

MOISTURE AND FROST RESISTANCE OF THE RECYCLED BASE REHABILITATED WITH THE FOAMED BITUMEN TECHNOLOGY

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The technology of recycling with foamed bitumen is a new technology of road rehabilitation. Due to the climatic conditions in the Central European countries, road pavement structure should be moisture and frost resistant. Because of its specific production conditions, this is especially important for pavements rehabilitation with the cold recycling technology. Determining the physical and mechanical properties, as well as moisture and frost resistance, depends on binder and filler contents. They are the key elements before its use for road building. The tests presented here have been performed on mineral recycled base mixes with foamed bitumen. The material from the existing layers was used. The content of bitumen binder amounted to 2.0%, 2.5%, 3.0% and 3.5%, while that of cement to 1.0%, 1.5%, 2.0%, 2.5%. The results were subject to the optimization process. This allowed to state that with the use of 2.5% foamed bitumen and 2.0% of cement, the base had the required properties, as well as the moisture and frost resistance.

Key words: foamed bitumen, cold recycling technology, moisture and frost resistance.

1. INTRODUCTION

In recent years, while introducing new technologies, attention is paid to the fact that – besides being economical – they also should be environmentally friendly. Deep cold recycling technology fulfills these requirements. It seems to be interesting because of the possibility to reuse the previously used materials, to decrease of the use of new bitumen and aggregates, and to limit energy in rehabilitation. That in turn contributes to decrease the costs of road maintenance. Cold recycling is based on milling the material from a damaged, exploited road surface. Then, on mixing it in specified way with cement and binder (e.g. emulsion or foam bitumen) or with new dolomite aggregate (or its combination). This enables to rebuilt the whole surface construction. It also uses the waste material during the milling process. While applying this technology, the emission of harmful compounds to the atmosphere is limited. Reusing materials taken from old pavements lowers the rate of exploitation of mineral deposits. Thus, it also reduces the

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influence on the environment. The pavement cold recycling technology with mixes of mineral-cement-emulsion (M-C-E) is common in Poland. However, the need to improve the load capacity of surface construction calls for more advanced technologies. In cold recycling technology, the foamed bitumen is used instead of bitumen emulsion. This bitumen binder enables to obtain more durable road pavements under heavy traffic loads and is more resistant to weather conditions. (IWAŃSKI and CHOMICZ [1]).

At the end of XX century the technical development enabled the use of foamed bitumen in making the construction layers of the road surface.

During the deep recycling of road surface, due to the fact that foamed bitumen contains very little water, the required mechanical parameters of the pavement material are quickly obtained. Consequently, the curing period is shorter as compared to technology in which bitumen emulsion is used. With this new technology, the pavement rehabilitation can almost immediately be covered with other layers of the road surface. The highest temperature of recycled material that enables the use of the foamed bitumen is 10°C. Below that – when the foamed bitumen in the form of foam is in contact with a cold material – it immediately precipitates and loses its binding properties. Consequently, the rehabilitation pavement does not meet the specified requirements.

The deep recycling with foamed bitumen is widely used, mainly in Africa and Australia. There the impact of temperatures below 0°C (frost) and water on road construction is not significant. Therefore, in requirements (JENKINS *et al.* [2]), only tensile strength retained [TSR] was taken as water resistance criterion. TSR is a ratio of the values of indirect tensile strength before and after soaking pavement samples with water. This parameter enables to assess the water tightness and the resistance to the effects of water.

The weather conditions in Poland are much more severe with regard to both: moisture and frost interaction with the pavement. Regarding the moisture and frost resistance for the pavement structure with foamed bitumen no detailed data is available in moderate climate. So, it is vital to assess the resistance of the material to these two factors in a range broader than determined requirements for this technology.

2. ASSESSMENT OF THE USEFULNESS OF BITUMEN FOR FOAMING TECHNOLOGY IN POLAND

There are various kinds of bitumen used in road building. They differ by origin, the kind of petroleum which they were made of, group composition, consistency, physical and mechanical parameters. Consequently, it can be expected that every kind of bitumen subjected to the process of foaming reacts in a different way. The bitumen of different penetration is used in the foaming technology worldwide. Thus, an important element of the tests was to preliminarily determine the suitability of bitumen applied in Polish conditions (IWAŃSKI and CHOMICZ [3]). The tests were performed on six kinds of road bitumen: 50/70O, 160/220O, 70/100L, 70/100eL, 50/70N and N80. Their selection was

not accidental. These kinds of bitumen are commonly used in Poland for production of different kinds of mineral – bitumen mixes, in many construction layers of road surfaces.

The tests of bitumen properties are important while designing the recycled pavement mix. Based on the results of laboratory tests it is possible to choose the bitumen, whose use during deep cold recycling should provide high physical - mechanical parameters of the pavement.

The suitability analysis covered the determination of the basic properties and foaming parameters. In order to describe the dependence between the foaming parameters (expansion ratio and half life) of the tested bitumen and its water content, the exponential function was used. A correlation determined on the basis of the obtained results for these parameters is characterized by quite a good determination coefficient ($R^2 > 0.91$). This allowed to assess the dependence between tested features as acceptable. Based on the results (IWAŃSKI and CHOMICZ [3]), it was concluded that the N80 bitumen (Fig. 1) has the most favourable foaming parameters: the expansion ratio $WE=15.1$ and half – life of the bitumen foam $t_{1/2} = 14.4s$. Thus, its application for the deep cold recycling should guarantee obtaining pavements of high physical and mechanical parameters.

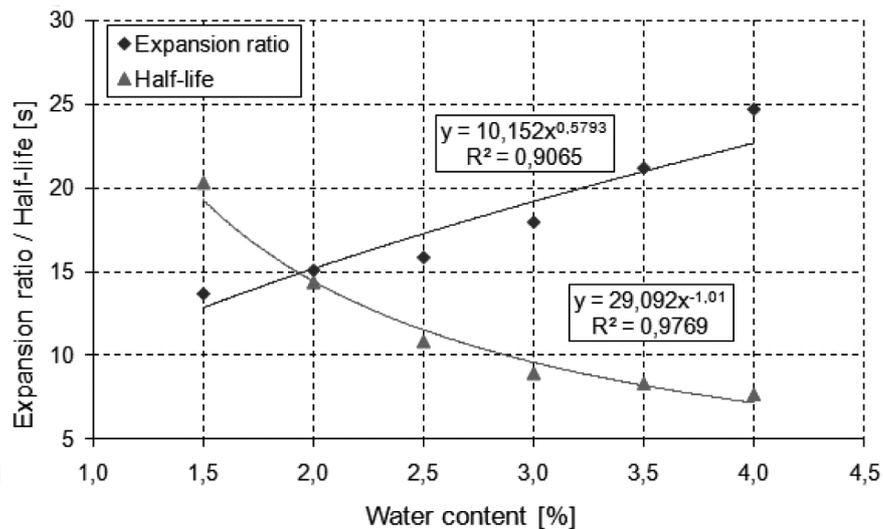


Fig. 1. Characteristics of foamed bitumen for N80 bitumen.

Rys. 1. Charakterystyki asfaltu spienionego dla asfaltu N80

3. DEEP COLD RECYCLING OF A SURFACE IN FOAMED BITUMEN TECHNOLOGY

In the cold recycling technology with foamed bitumen different kinds of materials can be used. Mineral mix of the recycled pavement can constitute (IWAŃSKI [1]):

- existing loose base,
- new mineral material,
- recycled asphalt pavement and existing pavement material,
- combinations of the above mentioned materials.

The most economical and commonly used is the application of foamed bitumen as a binder. This binder joins the recycled asphalt pavement and mineral pavement material. Portland cement, hydrated lime, and fly ash can be added in order to improve the mechanical parameters of pavement structures with foamed bitumen.

The role of the binder used is based on the development of the surface and – at the same time – on increasing the quantity of foamed bitumen. That guarantees the required properties of the pavement. The kind of binder depends on the quality of mineral mix, the content of organic component, the content of the fraction below 0.075 mm, the grading, and the kind of aggregate. That is because almost every stone material can be used to make recycled pavement.

Mineral mix of the recycled pavement with foamed bitumen should contain, according to the requirements (WIRTGEN COLD RECYCLING MANUAL [4]), from 5% to 20% of the fraction below 0.075 mm. However, the higher the small fractions component the better physical and mechanical properties of the recycled pavement. It is so because the foamed bitumen is based on these small fractions. Recycled construction materials do not content the required quantity of these small fractions. Therefore its recommended to apply as a grading material not only the binder, but also small 0 – 4.0 mm grading aggregate. The binder also improves the tightness of recycled pavement layers. Because the pavement can be subjected to harmful water impact, the Portland cement is used as a binder. That favorably influences the tightness of the pavement. But it can also cause the stiffening of the pavement's layers. Consequently, it does not improve its quality but on the contrary: its quality is deteriorated. Thus, it is essential to determine the maximal allowable quantity of Portland cement used.

3.1. DESIGN OF THE RECYCLED PAVEMENT MIXES

The laboratory tests were carried out on the mineral mix specimens. The specimens were produced with construction layers of road surfaces with the addition of foamed bitumen. These mixes meet grading criteria requirements given in literature (WIRTGEN COLD RECYCLING MANUAL [4], ZAWADZKI *et al.* [5]). Cement and water were also added to the recycled mix in order to obtain optimal compaction conditions.

The designed mineral mix of the recycled pavement (Fig. 2) contained 48% of milled asphalt layers, 22% of the existing stone base and 30% of a new material – 0/4mm dolomite aggregate. To determine the influence of the quantity of bitumen blend (foamed bitumen) and the binder (cement) the mix with the content of these two constituents was designed.

In the tests, the bitumen binder N80 bitumen was also used, which was foamed by adding 2.0% of water. Its content in the recycled mix was 2.0%, 2.5%, 3.0%, and

3.5%. To determine the influence of cement quantity on the physical and mechanical properties its concentration in mixes amounted to 1.0%, 1.5%, 2.0% and 2.5% in relation to the mineral mix. Cement was applied to increase the content of the fraction below 0.075 mm in the recycled material [6]. Moreover, the cement content of Bitumen Stabilized Materials (with foamed bitumen and bitumen emulsion) according to the guideline (TECHNICAL GUIDELINE [6]) should be $\leq 1\%$. The cement content should not exceed the bitumen content.

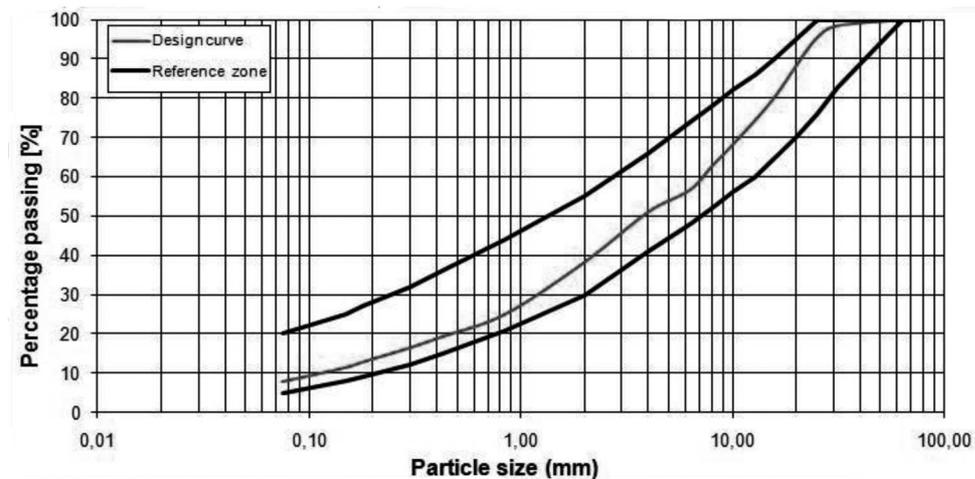


Fig. 2. Grading curves of the mineral mix for the production of pavements in the recycling technology with foamed bitumen.

Rys. 2. Krzywa uziarnienia mieszanki mineralnej na warstwę podbudowy w technologii recyklingu głębokiego na zimno z asfaltem spienionym

3.2. METHODOLOGY AND ANALYSIS OF THE TEST RESULTS

The aim of this project was to determine the impact of foamed bitumen and cement content on the physical and mechanical properties of the pavement rehabilitation with the deep cold recycling technology, and also to determine its moisture and frost resistance.

An important element of the tests was to assess the homogeneity of the conducted works. The measurements were taken only for samples which void fraction content ranged between $(V-2s ; V+2s)$, where V – mean void fraction content in the pavement, s – standard deviation (PIASTA and LENARCIK [7]). The tests were performed on series of 9 samples. The presented results are the mean values. The mean values which concern the tested physical and mechanical parameters have the coefficient of variation less than 15% for every kind of bitumen binder.

With regard to the amount of binding materials (foamed bitumen and cement) the following parameters were determined:

- Marshall stability (S),
- indirect tensile strength (ITS).

The test of indirect tensile strength on dry Marshall sample is the basic parameter. It enables to assess the usefulness of the recycled pavement material. It was determined from the formula (Wirtgen Cold Recycling Manual [4]):

$$(3.1) \quad ITS = \frac{2 \cdot P}{\pi \cdot h \cdot d} \cdot 10000 \text{ [kPa]}$$

where P is the maximal applied load [kN], h is the height of the specimen [cm] and d is the diameter of the specimen [cm].

It was assumed that the proper material for surface pavement with foamed bitumen is required to have indirect tensile strength over 150 kPa ($ITS > 150 \text{ kPa}$) (WIRTGEN COLD RECYCLING MANUAL [4]).

While analyzing the influence of the quantity of bitumen binder (foamed bitumen) and the binder (cement) on the tested physical and mechanical properties (S, ITS) it should be stated that, in order to describe them, it is statistically essential to use the polynomial model of the second order (PIASTA and LENARCIK [7], MONTGOMERY [8]). It can be expressed as:

$$(3.2) \quad y = b_0 + b_1 \cdot x_1 + b_2 \cdot x_2 + b_3 \cdot x_2 \cdot x_1 + b_4 \cdot x_1^2 + b_5 \cdot x_2^2$$

Where x_1 is the amount of foamed bitumen [%], x_2 is the amount of cement [%] and $b_0 \div b_5$ are the experimental ratios values.

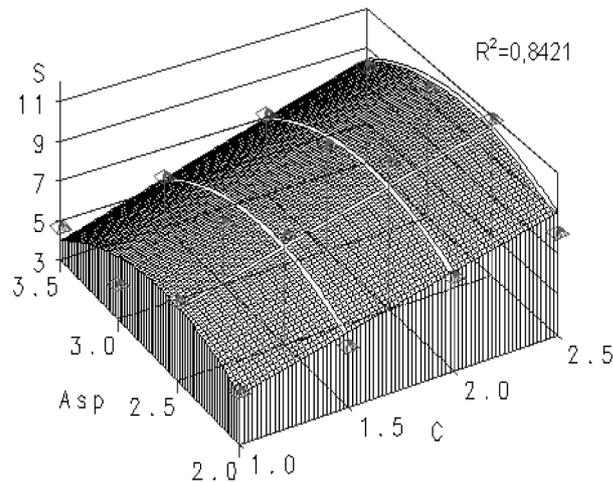


Fig. 3. The influence of the content of foamed bitumen and cement on Marshall stability.

Rys. 3. Wpływ zawartości asfaltu spienionego i cementu na stabilność wg Marshalla

As mentioned earlier, the following physical and mechanical parameters were analyzed: Marshall stability (S) and indirect tensile strength (ITS). Their regression models are presented in Fig. 3 and 4.

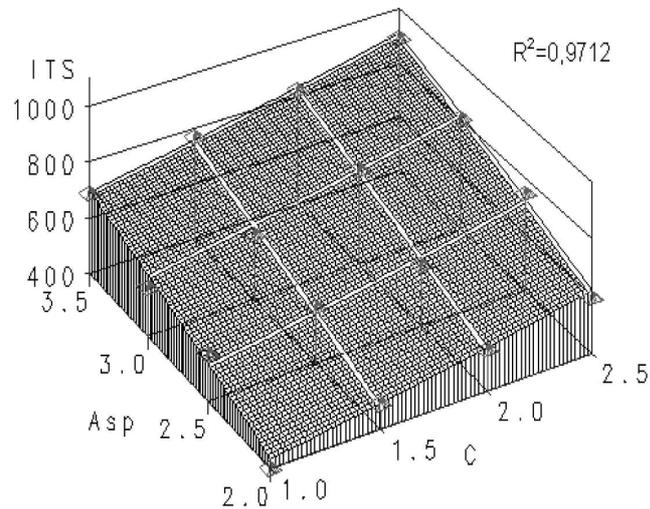


Fig. 4. The influence of the content of foamed bitumen and cement on indirect tensile strength.
Rys. 4. Wpływ zawartości asfaltu spienionego i cementu na wytrzymałość na pośrednie rozciąganie

The analysis of the results was done with the polynomial second order regression. That assessed the influence of experimental factors on the values of the tested parameters. They were: stability (S) and indirect tensile strength (ITS). At first it was necessary to assess the level of regression coefficients R^2 and the influence of given factors on the character of distribution of the analyzed parameters. The regression coefficient describes the total variability with the regression function model.

The assessment of R^2 and influence of the factors is presented in Table 1. The values of R^2 indicate proper fitting of the obtained models.

Table 1

R^2 coefficient and the factors' impact assessment.
Współczynnik R^2 oraz istotność efektu wpływu czynników

Parameter	R^2	Foamed bitumen (Asp)	Cement (C)
S	0.8421	0.0240	0.0009
ITS	0.9712	<.0001	<.0001

The values of the experimental coefficients of the regression models are shown in Table 2.

The analysis of the obtained regression models (Fig. 3 and 4) reveals, that the amount of the applied foamed bitumen and cement have an important influence on the tested features.

Table 2

The values of the experimental coefficients for S, ITS.
Wartości współczynników eksperymentalnych dla cechy S, ITS

Parameter	b ₀	b ₁	b ₂	b ₃	b ₄	b ₅
S	-18.452300	17.409450	1.951850	0.339600	-3.397500	-0.047500
ITS	-91.141600	251.886900	46.898700	13.799200	-16.865000	14.085000

While assessing the Marshall stability it can be noticed, that mixes with 2.5% foamed bitumen content have the highest value of the tested parameter. Applying 1.5% cement content leads to higher stability than required (8 kN). That is with regard to the technical conditions (ZAWADZKI *et al.* [5]) of the production of the pavement layers (MCE), in which the bitumen emulsion is used as a binder. Moreover, it was observed that the increase of concentration of foamed bitumen to 2.5% caused the increase of pavement stability; but a further increase caused its decrease. This dependence was not observed in the test of the recycled pavement indirect tensile strength. While conducting this test, together with the increase of the foamed bitumen and cement contents, the indirect tensile strength increased. All the mixes had higher ITS values than 150 kPa – the minimal value required according to Wirtgen Cold Recycling Manual ([4]). The most significant influence on the investigated parameters had, above all, temperature, time, and the kind of curing (air- dry state / soaking with water) of the samples directly before the tests were done.

However positive were the results of the tests, they are not sufficient. So, they were broadened with procedures used to assess moisture and frost resistance of traditional mineral and bitumen mixes in hot technology. The American and Finnish methods were used – PANK 4302 standard enables the assessment of mineral and bitumen mixes resistance to low temperature cracking. The modified AASHTO T283 method covers the influence of water on mineral and bitumen mixes as well as water interaction and freezing cycles.

To assess moisture and frost resistance the following parameters were determined:

- tensile strength retained TSR (Wirtgen Cold Recycling Manual [4]),
- resistance to low temperature cracking according to the Finnish PANK 4302 standard (PANK 4302 Standard [9]),
- indirect tensile strength after curing in water and frost according to the American guidelines, e.g. the AASHTO T283 method (AASHTO T283 Standard [10], JUDYCKI and JASKUŁA [11], IWAŃSKI [12]).

As mentioned in the requirements (Wirtgen Cold Recycling Manual [4]), the tensile strength retained (TSR) was taken as water resistance criterion. The TSR enables only to assess the water tightness and the resistance due to the effects of water. According to the criterion proposed by Jenkins (JENKINS *et al.* [2]) the parameter ITS_{wet} is determined. Specimens after curing in dry conditions, are submerged in water for 24 hours. TSR is calculated from the equation:

$$(3.3) \quad TSR = \frac{ITS_{wet}}{ITS_{dry}}$$

Where ITS_{dry} – indirect tensile strength in the dry state [kPa] and ITS_{wet} – indirect tensile strength after soaking with water [kPa].

According Wirtgen Cold Recycling Manual ([4]), the pavement construction is protected from below against the effects of water when its TSR is ≤ 0.70 .

Investigation of the resistance to low temperature cracking according to PANK 4302 is based on determination of the indirect tensile strength of specimens kept in an air chamber at the temperature of -2°C for 16 hours as described [9]. The tests are conducted in the Marshall apparatus at the temperature of -2°C .

Figure 5 and 6 presents the regression for TSR (tensile strength retained) and R_r (indirect tensile strength according to PANK 4302). Figure 7 presents WR_W and WR_{W+M} values (indirect tensile strength after curing only in water and in water and frost according to AASHTO T283).

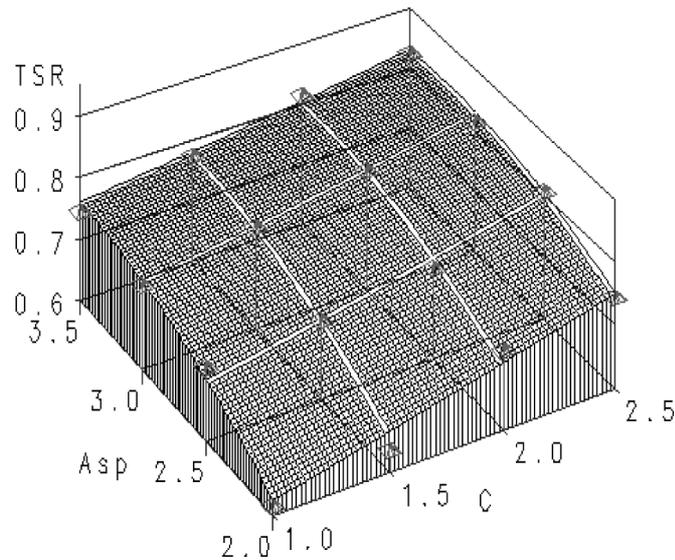


Fig. 5. The impact of foamed bitumen and cement contents on tensile strength retained TSR.
Rys. 5. Wpływ zawartości asfaltu spienionego i cementu na wskaźnik odporności na oddziaływanie wody TSR

Analysis of the results focused on the influence on the tested parameters, namely: TSR, R_r , WR_W and WR_{W+M} . It is important to first determine the level of the regression coefficients R^2 . Next, the influence of the given factors on the character of distribution of the assessed parameters. These are presented in Table 3.

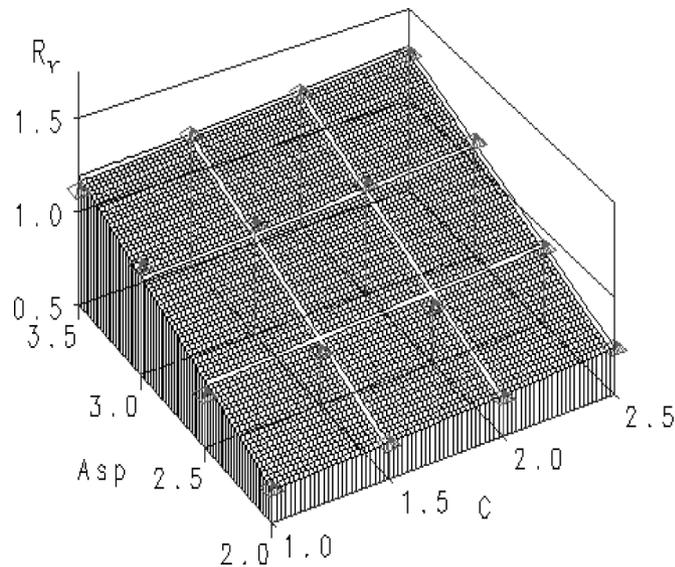


Fig. 6. The impact of foamed bitumen and cement contents on frost resistance according to PANK 4302.
Rys. 6. Wpływ zawartości asfaltu spienionego i cementu na odporność na oddziaływanie mrozu wg PANK 4302

Table 3

The coefficient R^2 and the importance of the impact of given factors.
Współczynnik R^2 oraz istotność efektu wpływu czynników

Parameter	R^2	Foamed bitumen (Asp)	Cement (C)
TSR	0.9545	<.0001	<.0001
R_r	0.9618	<.0001	0.1343
WR_W	0.9640	<.0001	<.0001
WR_{W+M}	0.9587	<.0001	<.0001

The results of the experimental coefficients of the regression models are presented in Table 4.

Table 4

The values of experimental coefficients for the properties: TSR, R_r , WR_W , WR_{W+M} .
Wartości współczynników eksperymentalnych dla cechy: TSR, R_r , WR_W , WR_{W+M}

Parameter	b_0	b_1	b_2	b_3	b_4	b_5
TSR	-0.064100	0.417900	0.116700	-0.024800	-0.055000	0.005000
R_r	-0.029450	0.343550	-0.026350	0.016400	-0.002500	0.012500
WR_W	10.680500	30.830500	14.511500	-5.475000	1.924000	-3.825000
WR_{W+M}	-13.152500	27.252500	28.307500	0.460000	-3.875000	-5.525000

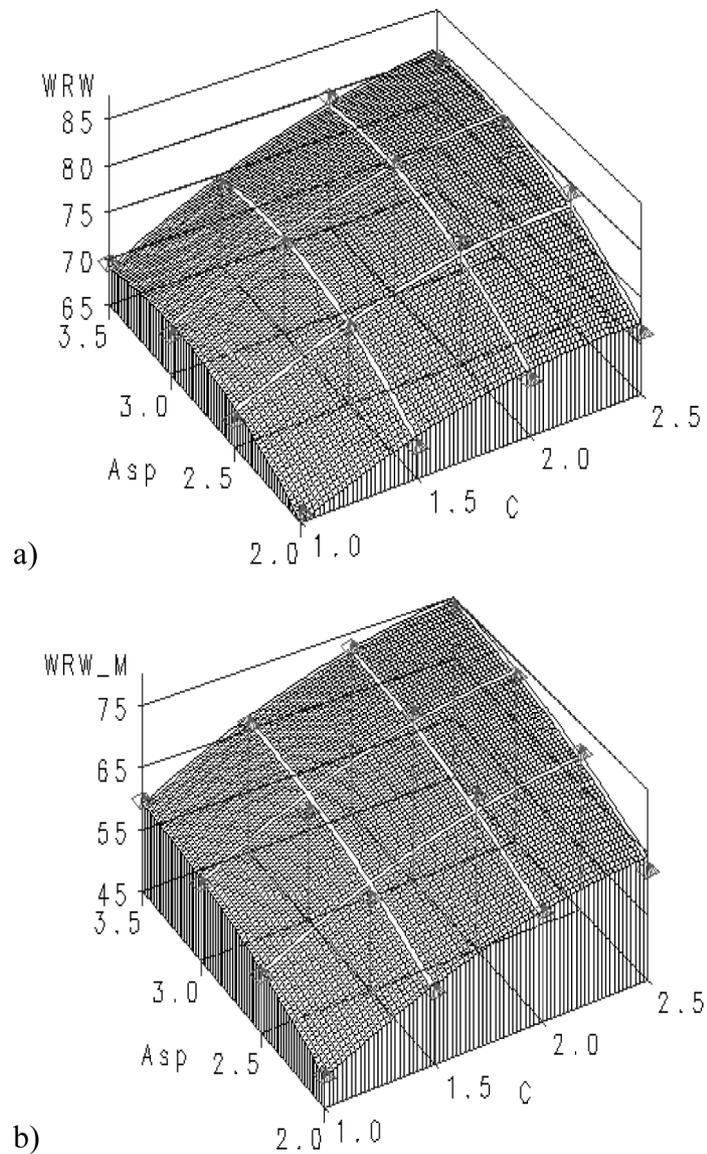


Fig. 7. The influence of foamed bitumen and cement contents on: a) water resistance WR_W b) water and frost resistance WR_{W+M} according to AASHTO T283.

Rys. 7. Wpływ zawartości asfaltu spienionego i cementu na: a) odporność na oddziaływanie wody WR_W oraz b) wody i mrozu WR_{W+M} wg AASHTO T283

From Fig. 5, 6 and 7 it is evident, that the amount of both binding agents has an important influence on water and frost resistance. Together with the increase of binder and cement concentration the value of the parameters rises.

The increase in the content of binding materials in recycled pavement mixes leads to obtaining the TSR at the higher level. Tightness and water resistance is ensured with 2.0% cement content in recycled pavement which already contains 2.0% of foamed bitumen. In this case the TSR was higher than the required minimal value (0.7). Consequently, it is useless to apply more cement. That may cause cracking in pavement layer and layers of road surface above.

Indirect tensile strength at -2°C according to PANK 4302 ([9]) after the curing process (which simulated the effects of low temperatures), does not exceed the limiting value of 4.8 MPa. As a result, such pavement structures will be resistant to cracking at low temperatures during winter.

A thorough assessment of water and frost resistance was performed according to AASHTO T283. When the strength ratio is higher than 0.7, it is assumed that the mixes made by traditional technologies are water and frost resistant. From the analysis of the results we may state however, that the required value is not obtained in every case. It should be noted that with 2.5% bitumen binder content and 2.0% cement content, the required strength characteristics of tested material is obtained. The strength ratio for the tested material is higher than the minimal value ($\text{WR}_W = 78.3\%$, $\text{WR}_{W+M} = 70.2\%$). That assures its water and frost resistance. While the higher resistance was ensured by the application of higher contents of these two binding materials in the recycled pavement composition.

From the laboratory tests we may state, that water resistance criterion of the recycled pavement based solely on the TSR parameter in Polish weather conditions should be broadened. It should include – for example – the proposed AASHTO T283 method (AASHTO T283 Standard [10]).

4. CONCLUSIONS

From this investigation based solely on the laboratory tests, the following conclusions can be drawn:

- the indirect tensile strength of surface pavement with foamed bitumen increases with the increase in foamed bitumen content in recycled pavement material;
- the increase in the foamed bitumen content up to 2.5% in the recycled material for surface pavement improves its mechanical properties: Marshall stability and the stiffness. The further increase in the foamed bitumen content causes a deterioration in these parameters;
- the water resistance criterion of the recycled pavement based only on the TSR parameter is insufficient. It should be broadened in order to include the proposed AASHTO T283 method;

- the recycled pavement with foamed bitumen has higher static creep modulus when less foamed bitumen is applied. It should ensure the pavement production which is more resistant to plastic deformations;
- the application of 2.5% foamed bitumen ensures the water and frost resistance;
- the foamed bitumen and cement contents of 2.5% and 2.0%, ensures the required mechanical parameters and water resistance.

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ODPORNOŚĆ NA ODDZIAŁYWANIE WODY I MROZU PODBUDOWY W TECHNOLOGII RECYKLINGU Z ASFALTEM SPIENIONYM

Streszczenie

Ze względu na warunki klimatyczne występujące w krajach Europy Centralnej podbudowa powinna charakteryzować się wysokimi parametrami mechanicznymi oraz odpornością na działanie wody i mrozu.

Przedmiotem badań była ocena właściwości recyklowanych mieszanek mineralnych z asfaltem spienionym w zależności od ilości zastosowanych materiałów wiążących (lepiszcza i spoiwa). Badania wykonano na mieszankach, w których wykorzystano materiał istniejących warstw konstrukcji nawierzchni drogowej. Zawartość lepiszcza asfaltowego wynosiła 2,0%, 2,5%, 3,0% i 3,5%, natomiast cementu 1,0%, 1,5%, 2,0%, 2,5%. Otrzymane wyniki badań poddane procesowi optymalizacji pozwoliły stwierdzić, że przy zastosowaniu 2,5% asfaltu spienionego oraz 2,0% cementu materiał podbudowy charakteryzuje się odpowiednimi właściwościami fizykomechanicznymi oraz wymaganą wodo- i mrozoodpornością wg. zastosowanych kryteriów.

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