetrically at mid-span between the supports. The process of conducting the flexural strength test for the sample made with aggregate no. 1 is depicted in Figure 4. Subsequently,


a) with aggregate no. 1
b) with aggregate no. 2

Figure 3. Drying process of prepared samples

the compressive strength test was carried out using the six specimens left from the flexural strength test. The test involved placing the specimens between the plates of the testing machine and gradually and uniformly loading them axially. Testing was performed after 24 h, 7 days, and 28 days of placing the mortar in the sample forms.

Frost resistance is a critical property for pavement materials, significantly impacting the durability of constructed surfaces. In winter months, frequent temperature fluctuations caused by alternating influences of humid, warm air from the Atlantic and dry continental air result in multiple cycles of ice thawing and refreezing within the free spaces between pavement aggregates. It is estimated that Poland experiences an average of around 100 days per year with temperatures below 0 °C, although this number can vary considerably in certain winters.

Resin pavements are particularly vulnerable to de-icing agents like salt (NaCl), commonly used during winter. These agents accelerate pavement degradation in low-temperature conditions, leading to surface exfoliation. It has been suggested that the corrosion rate can increase four or fivefold in the presence of salt compared to normal conditions. Overall, it effectively conveys the impact of frost and de-icing agents on pavement materials.

Figure 4. Flexural test of sample made with aggregate no. 1

Due to the absence of official requirements for determining the frost resistance of mineral-resin surfaces, PN-B-06265 (2022) was chosen owing to its similarity to concrete. Frost resistance testing is classified as destructive and should follow the determination of basic physical properties of the samples.

According to the national supplement to standard PN-EN 206+A2 (2021), frost resistance evaluation should be conducted under normal conditions and in the presence of salts. This standard specifies the number of freeze-thaw cycles based on the intended use of the samples.

Compliance with PN-EN 12371 (2010) allows for two methods to determine frost resistance of natural stone materials: technological and mass change identification methods. The technological method assesses the impact of freezing-thawing process on selected resistance properties, such as flexural and compressive strength, while the identification method measures sample mass before and after frost resistance testing to calculate mass loss. Visual assessment of sample changes is also recommended. The research covers both testing methods, considering their significance for pedestrian safety.

The frost resistance test procedure for stone samples in water followed standard PN-B-06265 (2022), specifying 28 cycles for materials intended for road construction. Each cycle involved 6 h of sample freezing in air followed by 6 h of thawing in water, with temperatures ranging from about −10 °C to approximately 20 °C, monitored by thermocouples. After 28 cycles, samples were dried, weighed to assess mass loss, and visually inspected. Subsequently, sample strength testing was conducted.

Frost resistance in salt was determined using a methodology based on PN-B-06265 (2022), assessing the impact of de-icing agents on concrete subjected to freeze-thaw cycles. Samples were immersed in a 3% NaCl water mixture placed in plastic boxes for testing in the frost resistance machine.

The objective of the skid resistance test is to evaluate the roughness index, which is considered one of the operational parameters of pavement surfaces. To determine this index, a series of tests must be conducted on the prepared samples.

The most common method for conducting these tests is using a pendulum device, often referred to as the English pendulum. The Pendulum Test Value (PTV) method is based on determining the energy loss of a skid rubber due to friction. The English pendulum is a portable device, allowing for slip resistance tests to be conducted both in the laboratory and on-site. PTV slip resistance values serve as the basis for classifying surface slip risk (Czerwińska & Zalewa, 2016; Pożarycki, 2019).

Another frequently used method for assessing surface resistance to skidding is the acceptable angle test, also known as the ramp test. This test can be performed with either a shoe or barefoot. The test determines the maximum surface inclination angle at which a person walking on it begins to slide. Due to the device design, the acceptable angle test can only be conducted in a laboratory.

For the selected types of surfaces, skid resistance can be determined using the PN - EN 1436 (2018) standard, although the actual test procedure is detailed in PN - EN 13036 - 4 (2011). This method has become increasingly popular in Poland in recent years. It is worth noting that in PN -EN 13036 - 4 (2011) and PN - EN 1436 (2018) standards, PTV and Skid Resistance Tester (SRT) values are considered equivalent.

3. Results and discussion of the conducted research

To obtain reliable results, the strength of three beams must be determined, and the arithmetic mean of these measurements calculated. The results, obtained with an accuracy of 0.05 N/mm^2, are presented graphically depending on the time of the conducted tests, as shown in Figures 5 and 6. The figures display boxes specifying the standard error range, while the whiskers indicate the range from minimum to maximum values.

The tests reveal that around 80% of the material strength is attained within the first 24 h after mixing the ingredients, underscoring the importance of proper site protection at the onset of work, as it significantly influences the final surface quality. As depicted in Figure 6, the mixture made from aggregate no. 1 exhibits higher final flexural strength (5.86 MPa). However, after the first 24 h, the mixture made from the white grit displays a higher parameter. This may be attributed to the lighter weight of grit compared to granite (Figure 7a), resulting in quicker adhesion with the hardener and resin initially, followed by superior results after complete drying.

The compressive strength was notably low, which could be attributed to the quality of the hardener or resin. The average strength after 28 days was 10.02 MPa for aggregate no. 1 and 8.02 MPa for aggregate no. 2, respectively. The destruction of samples was caused by the decomposition of the mixture rather than aggregate crushing; the structure of the stone pieces remained intact. Therefore, it is imperative to prepare the mixture immediately after opening the containers, as it significantly influences the final mechanical parameters of the surface (Figure 7b).

Figure 8 presents detailed results showing the change in weight of individual samples after 28 freeze-thaw cycles. It is evident that the average weight loss for both samples, under both freezing conditions, did not exceed 2%. The maximum loss, reaching 2.23%, was observed for aggregate no. 2 samples when frozen without salt. Based on these preliminary findings, it can be concluded that salt will not significantly affect the structural changes of the mineral-resin surface.

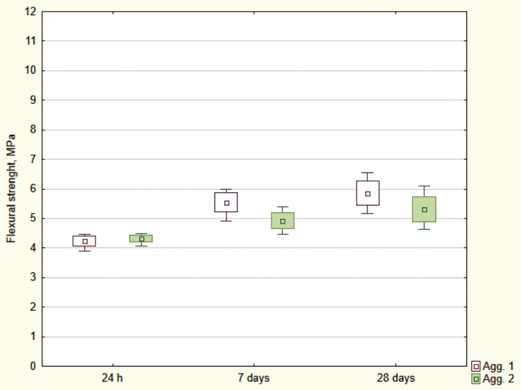


Figure 5. Comparison of flexural strength test results for both aggregates

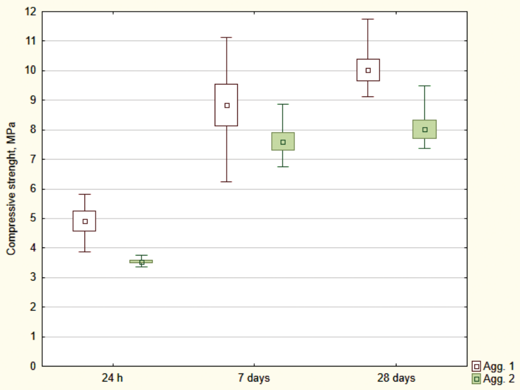


Figure 6. Comparison of compressive strength test results for both aggregates

a) flexural strength test

b) compressive strength test

Figure 7. Sample destruction after performing flexural (a) and compressive (b) strength test

None of samples have any visible changes after performed cycles. Next stage was to calculate average strength reduction after tests using Equation (1):

$$\Delta f_w = \frac{\left(f_{28} - f_1\right) \cdot 100\%}{f_1}, \tag{1}$$

where

Δf_w – changes in strength after water frost resistance test, %;
f_1 – initial sample strength, MPa;
f_{28} – sample strength after 28 cycles of water frost resistance testing, MPa.

The results of the performed tests are presented in Figures 9 and 10. Figures 11 and 12 illustrate the graphical average changes in flexural and compressive strengths. It is evident that freezing leads to a reduction in both flexural and compressive strengths. Notably, freezing in salt yields similar reductions in these parameters.

For samples made from aggregate no. 1, the decrease in flexural strength after freezing was 16.0%, and after freezing in salt, it was 18.7%. However, for samples made from aggregate no. 2, the changes were significantly greater, amounting to 35.4% and 46.8%, respectively.

Regarding compressive strength, samples made from aggregate no. 1 exhibited better performance, with similar decreases of about 20% observed after freezing with and without salt. Conversely, for samples made from aggregate no. 2, the compressive strength decreased by 27.8% after freezing in salt and by 32.2% without salt.

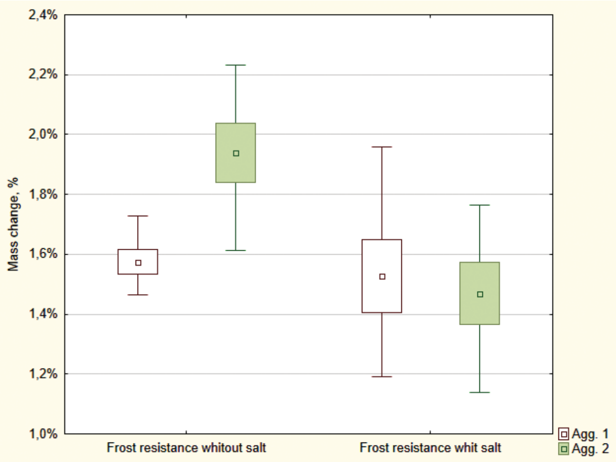


Figure 8. Results of identification method for frost resistance

Table 3. Criteria for evaluating pavement roughness based on the value of the BSRT index determined by the English Pendulum (Piłat et al., 2015)

Skid resistance indicator	Roughness
>65	Good
55–65	Satisfactory
45–55	Sufficient
<45	Insufficient

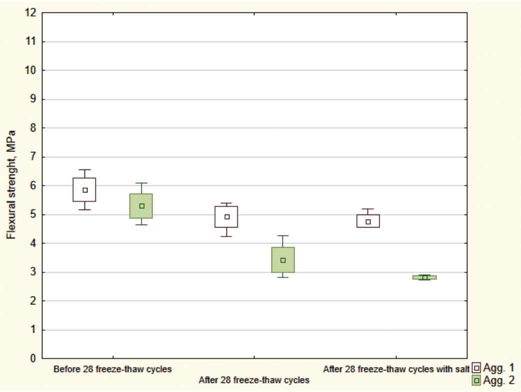


Figure 9. Comparison of flexural strength values before and after freeze – thaw cycles

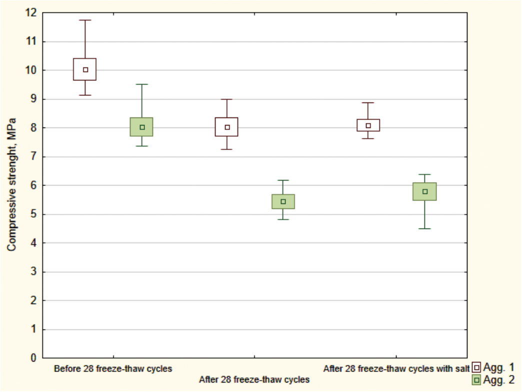


Figure 10. Comparison of compressive strength values before and after freeze – thaw cycles

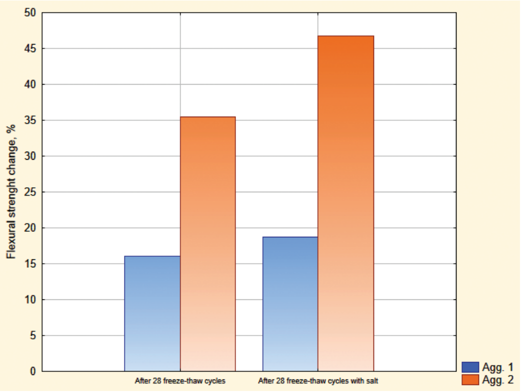


Figure 11. Flexural strength changes after frost resistance

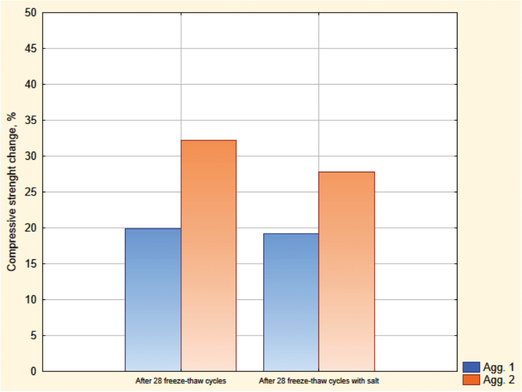


Figure 12. Compressive strength changes after frost resistance

In Table 3, commonly used limits defining the skid resistance quality of a surface are presented. According to PN - EN 14157 (2017), the SRT Roughness Index value must be at least 45 SRT units throughout the entire service life of the surface, corresponding to class S1 according to PN- EN 13036 – 4 (2011).

The accomplished results of the performed tests (Figure 13) demonstrate that in both cases, the required values of SRT were achieved. Consequently, the surfaces can be classified under the S4 class of skid resistance according to EN 13036 – 4 (2011), indicating that the surface is suitable for pedestrian usage with a low slip risk.

Notably, there is no significant difference in the values between the dry and wet surfaces, indicating that the material is perfectly suitable for outdoor pavements. Constructing roads using mineral-resin surfaces would enhance pedestrian safety, reducing the risk of slip injuries.

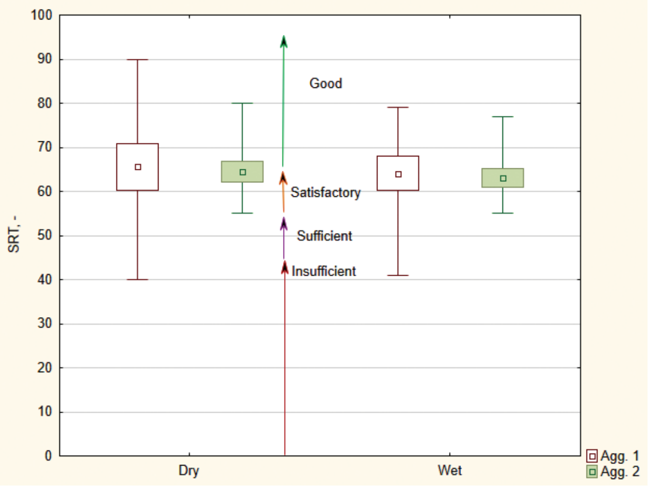


Figure 13. Comparison of SRT values for dry and wet samples

After conducting the research, a statistical analysis of the obtained results was performed. Table 4 shows the average values ($\overline{x}$), standard deviation (s) and the coefficient of variation (v), which is the quotient of the standard deviation and the arithmetic mean.

Samples prepared using aggregate no. 1 exhibit much better qualities and meet current requirements, although the compressive strength is relatively low. However, there are no guidelines specifying a minimum value for such surfaces.

Samples made from aggregate no. 2 demonstrate poorer parameters. However, the results obtained are less variable. The coefficient of variation here reaches a maximum value of 0.22 for flexural strength after frost resistance without salt. The greatest variability in results is noticeable in the slip resistance test. The standard deviation for samples with aggregate no. 1 is as high as 15.91 MPa. Such large discrepancies may result from surface irregularities of the samples caused by the size and shape of the grains of the aggregate used. In this scenario, the resin manufacturer recommends adjusting the proportions of the ingredients

Table 4. Values of statistical parameters from the conducted tests

Parameter		**Aggregate no. 1**			**Aggregate no. 2**		
		$\overline{x}$, MPa	**s, MPa**	**v, –**	**$\overline{x}$, MPa**	**s, MPa**	**v, –**
Compressive strength	after 24 h	4.93	0.83	0.17	3.54	0.13	0.04
	after 7 days	8.83	1.74	0.20	7.60	0.72	0.09
	after 28 days	10.02	0.92	0.09	8.02	0.78	0.10
Flexural strength	after 24 h	4.23	0.30	0.07	4.32	0.21	0.05
	after 7 days	5.54	0.56	0.10	4.92	0.47	0.10
	after 28 days	5.86	0.70	0.12	5.30	0.74	0.14
Compressive strength values after freeze – thaw cycles	without salt	8.03	0.77	0.10	5.44	0.59	0.11
	whit salt	8.09	0.46	0.06	5.79	0.76	0.13
Flexural strength values after freeze – thaw cycles	without salt	4.92	0.62	0.13	3.42	0.76	0.22
	whit salt	4.77	0.38	0.08	2.82	0.10	0.03
SRT	dry	65.56	15.91	0.24	64.56	6.94	0.11
	wet	64.11	11.48	0.18	63.11	6.43	0.10

by adding more hardener and resin. After making such adjustments, all tests should be repeated.

Comparing the obtained results with those of alternative materials reveals interesting insights. Porous asphalt, for instance, exhibits compressive strength results ranging from 0.83 MPa to 1.28 MPa (Tjaronge et al., 2020), while porous concrete ranges from 1.06 MPa to 20.60 MPa (Ibrahim et al., 2014; Sumanasooriya & Neithalath, 2011). Consequently, mineral-resin surfaces demonstrate better durability than porous asphalt but may be inferior to porous concrete. In terms of bending strength, mineral-resin surfaces outperform porous asphalt (0.6 MPa) (Hammes & Thives, 2023) but are surpassed by porous concrete (3.7 MPa) (Meng et al., 2019).

The conducted research provides valuable information about the surfaces and clarifies their suitability for specific projects. Such research facilitates the accessibility and usability of new materials and pavement systems for designers or subcontractors.

In this article, two mixtures of mineral-resin surfaces were prepared using different aggregates. Results indicate that samples made from aggregate no. 1 are better suited for various applications, including parking lots, park and garden paths, sports fields, bicycle paths, playgrounds, ramps for the disabled, walking paths in historic parks, and house terraces.

The paper highlights the verification procedures for the most important parameters required for road elements. However, it acknowledges that current standards lack complete requirements for physico-mechanical parameters determining their specific use. It is suggested that national guidelines need to be developed for these remaining parameters.

When it comes to the cost of constructing a mineral- resin surface, it depends on several factors. Particularly significant are the type and thickness of the sub-base, the type of resin used, and the aggregate. This article presents the results of tests conducted with granite aggregate and marble gravel. In both cases, this can have a significant impact on costs. The construction of 1 m^2 of permeable surface starts from 100–150 PLN (equivalent to the costs of paving stones) to as much as 250–350 PLN (which is the cost of constructing a surface with granite aggregate) (muratordom.pl).

Conclusions

Based on the results obtained from the conducted research, the following conclusions can be drawn:

- The strength of a permeable surface is somewhat dependent on the aggregate used. Tests conducted with aggregate no. 1 exhibited higher compressive strength (10.02 MPa). However, for bending strength, the values obtained for both tested cases were very similar (aggregate no. 1: 5.86 MPa, aggregate no. 2: 5.30 MPa).
- Atmospheric factors may influence the strength parameters of permeable surfaces. The decrease in compressive strength after the frost resistance test was up to 32.21% for samples from aggregate no. 2. However, in the case of bending, the decrease in strength was 35.44% (for samples from aggregate no. 2). The presence of salt did not cause a significant decrease in strength.
- Permeable surfaces exhibit a high level of slip resistance. Samples tested both dry and wet were classified as “satisfactory” based on the SRT value.

Among the positive aspects of using mineral-resin surfaces in historic gardens, public parks, streets, and private territories, the following should be mentioned:

- *Functional benefits*: Easy adaptation to terrain conditions and historical road routes, reduced risk of skidding, increased comfort and accessibility for users, including facilitation for disabled individuals.
- *Technical and economic advantages*: Positive impact on rainwater drainage systems, reduced water drainage costs, closer proximity to plants, limiting negative effects on the substrate and system.
- *Aesthetic benefits*: Contribution to maintaining the traditional character of objects, increased visual attractiveness through reference to historical material features, reducing the loss of authenticity resulting from changes made in subsequent decades.
- *Environmental advantages*: Pro-ecological properties contribute to rainwater retention, creation of a non-toxic substrate, increased water and air access to plant roots, and potential for recycling a significant portion of the pavement.
- Ensuring a positive final effect in the use of mineral and mineral-resin surfaces as alternatives to earth and gravel involves appropriate material matching, detailed analyses, high-performance surface standards, proper adaptation to traffic types, and effective maintenance procedures in subsequent years.

- Despite these advantages, mineral-resin surfaces remain relatively unpopular in Poland and other European countries due to the lack of official requirements and approval procedures. The research presented various standards to provide a clear understanding of surface quality and address this issue.

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