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WATER AND FROST RESISTANCE OF GAP – GRADED ASPHALT MODIFIED WITH THE SBS POLYMER AND HYDRATED LIME

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Gap – graded asphalt (MNU) has high resistance to the traffic, however, due to its specific grading it is more prone to a destructive effect of the climatic factors compared to other bituminous mixes. In order to ensure its durability, the mixture was modified with the use of the SBS polymer and hydrated lime. Asphalt was modified with the addition of 2, 4, 6, 8 % of the SBS polymer, while hydrated lime was dispensed in the filler in the amounts 10, 20, 30, 40 and 50 %. The performed research into the resistance of MNU to high and low temperatures as well as to water and frost showed a positive impact of the two modifiers on the durability and high mechanical properties of MNU.

Key words: water and frost action, gap – graded asphalt, stripping, anti-stripping additives, hydrated lime, SBS polymer

1. INTRODUCTION

The road building technology of gap – graded asphalt MNU 0/20 enables to obtain bituminous surfaces which are not prone to permanent plastic deformations and which ensure required roughness during their operation. An important factor responsible for these favorable properties is the grading characteristic. The amount of 0,085 – 0,63 mm fraction has been significantly reduced in the

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mineral mix and, as a result, the mix consists mainly of the coarse chippings fraction and the filler. Consequently, such a mineral and bitumen mix can be prone to the effects of water and frost.

The necessity to use acid aggregate e.g. quartzite or granite is an additional factor that can be responsible for insufficient water and frost resistance of the MNU 0/20 mm asphalt mix because these kinds of aggregate play a significant role in the creation of the asphalt pavement roughness. However, they contain a lot of silica, whose content in the rock can be as high as 95%. Consequently, aggregate has weak adhesion to bitumen. As a result, road surfaces made of this kind of mineral and bitumen mix can be prone to the destructive effects of such climatic factors as temperatures below 0 ^{0}C, water and defrosting salt used in the winter to fight glazed frost. These factors damage the internal structure of the mineral and bitumen mix as a result of:

- the loss of adhesion between aggregate and bitumen,
- the removal of bitumen from the surface of aggregate,
- the loss of cohesion and stiffness of the thin layer of bitumen.

The structural changes of the mineral and bitumen mix can lead to the degradation of bituminous surfaces in the form of voids, losses of aggregate grains and mastic, which can result in the total destruction of the surface.

In order to counteract these destructive processes occurring in the mineral and bitumen mix it is advisable to use adhesive agents, whose aim is to improve the process of covering the grains of the acid aggregate with bitumen and, consequently, to strengthen the internal structure of the mix. The most commonly used adhesive agents are amines of fatty acids. The application of this kind of adhesive agents can result in the lowering of the softening point of bitumen, which leads to a reduction in the resistance of the asphalt pavement to high temperatures during the summer. Consequently, unfavorable phenomena occur such as flowing, hollows and the most dangerous one – ruts. It is, thus, advisable to use mineral adhesive agents e.g. hydrated lime [1, 2].

An additional factor that can have a significant impact on the improvement of the resistance of MNU 0/20 mm asphalt mix to the effects of water and frost is the bitumen modification with the SBS polymer. As a result, covering the grains of the mineral mix is more effective and resistance of the mix to the effects of destructive climatic factors is higher [3].

The paper presents the experimental results of the impact of hydrated lime and the SBS polymer on the physical and mechanical properties of the MNU 0/20 mm asphalt mix. The mix has been made of quartzite aggregate from Wisniowka, which is one of the most acid aggregate in Poland with the silica content of 95 %. The research has been particularly focused on resistance of the asphalt mix to the effects of water and frost.

2. INVESTIGATED MATERIAL

2.1. Composition of the asphalt concrete

The tests were performed on the gap – graded asphalt mix MNU of the 0/20 mm fraction, which is used for the production of road surfacings with traffic loads classified as KR5 according to the Polish standard PN-S-96025:2000. The quartzite aggregate from a mine in Wisniowka, near Kielce was used as the principle aggregate. The optimal bitumen content in the gap – graded asphalt mix was determined with the Marshall method.

Limestone filler from Bukowa and manufactured lime sand from Trzuskawica were used in the mineral mixes. The application of the manufactured lime sand is particularly important when quartzite aggregate is used in the mineral mix. This kind of sand is responsible for the lowering of the negative potential of the mineral mix. Consequently, it significantly improves water and frost resistance of the mineral and bitumen mix [4].

In the course of the experiment the gap – graded asphalt mix MNU 0/20 mm of the following composition has been designed:

- limestone filler from Bukowa – 12 %;
- manufactured lime sand from Trzuskawica – 13 %;
- 6,3/12,8 mm granulated quartzite aggregate from Wisniowka – 75 %.

In the laboratory tests the 35/50 bitumen from Płock was used. It was modified with the SBS polymer in the amounts of 0; 2; 4; 6 and 8 % in relation to the amount of the bitumen. Hydrated lime was used as a mineral adhesive agent. The hydrated lime content in the limestone filler from Trzuskawica was 10, 20, 30, 40 and 50 %.

2.2. Methodology and analysis of the test results

With the aim of analyzing the impact of the additives (the SBS polymer and hydrated lime) on the durability of the MNU 0/20 mm asphalt mix with regard to its water and frost resistance the following properties were determined:

- standard properties according to PN-S-96025;
- water resistance through measuring the compressive strength according to AASHTO T165 [5];
- resistance to low temperature cracking according to PANK 4302 [4];
- water and frost resistance through measuring indirect tensile strength AASHTO T283 [5].

The determination of the uniformity of the tests was an important element of the research program. Samples were selected for the tests only if their void

fraction content ranged between (V - 2s ; V + 2s), where *V* – denotes void fraction content in the MNU asphalt mix, *s* – standard deviation.
In order to analyze the impact of hydrated lime and the SBS polymer on the properties of the MNU 0/20 mm asphalt mix the following mathematical model has been proposed [6]:

$$y = b_0 + \sum_{i=1}^{n} b_i \cdot x_i + \sum_{i=j=1}^{n} b_{i=j} \cdot x_i \cdot x_j + \sum_{i=1}^{n} b_{ii} \cdot x_i^2 \tag{2.1}$$

which in the analyzed case can be written in the form:

$$y = b_0 + b_1 \cdot x_1 + b_2 \cdot x_2 + b_3 \cdot x_1^2 + b_4 \cdot x_1 \cdot x_2 + b_5 \cdot x_2^{\ 2} \tag{2.2}$$

where: x_1 – SBS polymer content in the bitumen [%];
x_2 – $Ca(OH)_2$ hydrated lime content in the filler [%];
b_{0-5} – values of experimental coefficients.

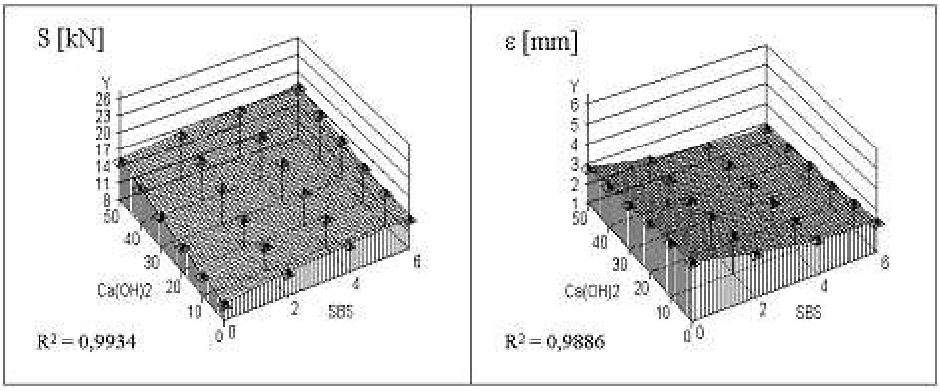
The principal physical and mechanical properties of the MNU 0/20 mm asphalt mix with quartzite aggregate have been listen in table 1.

Table 1. Physical and mechanical properties of the gap – graded asphalt MNU 0/20 mm

No.	Parametr		Value
1	Density MMB	[Mg/m^3]	2,485
2	Bulk density MMB	[Mg/m^3]	2,408
3	Void fraction content	[%]	3,1
4	Degree of filling of void fraction with the binder	[%]	79,6
5	Marshall stability	[kN]	13,2
6	Marshall deformation	[mm]	3,5
7	Marshall stiffness	[kN/mm]	3,77
8	Static creep modulus	[MPa]	22,5

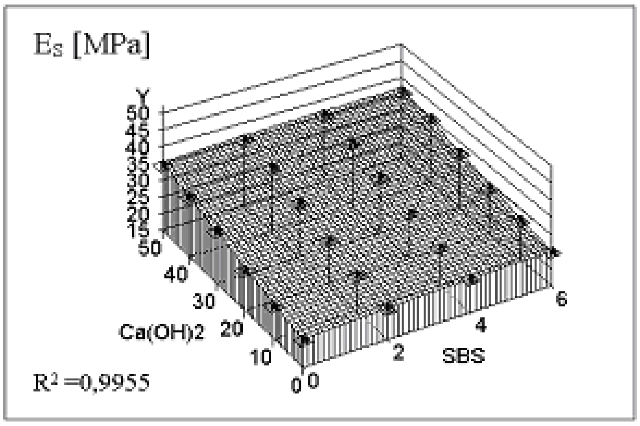
The analysis of the results reveals that the MNU 0/20 mm asphalt mix with quartzite aggregate has high mechanical properties regarding Marshall stability and the static creep modulus. It should also be noted that Marshall stiffness was high, reaching the value of 3,77 kN/mm. It shows that the MNU 0/20 mm asphalt mix will be resistant to high summer temperatures and the traffic load.

The laboratory tests on the standard properties of the MNU 0/20 mm asphalt mix were also focused on determining of the impact of hydrated lime and the SBS polymer on Marshall stability and deformation as well as the static creep modulus. The investigation results of the above mentioned parameters have been presented in figure 1 and 2, respectively. The parameters were determined using the proposed mathematical model.



Parameter	b_0	b_1	b_2	b_3	b_4	b_5
Stability	14,37702	1,102202	0,124050	-0,092708	0,000329	-0,000054
Deformation	3,536607	-0,234226	-0,036173	0,015625	0,001186	0,000237

Fig. 1. Marshall stability and deformation of the gap – graded asphalt MNU 0/20 mm as a function of the SBS polymer content and hydrated lime content.



b_0	b_1	b_2	b_3	b_4	b_5
29,320536	1,073512	0,384259	-0,090625	0,001643	-0,001879

Fig. 2. The static creep modulus of the gap – graded asphalt MNU 0/20 mm as a function of the SBS polymer content and hydrated lime content.

The analysis of the test results of the impact of hydrated lime and the SBS polymer on such mechanical properties as Marshall stability and deformation as well as the static creep modulus reveals that the above mentioned additives increase the values of these measured parameters. For samples with the maximum concentrations of the additives Marshall stability rises over 60 %, while Marshall deformation decreases of 50 %. The static creep modulus increases by approximately 70 % when the maximum concentrations of the additives are present in the MNU 0/20 mm asphalt mix.

Analyzing the influence of the SBS polymer and hydrated lime on the measured parameters of the MNU 0/20 mm asphalt mix it can be concluded that their impact is synergetic. They improve resistance of the MNU 0/20 mm asphalt mix and thus counteract the possible occurrence of permanent plastic deformations.

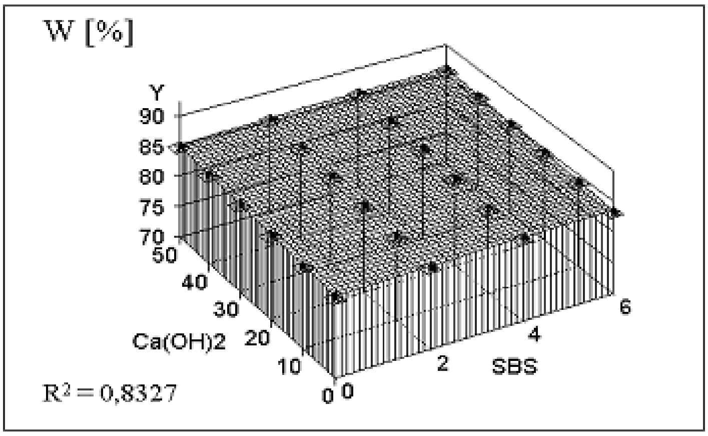
The tests were also carried out to determine water and frost resistance of the MNU 0/20 mm asphalt mix, which was conducted based on the previously mentioned experimental program. Resistance of the MNU 0/20 mm asphalt mix was first determined for the mix without the additives and then for the mix with the additives. The investigation results of the standard MNU 0/20 mm asphalt mix have been presented in Table 2.

Table 2. The investigation results of water and frost resistance of the gap – graded asphalt MNU 0/20 mm.

No.	Parameter		Value
1.	Compressive strength according to AASHTO T165	[MPa]	
	Without curing		7,2
	After curing in water		6,3
	Strength ratio	[%]	87,5
2.	Indirect tensile strength at temperature -2^0C according to PANK4301	[MPa]	4,1
3	Indirect tensile strength according to AASHATO T283	[MPa]	
3a	Without curing		1,32
	Curing in water		1,14
	Strength ratio W_w	[%]	86,4
3b	Strength ratio		
	Without curing		1,32
	Curing in water and frost		0,98
	Strength ratio W_{wm}	[%]	74,2

The analysis of the test results of water and frost resistance of the MNU 0/20 mm asphalt mix shows that the mix fulfils the above mentioned criteria. The strength ratio according to AASHTO T165 is much higher than the limiting value of 70 %. A similar situation occurs with the strength ratio W_w, which represents water resistance of the MNU 0/20 mm asphalt mix according to ASSHTO T283. Water and frost resistance of the MNU 0/20 mm asphalt mix is lower – the strength ratio W_{wm} is only 74,2 %, although still higher than the limiting value of 70 %. The tested MNU 0/20 mm asphalt mix is also resistant to low temperature cracking according to PANK 4302, because indirect tensile strength is lower than 4,8 MPa.

Determining the impact of the SBS polymer and hydrated lime on water and frost resistance of the MNU 0/20 mm asphalt mix was an important element of the research project. Figure 3 presents the resistance ratio of the mix to the effects of water according to AASHTO T165 as a function of the SBS polymer content and hydrated lime content.

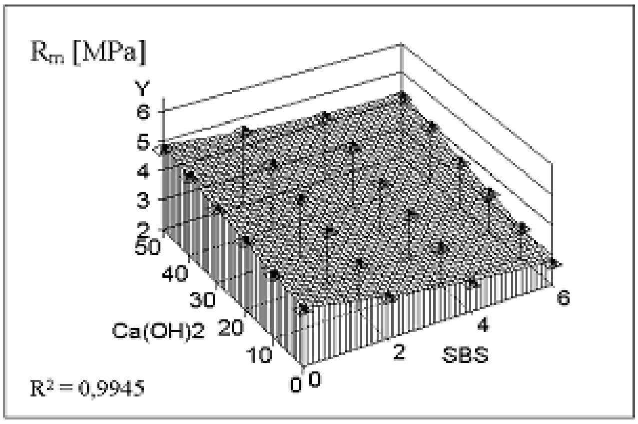


b_0	b_1	b_2	b_3	b_4	b_5
74,677083	0,266667	0,026066	0,020833	-0,005400	0,000674

Fig. 3. The resistance ratio of the gap – graded asphalt MNU 0/20 mm to the effects of water according to AASHTO T165 as a function of the SBS polymer content and hydrated lime content

Analyzing the impact of the additives on water resistance of the MNU 0/20 mm asphalt mix according to AASHTO T165 it can be concluded that their influence is of a similar kind as in the case of the tests on the standard properties of the MNU 0/20 mm asphalt mix. However, it should be noted that an increase in the SBS polymer content and hydrated lime content causes a less rapid rise in the resistance of the MNU 0/20 mm asphalt mix. This effect might be explained by already high resistance of the MNU 0/20 mm asphalt mix without the additives.

The investigation results of the impact of the additives on the resistance of the MNU 0/20 mm asphalt mix to low temperature cracking according to PANK 4302 have been presented in figure 4.

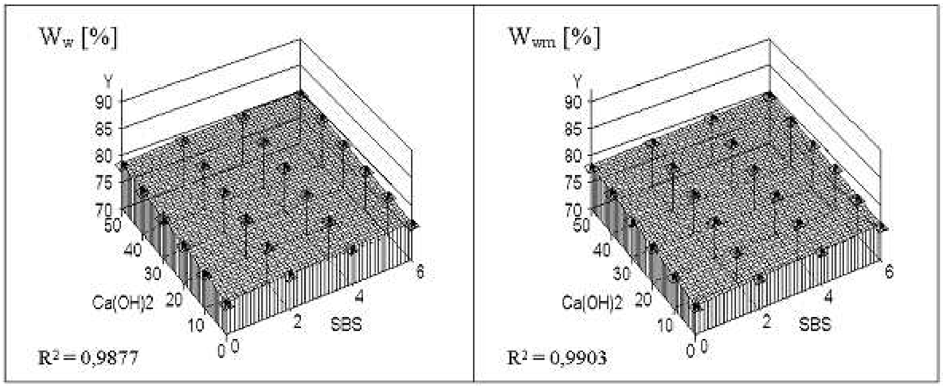


b_0	b_1	b_2	b_3	b_4	b_5
4,165655	-0,277738	0,009088	0,014583	0,002343	0,000121

Fig. 4. Indirect tensile strength of the gap – graded asphalt MNU to the effects of water as a function of the SBS polymer content and hydrated lime content according to PANK 4302.

An increase in the hydrated lime content results in a rise in indirect tensile strength of the MNU 0/20 mm asphalt mix at –20 ^{0}C, which – in this regard – is an unfavorable phenomenon according to PANK 4302. If the hydrated lime content in the filler is maximum (50 %), the resistance to low temperature cracking is reduced, because indirect tensile strength exceeds the limiting value of 4,8 MPa. The addition of the SBS polymer is much more favorable. Indirect tensile strength decreases with an increase in the polymer content in the bitumen and, consequently, the resistance to low temperature cracking of the surface is higher. In the analyzed case an increase in the hydrated lime content and the SBS polymer content have contradictory impacts in the MNU 0/20 mm asphalt mix.

The last stage of the research project was focused on determining of the influence of the additives on water resistance as well as on water and frost resistance according to AASHTO T283. The test results have been presented in figure 5.



Parameter	b_0	b_1	b_2	b_3	b_4	b_5
W_m [%]	71,126429	0,331369	0,068118	-0,015625	-0,001271	-0,000187
W_{rm} [%]	71,750655	0,335893	0,059584	-0,019792	-0,001186	-0,000085

Fig. 5. Strength ratio of water resistance Ww and strength ratio of water and frost resistance Wwm of the gap – graded asphalt MNU 0/20 mm as a function of the SBS polymer content and hydrated lime content.

The use of hydrated lime and the SBS polymer as additives to the MNU 0/20 mm asphalt mix has a favorable affect – a synergy of their use can be observed. Water resistance as well as water and frost resistance of the MNU mix increase with an increase in the contents of the additives. It should be noted, however, that hydrated lime has a more significant impact than the SBS polymer. Assuring higher water and frost resistance of the MNU 0/20 mm asphalt mix is particularly important when quartzite acid aggregate is used. The strength ratio W_{wm} exceeds 80 %, which guarantees durability of the asphalt surface made of such a mineral and bitumen mix.

The analysis of the experimental results conducted using a utility function [6] has enabled to calculate the amount of the additives with regard to the considered parameters of the gap – graded asphalt MNU 0/20 mm. It has been determined that the optimum hydrated lime content in the filler is 30 % and the polymer content is 4 % in relation to bitumen. Such a composition assures high durability of the gap – graded asphalt MNU 0/20 mm.

3. CONCLUSIONS

Analyzing the impact of the SBS polymer and hydrated lime used as additives to the gap – graded asphalt MNU 0/20 mm the following conclusions can be drawn:

- the SBS polymer and hydrated lime significantly influence the physical and mechanical properties as well as water and frost resistance of the gap – graded asphalt MNU;
- an increase in the concentrations of these additives results in improving the mechanical properties of the MNU 0/20 mm asphalt mix such as Marshall stability and the static creep modulus;
- water and frost resistance of the gap – graded asphalt MNU 0/20 mm is increased as a result of the use of the SBS polymer and hydrated lime; a significant rise in the frost resistance is particularly noticeable;
- the use of hydrated lime as a constituent of the gap – graded asphalt leads to a decrease in its resistance to low temperature cracking, however this unfavorable effect is partly mitigated by the SBS polymer;
- the SBS polymer and hydrated lime have a significant impact on assuring durability of the gap – graded asphalt MNU 0/20 mm with regard to the effects of climatic factors, particularly when aggregate of a high silica content e.g. quartzite is used as a constituent of the mix;
- the impact of the SBS polymer and hydrated lime on the properties of the gap – graded asphalt MNU 0/20 mm is synergetic.

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