MATEC Web of Conferences **396**, 02005 (2024) https://doi.org/10.1051/matecconf/202439602005
WMCAUS 2023

Preliminary assessment of the properties of composite layers based on porous asphalt and coloured mortar

Marta Wasilewska[1], *Dominik* Grzyb[1*] and *Władysław* Gardziejczyk[1]

[1]Bialystok University of Technology, Wiejska 45E, 15-351 Bialystok, Poland

Abstract. The paper presents the results of the properties of composite layers made of porous asphalt, with a void content above 30%, filled with a special-coloured mortar. Three mortars of white, red and blue colours were selected, whose compressive strength after 2 days was over 60 MPa and the flexural strength was over 7 MPa. The study of composite layer aimed at determination of the water sensitivity expressed in ITSR (Indirect Tensile Strength Ratio) according to the standard EN 12697-12 (method A) and rutting resistance according to standard EN 12697-22 in the small apparatus (method B). The results indicate that such solutions will be justified in places with extremely heavy traffic, such as bus stops. In addition, the condition of the layer surface after simulating its wear was assessed using of the CTM (Circular Track Meter), the BPT (British Pendulum Tester) and a reflectometer. The results indicate that they can be used in areas with low speed limits. On the other hand, the possibility of introducing the pigment into the mortar has a positive effect on surface of those elements of the communication system, which should have a different color than the road surface. These are the surfaces of bicycle paths, pedestrian and bicycle routes, areas of intersections, where their visibility plays an important role due to the safety of users.

1 Introduction

The wearing course is directly exposed to both traffic and weather conditions. It should guarantee durability and meet the requirements for parameters relating to transverse and longitudinal unevenness and skid resistance for a specified period of use of the road pavement. Meeting these challenges involves making the right choice of the technology that takes into account its traffic load conditions in the place of application. In the case of flexible and semi-rigid pavements, the wearing course is very often designed from AC (Asphalt Concrete) and SMA (Stone Mastic Asphalt). Considering the reduction of noise and aquaplaning, in some countries permeable layers of porous asphalt are used [1,2]. However, these solutions have a limited scope of application due to climatic conditions [3]. Another solution is to build the upper layers with SMA LA and BBTM (Concrete Bitumineuse Tres Mince) mixtures. These are intermediate solutions between the permeable layer and the SMA layer. The content of voids in asphalt mixture in the range from 9 to 18 % (depend on the

* Corresponding author: dominik.grzyb@doktoranci.pb.edu.pl

type) allows to guarantee noise reduction and to effectively limit the negative impact of water on friction pavement [4,5]. However, in the case of the construction of pavements in the area of bus bays and squares, their durability is important due to static loads from heavy vehicles. In this case, rigid pavement are very often used. However, this solution in this area requires the design and implementation of a different type of base. The care of this type of road pavement also extends the period of putting the section into use, and the texturing and joints requires additional maintenance. The best solution would be a hybrid technological solution that would combine the benefits of asphalt and concrete mixes. The technology to meet these challenges was developed in the 1960s in France [6]. The mortar was applied to the laid out permeable layer of the asphalt mix, filling its free spaces. In this way, a composite layer was created. Based on this idea, the STRABAPHALT® solution was developed in Germany in the 1990s. It is used in Poland especially for the construction of bus bays. Tests to compare different technologies have shown that it is characterized by the best resistant to permanent deformation compared to flexible and semi-rigid pavements [7]. For safety reasons, the wearing course should ensure adequate visibility of both traffic users and obstacles located on it. One method of improving visibility is to increase the contrast between the traffic user and the road surface. Contrast can be increased by selecting the appropriate parameters of street lighting or changing the luminance level of the surface [8]. The paint used to paint the surface wears off over the years and needs to be renewed. On the other hand, the use of coloured mortar to fill the air voids in the asphalt mixture may allow for longer colour retention and increase the visibility of the surface, which will also impact on safety and aesthetic aspects.

The objective of the paper is to present preliminary studies on a composite layer made of porous asphalt that the air voids are filled with coloured mortar. These types of solutions were assessed in terms of their incorporation into road pavement with heavy traffic, such as parking lots, bus stops, which should be particularly visible to the traffic user.

2 Research program

The research program was divided into two stages. In the first stage, the basic properties of mortars were assessed. The selected mortars differed in pigment. The following mortars were selected for tests: white, blue and red.

The following properties were tested:

- Kinematic viscosity according to ASTM 06910,
- Compressive strength according to EN 196-1,
- Flexural strength according to EN 196-1.

According to the manufacturer's recommendations, mortars were prepared by adding water in the following proportions :white (80% cement - 20% water), blue (80% cement - 20% water) and red (78% cement - 22% water)

In the second stage, composite layers were made, which required the design of a Porous Asphalt mix with a maximum aggregate size of 11. Bitumen modified with SBS polymer (PMB 45/80-55) was used in accordance with the standard EN 14023 and Polish National Specification. The mineral mixture was based on aggregate from trachybasalt rock.

Table 1. Physical properties of coarse aggregate

Properties	Test method	Trachybasalt
Resistance to polishing, *PSV* [-]	EN 1097-8	53
Resistance to wear, M_{DE} [%]	EN 1097-1	8
Resistance to fragmentation, *LA* [%]	EN 1097-2	12
Resistance to freezing and thawing, F_{NaCl} [%]	EN 1367-6	1
Density, ρ_a [Mg/m^3]	EN 1097-6	2.70
Water Absorption, WA_{24} [%]	EN 1097-6	0.5

The volumetric parameters of the PA 11 mixture are presented in Table 2.

Table 2. Volumetric parameters of PA 11 mixture

Parameters	Test method	PA11
Density ρ_{mv} [Mg/m^3]	EN 12697-5	2.454
Bulk density $\rho_{b,dim}$ [Mg/m^3]	EN 12697-6	1.702
Air voids V_m [%]	EN 12697-8	30.7
Voids filled with binder VFB [%]	EN 12697-8	40.7
Voids in mineral aggregate VMA [%]	EN 12697-8	24.5

The high content of voids in the porous asphalt was determined so that it was possible to fill them with mortar. In order to access the properties of composite layers, the following tests were carried out:

- water sensitivity according to EN 12697-12,
- rutting resistance according to EN 12697-22,
- brightness according to Polish National Specification WT-2:2014,
- skid resistance according to ASTM E303-9,
- macrotexture according to ASTM E2157-1.

Due to the fact that the tests are carried out on specimens of various dimensions, a method for making specimens of composite layers was developed. The porous asphalt slabs were made in a plate compactor. For the purposes of the tests, plates with a thickness of 63 mm (water sensitivity) and 40 mm (rutting resistance, brightness, skid resistance and macrotexture) were made. Then, the specimens were secured with foil and placed in the mold to prevent the mortar from flowing out. The mortar was poured onto the surface of the prepared specimens and pressed inside by vibration.

2.1 Experimental procedure

2.1.1 Kinematic viscosity

The kinematic viscosity was tested in accordance with ASTM 06910. Using a Marsh funnel viscometer in the room temperature of 22° C, the mortar outflow time into a marked vessel with a capacity of 1000 cm^3 was determined. Flow time is a conventional measure of the viscosity.

2.1.2 Flexural and compressive strength

Flexural and compressive strength of tested mortars was carried out according to EN 196-1. The specimens with dimensions of 40x40x160 mm we made and conditioned for 2 tests – after 2 and 28 days (Fig. 1). The flexural strength test was carried out on 3 samples using the three-point loading method. The samples were placed in the machine so that the longitudinal axis was perpendicular to the support. The load was applied vertically by means of the loading roller to the opposite side face of the specimen and was increasing smoothly as the rate of 50±10 N/s until fracture. The flexural strength was calculated according to the equation (1). The average value of 3 samples was reported as the final result. For testing the compressive strength, broken specimens used for testing the flexural strength were used. The specimens were put laterally in the centre on the auxiliary platens of hard steel which exactly determines the compressive area. The load was increasing smoothly at the rate of 2400±200 N/s over the entire load application until fracture. The compressive strength was calculated from the formula (2). The average of the 6 results was given as the final result.

$$R_f = \frac{1,5 * F_f * l}{b^3} \tag{1}$$

where:
R_f – flexural strength [MPa];
b – specimens width [mm];
F_f – the maximum load at fracture [N];
l – the distance between supports [mm].

$$R_c = \frac{F_c}{1600} \tag{2}$$

where:
R_c – compressive strength [MPa];
F_c- the maximum load as fracture [N];
1600 is the surface area of steel plates (40x40 mm) [mm^2].

a) b) c)

Fig. 1. a) Preparation of specimens for tests, b) flexural strength test c) compressive strength test

2.1.3 Water sensitivity test

Water sensitivity test of composite mixtures was carried out according to EN 12697-12 (method A). The specimens with a diameter of 101.6 ± 0.1 mm were cut using a core drilling machine from a plate made of a composite layer with a thickness of 63.5 ± 2.5 mm (Fig. 2).

Ten specimens for each mixture were divided into two parts: "dry set" and "wet set". Specimens from "dry set" were conditioned at temperature 20 ± 5° C. Specimens from "wet set" were saturated with distilled water under vacuum (6.7±0.3 kPa, 30 minutes) and left in water for 30 minutes under atmospheric pressure. Then specimens were conditioned in water at temperature 40° C for 72 hours. In next step plastic-foiled specimens were freeze in -18° C for 16 hours, then they were put in water at temperature 25° C for 24 hours. Finally the ITS (Indirect Tensile Strength) test in accordance with EN 12697-23 on both sets of specimens has been conducted. The ITSR values was calculated according to equation (3).

$$ITSR = \frac{ITS_w}{ITS_d} \cdot 100\% \tag{3}$$

where:
ITS_d – mean values of ITS for specimens from „dry set" [kPa];
ITS_w – mean values of ITS for specimens from „wet set" [kPa].

a) b)

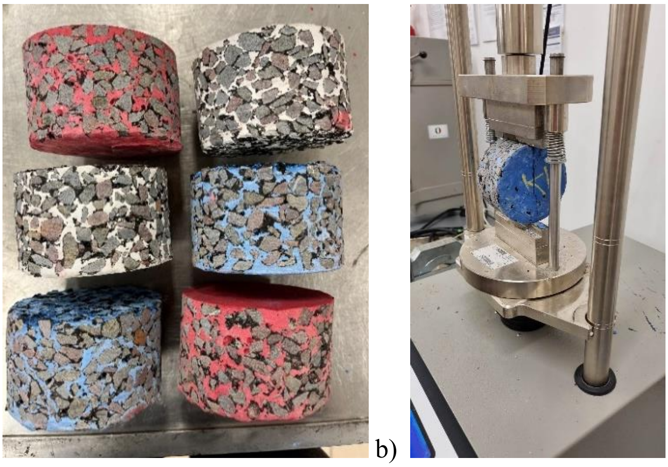


Fig. 2. a) Exemplary specimens for the ITS test, b) The specimen during ITS test

2.1.4 Rutting resistance test

Rutting resistance of composite mixtures was conducted according to EN 12697-22 in small apparatus (method B), in air. Two specimens from each composite mixture were prepared. The specimens had dimensions of 300x400x40 mm. Before testing specimens were conditioned at 60° C for 4 hours. The apparatus consists of the loaded wheel that repeatedly passes over the test specimen. The load of wheel was 700 N, frequency of 26.5±1.0 load cycles per minute. Test was performed at 60° C during the test. Evaluation of resistance to rutting is made on the basis of:

- RD (rut depth) after 10 000 cycles [mm],
- PRD (proportional rut depth) after 10 000 cycles as a percentage of the specimen thickness [%],
- WTS (wheel-tracking slope) [mm/10 000 load cycle].

2.1.5 Skid resistance test

The skid resistance of the specimens was determined using the method developed as Bialystok University of Technology. The tests specimens had dimensions of 300x300x40 mm. The test consisted in the simulation of phenomena occurring in real traffic conditions.

For this purpose, a machine consisting of three rubber wheels moving on the surface of the sample by means of a rotating disk was used (Fig. 3). The wheels were moving at a speed of 50±2 rotations per minute. The entire test consisted of two 3-hour phases. In the first phase, water and coarse emery (300/600 μm) were fed continuously to the surface of the sample on which the wheels were moving and in the second phase water and emery flour (< 53 μm) were fed. To determine the skid resistance the British Pendulum Tester was used in accordance with ASTM E303-9. The measurements were made before and after each phases in a trace of polishing wheels. The specimens during the test process are shown on Fig. 4.

a) 

b) 

Fig. 3. a) Polishing slab machine b) Measurements using a British Pendulum Tester

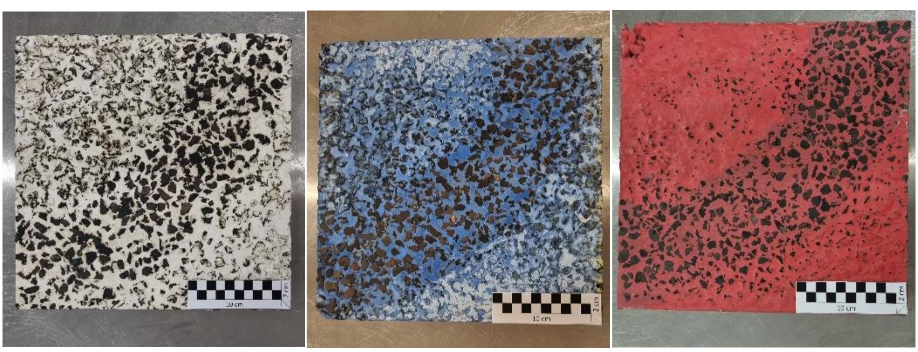


Fig. 4. Tested specimens after 6 hours of polishing process

2.1.6 Macrotexture test

The surface macrotexture of the samples was evaluated on the basis of MPD (Mean Profile Depth) using CTM (Circular Tester) in accordance with ASTM E2157-1. As with the skid resistance test, measurements were made before and after each of the polishing phases.

2.1.7 Brightness test

The brightness level was determined by the luminance coefficient Qd. The luminance coefficient was measured with a reflectometer and expressed in mcd/m^2*lx. The brightness test was carried out according to Polish National Specification WT-2:2014. Two specimens, with dimensions of 300x400x40 mm, were made for each kind of mortar. The test consists in making 5 measurements in the centre of the specimens, each time setting the reflectometer in a different direction. The final brightness level was calculated as the arithmetic mean of the taken measurements. The measurements were carried out before and after the skid resistance test.

3 Results and analysis

3.1 The evaluation of mortars properties

The kinematic viscosity test results are shown in Table 3. Both the white and blue mortars achieved similar time out of the Marsh funnel. Only the result of mortar with red pigment significantly differed from the others. The red mortar flow time was almost 2 times shorter than that of other materials.

Table 3. Kinematic viscosity test results

Mortar	Outflow time [s]	Stand. dev. σ [s]
White	35	4
Blue	37	5
Red	15	5

Fig. 5 shows the flexural and compressive strengths after 2 and 28 days. Strength control after 2 days is important due to the fact that the colostrum layer should be put into traffic after 2 days from its construction. It was found that the results of the flexural strength of the red and blue specimen are at a comparable level after 2 days. The results of white samples are significantly lower. However, the test after 28 days showed that they had the highest increase in compressive strength (140%) and the highest result (17.7 MPa). The lowest strength increase (12%) and the lowest R_f value were recorded for red samples (11.0 MPa). The compressive strengths of the tested materials after both 2 and 28 days are satisfactory because the values are higher than 50.0 MPa. The increase in strength of individual samples is at a comparable level of about 30%. The highest results were recorded for white specimen and the lowest for red specimen.

The probable cause of the lower values of red mortar may be related to the higher water content than in the case of white and blue mortar. However, the verification of this statement is possible after the analysis of the results of the properties performed in the second stage of the tests with composite layers.

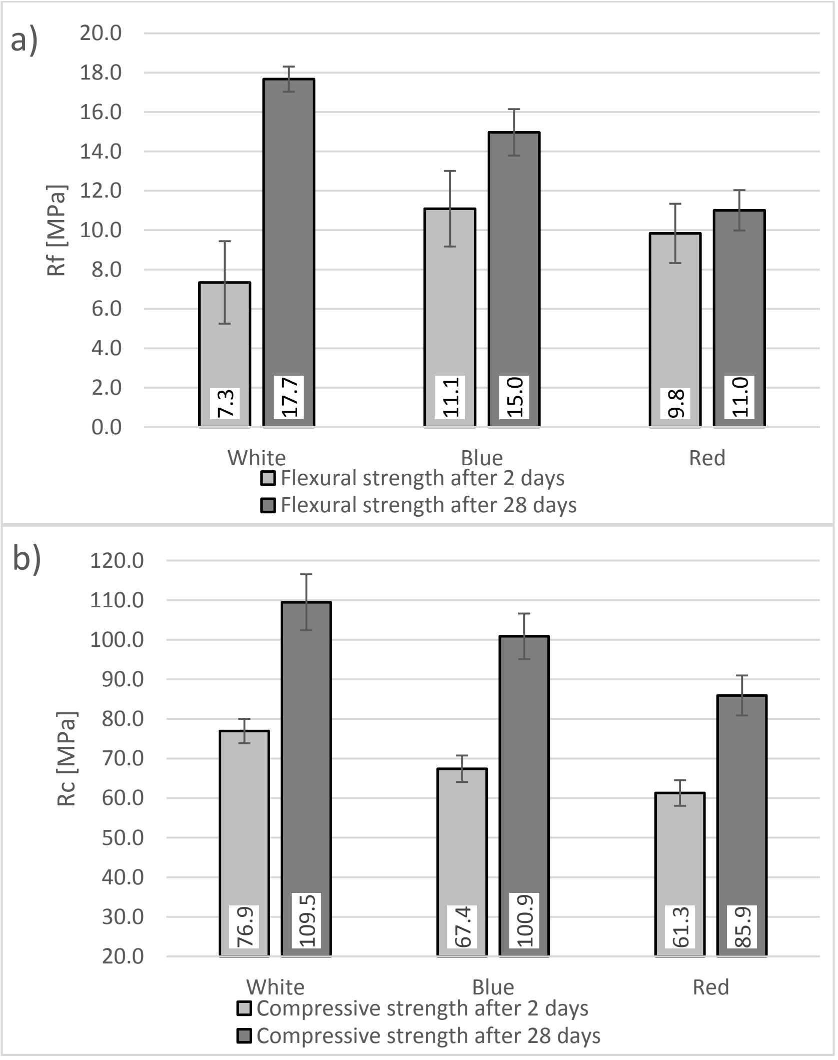


Fig. 5. a) The flexural strength of the tested mortars, b) The compressive strength of the tested mortars

3.2 The evaluation of composite mixtures properties

The results of the water sensitivity test are shown in Fig. 6. Mixtures with red mortar achieved ITSR <80%. The difference in ITS values between the wet and dry set is about 24%. In addition, these values are lower than the ITS results obtained for mixes with blue and white mortar. It was noticed that the relationship between the increase in the higher values of the flexural and compressive strength of mortars and the increase in the strength of the composite layer of mortars contributes to higher ITS values.

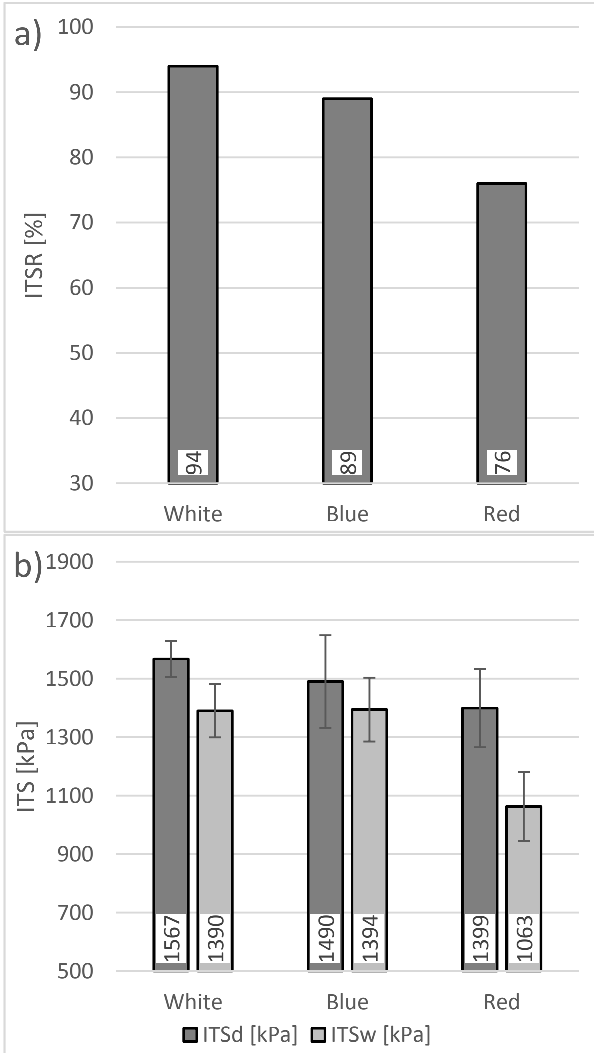


Fig. 6. a) Mean values of the ITSR values, b) Mean values of the ITS with standard deviation

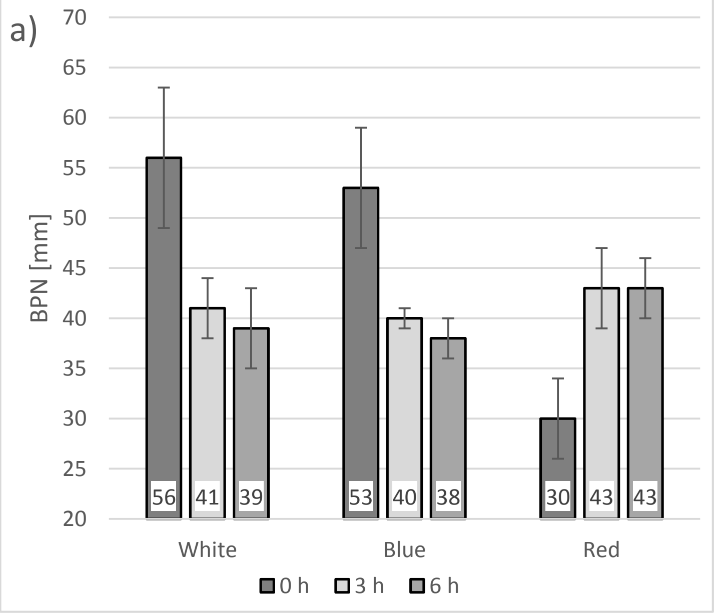
Table 4 presents the results of the parameters characterizing the rutting resistance of the composite layers. The favourable results prove that they are resistant to permanent deformations in the cross-section of the traffic lane. This is the result of filling the air voids of the porous asphalt with a mortar with high compressive strength (above 50 MPa), as a result of which the composite layers are similar to rigid pavements.

Table 4. Rutting test results

Parameter	White	Blue	Red
RD_{AIR} [mm]	0.26	0.07	0.04
PRD_{AIR} [%]	0.7`	0.2	0.1
WTS_{AIR} [mm/10 000 load cycle]	0	0	0

Each new technology for the construction of the upper layer of the road surface should be tested in order to determine its skid resistance. It is a very good practice to perform tests in laboratory conditions that reflect the factors accelerating the surface wear of the pavement in real conditions. For this purpose, a slab polisher was used, which allows the simulation of both abrasion and polishing. The assessment of skid resistance was carried out in a comprehensive manner based on the parameters relating to the microtexture determined based on the measurement of the BPT and the macrotexture based on the CTM measurement. Fig. 7 shows the results of these parameters determined on the surfaces of the composite layers in the individual phases of the test. Table 5 shows the macrotexture profiles of the tested surfaces.

Composite layers with white and blue mortar are marked with comparable BPN results before starting the test. Significantly lower values were obtained on composite layers with red mortar (BPN 30). Its surface was distinguished by a characteristic glassy coating in relation to the surface with blue and white mortar, as a result of which the average depth of the macrotexture profile is also lower than that of the other layers (MPD 0.46 mm). This may be related to the greater amount of water intended for the preparation of the red mortar. In the first phase of the test, which lasted 3 hours, a coarse abrasive and water were dosed on the surface, which were designed to simulate the phenomenon of abrasion. As a result of this process, a comparable decrease in the BPN value was recorded on the blue and white layers. This means that their irregularities in terms of the microtexture of the blue and white layers are comparable. The red layer behaves differently. Here, after removing the mortar, the BPN increases. This means that the mortar was the cause of the initial slipperiness of the surface. Then, under the influence of corundum powder with water, their surface was polished. There is a very slight decrease in BPN after the 6 h test. The BPN values of the three surfaces are comparable. The only differences are in the MPD results. It should be noted that the composite layers were built of the same mineral-asphalt mixture, so the differences in BPN and MPD values in individual stages are caused by the characteristics of a given mortar.



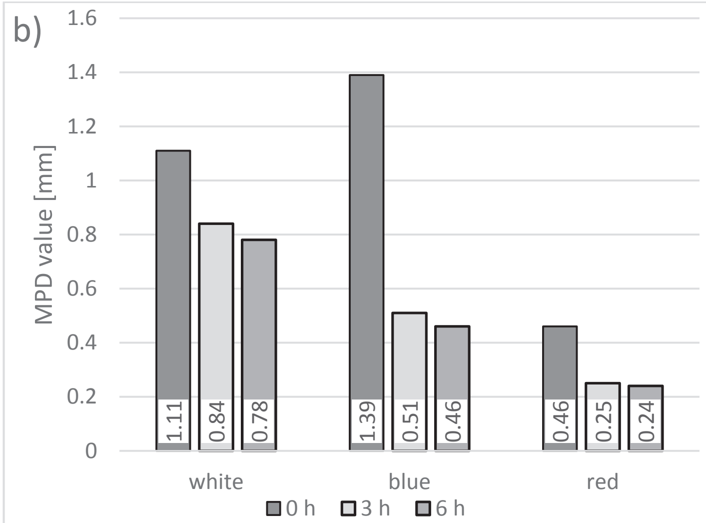


Fig. 7. a) The British Pendulum Number, b) The Mean Profile Depth parameter during the particular stage of the test

Fig. 8 shows the results of the luminance coefficient Qd. Due to the fact that changes in the microtexture and macrotexture have a significant impact on the level of luminance, the measurements were made before and after the process simulating the surface wear of the surface. Both before and after the test, the Qd values were above 90 mcd/m^2·lx. This is a satisfactory result taking into account the requirements in selected European countries [9]. The lower values after the polishing phase are influenced by the exposed grains of the coarse aggregate used for porous asphalt. Trachybasalt aggregate has a Qd equal to 53 mcd/m^2·lx. It is a dark aggregate. However, the measurement on a layer of porous asphalt with this aggregate without the addition of mortar proves that it is a dark material (Qd 44 mcd/m^2·lx). Therefore, the colour of the mortar will improve the visibility of a given area in the case of applying a composite layer there. This is of particular importance due to the safety of traffic users.

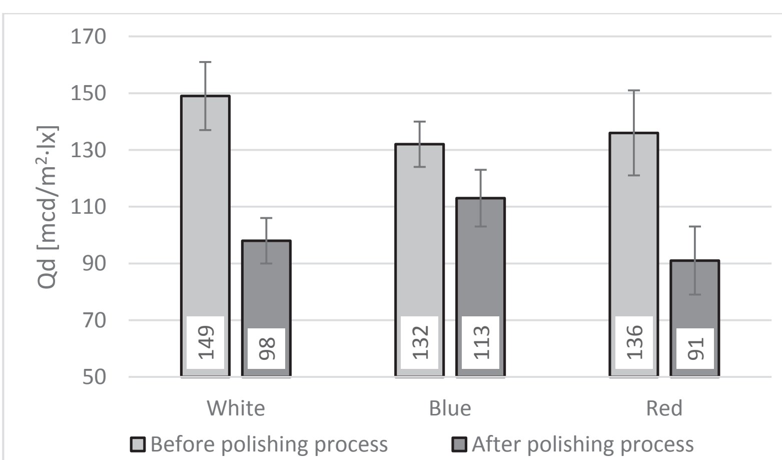
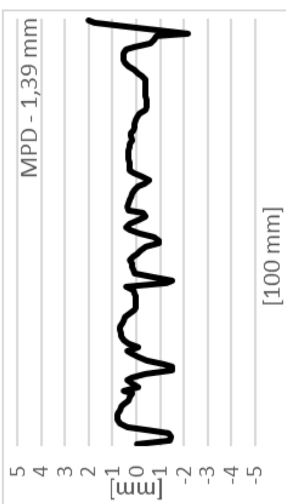
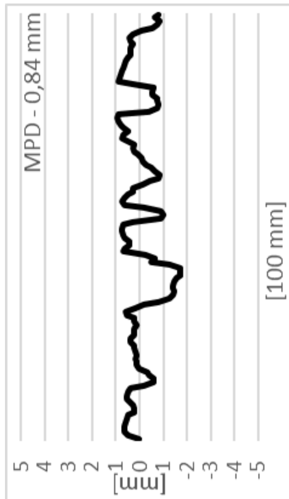
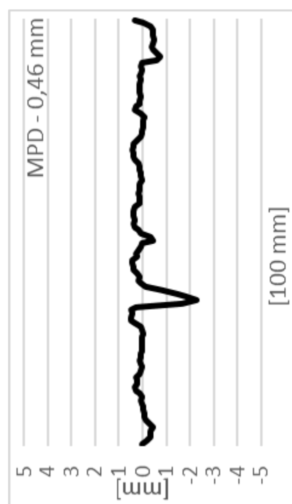
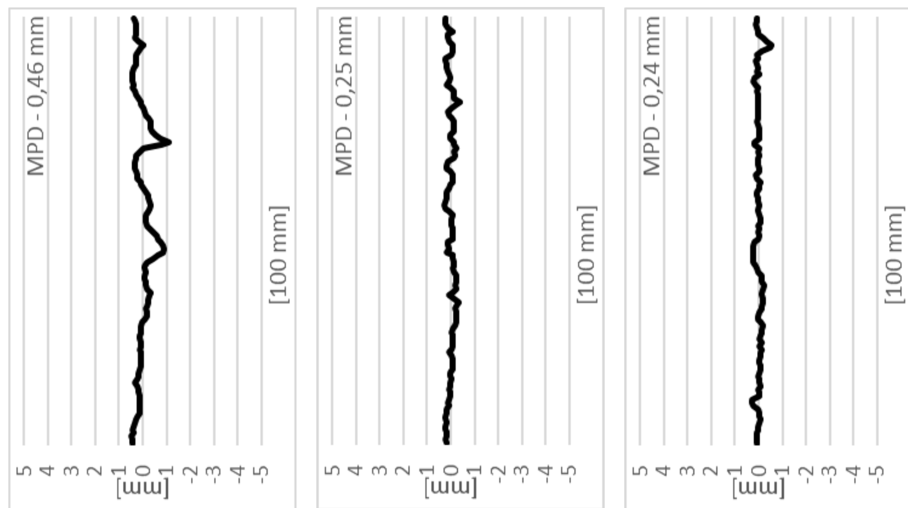


Fig. 8. Mean values of the Qd.

Table 5. Specimens texture profiles during the particular stages of the test

Mortar	White	Blue
0 h		
3 h		
6 h		

Red



4 Conclusion

The conducted tests showed that the use of coloured mortars to fill the voids in the porous asphalt allows to create a durable solution in terms of resistance to permanent deformation. In the case of composites made of blue and white mortar, satisfactory ITSR results of over 80% were obtained. However, with red mortar these values are lower. It should be added that its compressive strength was also lower than that of samples made of blue and white mortar. In further studies, the results of tests with red mortar with a lower water content than recommended by the manufacturer should be analyzed. To sum up, the addition of pigment to mortars and their use in composite allows to increase the visibility of places such as intersections or pedestrian crossings. The test results indicate that a composite surface made with a mortar with a coloured pigment can be used to build these elements. A further direction of research will be to check how the composite pavement designed in this way behaves in real traffic conditions.

Acknowledgments

The research was financed by projects Ministry of Education and Science of the Republic of Poland: Student scientific society creates innovations, WI/WB-IIL/6/2022, WZ/WB-IIL/7/2023 realized on Bialystok University of Technology, Poland.

References

1. Slebi-Acevedo, C. J., Lastra-González, P., Indacoechea-Vega, I., & Castro-Fresno, D. (2020). Laboratory assessment of porous asphalt mixtures reinforced with synthetic fibers. Construction and Building Materials, 234, 117224. https://doi.org/10.1016/j.conbuildmat.2019.117224
2. Afonso, M. L., Dinis-Almeida, M., Fael, C. S. (2017). Study of the porous asphalt performance with cellulosic fibres. Construction and Building Materials, 135, 104–111, https://doi.org/10.1016/j.conbuildmat.2016.12.222

3. Vaitkus, A., Andriejauskas, T., Vorobjovas, V., Jagniatinskis, A., Fiks, B., & Zofka, E. (2017). Asphalt wearing course optimization for road traffic noise reduction. Construction and Building Materials, 152, 345–356. https://doi.org/10.1016/j.conbuildmat.2017.06.130
4. Gardziejczyk, W., Plewa, A., Pakholak, R. (2020). Effect of Addition of Rubber Granulate and Type of Modified Binder on the Viscoelastic Properties of Stone Mastic Asphalt Reducing Tire/Road Noise (SMA LA). Materials, 13(16), 3446. https://doi.org/10.3390/ma13163446
5. Šernas, O., Vaitkus, A., Gražulytė, J., Skrodenis, D., Wasilewska, M., & Gierasimiuk, P. (2021). Development of low noise and durable semi-dense asphalt mixtures. Construction and Building Materials, 293, 123413. https://doi.org/10.1016/j.conbuildmat.2021.123413
6. Van de Ven, M.F.C., Molenaar, A. (2004). Mechanical characterization of combi-layer. Asphalt Paving Technology: Association of Asphalt Paving Technologists-Proceedings of the Technical Sessions. 73. 1-22.
7. Bańkowski W., Gajewski M. (2012). Accelerated loading tests in the full scale on innovative pavement structures. *Roads And Bridges - Drogi I Mosty, 11*(2), 89-121.
8. Zalesinska M., Wandachowicz K. (2021). On the Quality of Street Lighting in Pedestrian Crossings. *Energies* 14, no. 21: 7349. https://doi.org/10.3390/en14217349
9. Gidlund H., Lindgren M., Muzet V., Rossi G., Iacomussi P. (2019). Road Surface Photometric Characterisation and Its Impact on Energy Savings. *Coatings*, *9*(5), 286. https://doi.org/10.3390/coatings9050286