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# Rheological Properties of Mastic with the Addition of Synthetic Wax and Hydrated Lime within the Viscoelastic Region

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**Abstract.** Mastic has a significant effect on the properties of bituminous mixtures and acts as a real binder. It determines the resistance of the asphalt mixture to the formation of plastic deformation, the sensitivity to the effects of water and the low temperature cracking as well. In the article, advanced rheological research using the mastic with virgin bitumen 50/70 was presented. Mastic has been enriched by addition of the hydrated lime together with synthetic wax modified bitumen. The experiment design was based on the Box-Behnken plan. This experiment plan consisted of three controlled factors: the amount of synthetic wax, the amount of hydrated lime and the amount of filler in the asphalt mastic composition. The work highlights the interaction between synthetic wax and the amount of hydrated lime. The assessment of the influence of controlled factors was determined within the viscoelastic region performed by means of a dynamic shear rheometer. The experiment used the determination of viscoelastic properties of the mastic, i.e. complex dynamic viscosity  $\eta^*$ , dynamic shear modulus  $G^*$ , phase shift angle  $\delta$  at temperatures 40 °C, 60 °C and 80 °C. In addition, the influence of controlled factors was determined using MSCR tests in the 100 Pa and 3200 Pa range. As a result, creep compliance and elastic recovery were determined at 60 °C. The tests showed a diversified increase in the stiffness of the asphalt mastic with wax and hydrated lime additive, at given high test temperatures, in relation to the mastic with a traditional filler. It should be noted that the presence of crystallites of a synthetic wax also caused a significant increase in the stiffness of the mastic.

## 1. Introduction

Asphalt mastic is a suspension of filler in asphalt that coats coarse grains in asphalt mixture [1]. In reality, mastic is the correct binder in the asphalt mixture, playing a key role in the compaction of asphalt mixtures, and it also affects their durability throughout their service life [2,3]. The stiffening effect on asphalt caused by the mineral filler content affects the mechanical properties of asphalt mixtures in terms of resistance to permanent deformation and low temperatures [4,5]. The structuring function of the filler in the mastic depends on multiple parameters, including filler type, grain size distribution and filler concentration in the mastic [6]. A suitable amount of filler particles dispersed in the asphalt slow down crack propagation in mastics due to the “pinning” effect [7]. Hydrated lime, which also functions as the filler, owing to its basic reaction, successfully impacts asphalt properties



[8] and improves asphalt adhesion to the aggregate with high SiO<sub>2</sub> silica content. It also acts as an asphalt antioxidant, slowing down asphalt ageing and, consequently, the loss of visco-elastic properties [9]. The presence of an active filler increases the stiffness of the mastic and improves resistance to permanent deformation of the asphalt mixture, increasing the fatigue life and loading time sensitivity [10]. The key issue is to separate the function of the filler ( $d < 0.075$  mm) of coarse aggregate fractions in the asphalt mixture. The filler suspension in the bitumen fills the voids between coarse grains of the asphalt mixture. Consequently, the amount of bitumen absorbed by the filler is greater than the amount absorbed by fine and coarse aggregate grains. Thus, the impact of mastic on the properties of the asphalt mixture is much greater than the impact of the bitumen itself. This means that the critical level of the filler/bitumen concentration is the basis for the determination of the minimum amount of bitumen that ensures that the mastic in the diluted state can properly coat coarse aggregate grains [11]. The stiffness of the mastic may be affected not only by the concentration of the filler but also by the chemical composition of the filler itself and by the chemical composition of the bitumen [3,12], which has a significant impact on the formation of adsorbent-solvate liquid layers with various thickness different from the liquid located farther away from the surface [13]. Due to increasing road traffic loading and the need to take into account environmental aspects, innovative materials and technologies should be considered. In this context, the interest in the warm mix asphalt (WMA) technology keeps increasing [14]. The WMA technology involves the compaction of asphalt mixtures at temperatures ranging from 100 °C to 140 °C, which requires using modifiers [15]. Although there are certain summaries of the impact of F-T synthetic wax on the properties of bitumen and asphalt mixtures, there is no exhaustive information about the impact of wax on the mastic [16].

## 2. Materials and methods

### 2.1. Box-Behnken experimental design

The Box-Behnken design is an experimental design with variables of three levels: -1, 0, +1 (coded values). This design is suitable for the description of changes in the measured value by a second-degree polynomial [17]. The form of the function used in the experiment was as follows (1):

$$y = b_0 + \sum_{i=1}^k b_i \cdot x_i + \sum_{i=1}^{k-1} \sum_{j=i+1}^k b_{ij} \cdot x_i \cdot x_j + \sum_{i=1}^k b_{ii} \cdot x_i^2 \quad (1)$$

where:  $k$  – number of independent variables,  $b_{ij}$  – experimental factors,  $y$  – dependent (measured variable)

An advantage of this design is the fact that the independent variables do not simultaneously adopt all extreme values, which is convenient when extreme concentrations of the ingredients are present. In this case, this enables avoiding a highly viscous mastic composition, which would prevent the tests. All points (coded variables) of the design are located on the surface of a sphere with the  $\sqrt{2}$  radius. Consequently, variance depends only on the distance from the central point, not its location in the design. Also, the design enables reducing the number of variables in relation to the  $3^3$  full factorial design without losing any of the interaction terms. This enables reducing the full factorial design from 27 to the necessary 15 mastic compositions.

### 2.2. Bitumen modified with synthetic wax F-T

50/70 paving bitumen was used in the tests. Due to the small difference in density between bitumen and synthetic wax, synthetic wax (WAX) was added to the asphalt in amounts of 1.5% and 3.0% by weight. The preparation process involved sampling of bitumen for each modification level, in the amount of 250 g. The sample was subsequently heated up to 155 °C and kept at that temperature for 30 minutes. The next stage was to mix the bitumen with synthetic wax. In order to ensure homogeneity, the binder was mixed in a blender at a constant temperature at 400 rpm. The main parameters of the produced wax/bitumen mixtures are presented in table 1.

**Table 1.** Primary rheological parameters of 50/70 bitumen modified with synthetic wax

Parameter	Standard	Unit	Ingredient/mixture			
			Synthetic wax (WAX)	Asphalt 50/70	Wax-modified bitumen	
				0%	+ 1.5% WAX	+ 3% WAX
<b>Softening temperature</b>	PN-EN 1427:2015-0	°C	81	51.9	60.4	76
<b>Penetration</b>	PN-EN 1426:2015-08	0.1 mm	9	58	42	31
<b>G*/sinδ at 60 °C</b>	NCHRP REPORT 459	°C	-	717	1725	3541
<b>Jnr3200Pa at 60 °C</b>	PN-EN 16659:2016-02	kPa <sup>-1</sup>	-	0.55	0.42	0.12
<b>Fraass temperature</b>	PN-EN 12593:2015-08	°C	-	-10	-9	-7
<b>Density at 25 °C</b>	PN-EN 15326+A1:2010	Mg/m <sup>3</sup>	0.97	1.030	1.029	1.028

### 2.3. Mixed filler

The experiment involved using a reference limestone filler (LM) and mixed filler produced by combining hydrated lime (HL) and limestone filler in the ratio (HL/LM) of 0.15 and 0.3 (m/m), in accordance with the recommendations of study [6]. The samples of modified bitumen and filler were heated up to 155 °C and kept at that temperature for 30 minutes. The next stage was to mix bitumen and various filler compositions at a constant temperature at 400 rpm. After mixing, the mastic samples designed for the test were conditioned at 5 °C until the time of testing. Due to the different density of both ingredients, the volume fraction of hydrated lime (HL) in the limestone filler was within the range of 17.6% to 34.2% (v/v). The detailed summary of results required by EN 14043 is presented in table 2.

**Table 2.** Selected physical and mechanical parameters of mixed filler as per PN-EN 14043

Parameter	Standard	Unit	Ingredient/mixture		
			LS	HL/LS	
				0.15 (m/m)	0.3 (m/m)
<b>Rigden voids</b>	EN 1097-4	%	35.12	39.04	41.13
<b>Delta ring and ball temperature</b>	EN 13179-1	°C	11.08	15.93	18.51
<b>Filler composition particle density</b>	EN 1097-7	Mg/m <sup>3</sup>	2.71	2.63	2.55

Excessive amount of hydrated lime in relation to the volume of the limestone filler should also be avoided due to the intensive increase of mastic stiffness and significant reduction of the workability of the asphalt mixture. According to Wilanowicz et al. [4], the value of  $V_{fb}$  (volume of compacted filler) for dusts from the dust extraction system should be lower than 60% because it results in excessive stiffening of the mastic. Consequently, the experiment involved f/b ratios for which this value of  $V_{fb}$  was exceeded. The compositions had to be adapted to be used in the Box-Behnken design. The discussed cases of the mixtures (systems) are presented in table 3.

**Table 3.** Plan of the design and suitable mastic compositions

Layout	3 Box-Behnken design			F/B densities	$V_{\text{mix.filler}}$	$V_{\text{bit}}$	$V_{\text{fb}}$
	WAX	HL/L	F/B	$\text{Mg/m}^3$	% (v/v)	% (v/v)	%
	(w/w)	(w/w)	(w/w)				
1	0.00	0.00	2.00	1.75	43.03	56.97	66.33
2	3.00	0.00	2.00	1.75	42.93	57.07	66.17
3	0.00	0.30	2.00	1.70	44.54	55.46	75.66
4	3.00	0.30	2.00	1.70	44.44	55.56	75.48
5	0.00	0.15	1.00	1.47	28.04	71.96	46.00
6	3.00	0.15	1.00	1.47	27.96	72.04	45.86
7	0.00	0.15	3.00	1.89	53.89	46.11	88.41
8	3.00	0.15	3.00	1.88	53.79	46.21	88.24
9	1.50	0.00	1.00	1.48	27.38	72.62	42.19
10	1.50	0.30	1.00	1.46	28.61	71.39	48.60
11	1.50	0.00	3.00	1.92	53.07	46.93	81.80
12	1.50	0.30	3.00	1.86	54.59	45.41	92.73
13	1.50	0.15	2.00	1.72	43.75	56.25	71.76
14	1.50	0.15	2.00	1.72	43.75	56.25	71.76
15	1.50	0.15	2.00	1.72	43.75	56.25	71.76

It should be noted that the increase of the amount of hydrated lime (table 3) in the composition of the mixed filler resulted in a significant increase of the  $V_{\text{fb}}$  parameter. Also, in some cases, this value was much higher than 60%. Consequently, high stiffness of the mastic should be expected.

#### 2.4. Shear stiffness modulus $G^*$ and phase angle $\delta$

Dynamic tests were carried out using the Rheotest 4.1 rheometer in the oscillation mode. The tests were conducted using the “cone-plate” setup with the cone having a diameter of 25 mm. The stress amplitude was selected so as to conduct the test in the linear visco-elasticity region for the applied temperature range, and it was no lower than 100 Pa, in accordance with the conclusions of report SHRP-A-370. The tests were conducted for the frequency range of 0.01 Hz to 10 Hz at 40 °C, 60 °C and 80 °C. All tests conformed to EN 14770:2012.

#### 2.5. MSCR test

This method can be used to test compliance and recovery of the binder under simulated loading conditions similar to the actual conditions in the linear and non-linear visco-elastic range. The MSCR test was conducted in accordance with PN-EN 16659:2016-02 and AASHTO TP70. Binder compliance was tested for shear stress of 3200 kPa applied for 1 second, followed by the measurement of the elastic recovery of bitumen for 9 seconds with bitumen temperature of 60 °C. The entire cycle for a single stress range was 100 seconds. The test determined compliance  $J_{\text{nr}}$  (non-recoverable part of deformation divided by the applied stress) and elastic recovery  $\varepsilon_r$  % (percentage of relative elastic strain constituting the ratio of deformation at the 1st second at the beginning of the cycle to the deformation at the 10th second).

### 3. Test results

#### 3.1. Impact of mastic composition on complex modulus $G^*$ and complex viscosity $\eta^*$

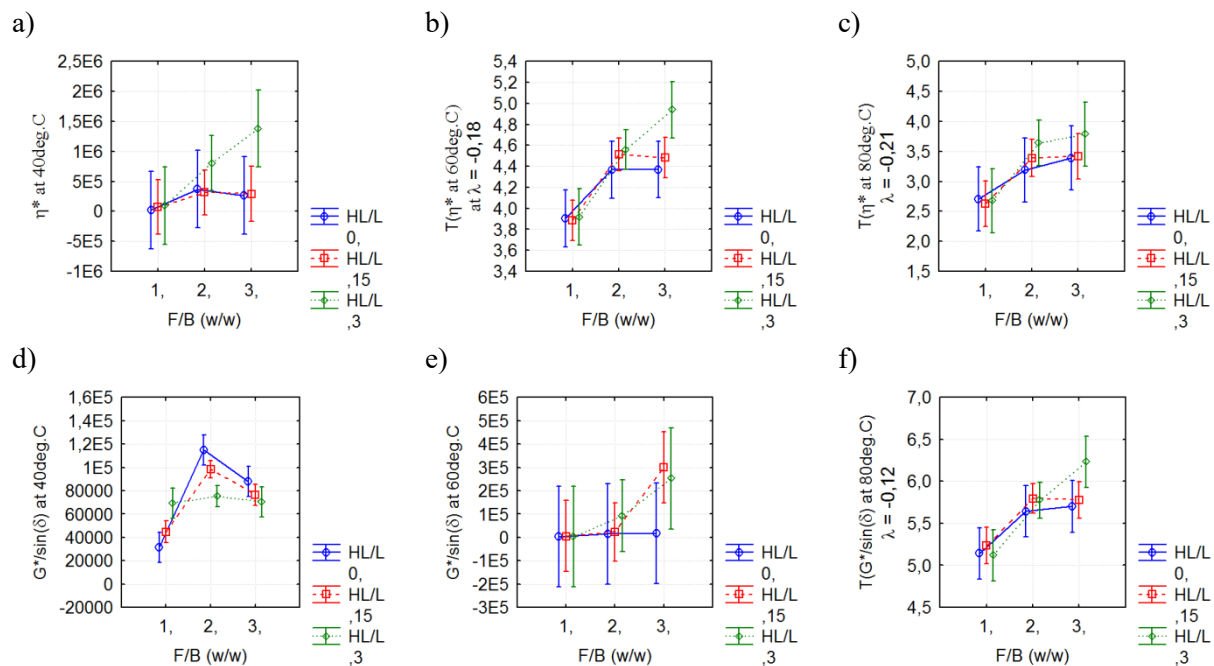
All mastic compositions were assigned to the Box-Behnken design so as to achieve full randomisation. The purpose of this was to eliminate systematic errors. In order to associate complex shear modulus  $G^*$  with phase angle  $\delta$ , the  $G^*/\sin\delta$  standard rutting parameter as per NCHRP REPORT 459 was used

during further analysis in the established linear visco-elasticity (LVE) range. Due to the large measuring range, the representation of the estimated models of the  $G^*/\sin\delta$  parameter in relation to the Box-Behnken design was presented at the frequency of 1.59 Hz (10 rad/s), while  $\eta^*$  was presented at 0.01 Hz (0.063 rad/s), which reflected the level of low-shear viscosity (LSV). A very important issue was to determine if the results of the experiment (dependent variable) corresponded to normal distribution. Following the determination, it was found that certain data sets did not conform to this criterion, which had a significant impact on the goodness of fit of the model parameters. Consequently, some variables involved in the experiment, i.e.:  $\eta^*$  (at 60 °C, 80 °C) and  $G^*/\sin\delta$  (at 80 °C) were transformed. In accordance with separate analyses, the best transformation function to stabilise variance was as follows (2):

$$Y' = Y^\lambda \quad (2)$$

where  $Y'$  = transformed variable,  $Y$  – experimental variable,  $\lambda$  – transformation variable.

All transformations of dependent variables were done for  $\lambda$  in the range of -0.12 to -0.21. The next step was to determine the parameters of the sought-out objective function of the response surface based on experimental results. The results of the observations of determined marginal means using the data from regression models for variables  $\eta^*$  and  $G^*/\sin\delta$  at 60 °C are presented in figure 1.



**Figure 1.** Results of observations of marginal means of the models of the response service for the complex viscosity parameter: a)  $\eta^*$  at 40 °C; b)  $T(\eta^*$  at 60 °C); c)  $T(\eta^*$  at 80 °C) and for the  $G^*/\sin\delta$  parameter: d)  $G^*/\sin\delta$  at 40 °C; e)  $G^*/\sin\delta$  at 60 °C; f)  $T(G^*/\sin\delta$  at 80 °C)

In figure 1, all values marked as  $T(Y)$  indicate that the specific variable has been transformed. All error bars have been determined based on MSE determined in the particular response surface model. It should be noted that error bars also represent the general variability introduced by the presence of synthetic wax in an amount of up to 3%. The greater the variability, the lower the impact of synthetic wax on the rheological properties of different mastic compositions.

It should also be noted that the increase of the filler/bitumen (f/b) ratio increases the stiffness of the mastic. Additionally, the increase of the amount of HL in the composition of LM rapidly increases the

stiffness of the mastic structure, as demonstrated by the different inclinations of  $G^*/\sin\delta$  and  $\eta^*$  lines. The presence of the WAX ingredient, representing the error bars, means that adding large quantities of synthetic wax and HL may cause an undesirable and, at the same time, extreme increase of mastic stiffness, which, in turn, greatly hinders the compaction of the asphalt mixture. Interesting observations were recorded during the measurement of the  $G^*/\sin\delta$  parameter. It is the equivalent of the imaginary part of compliance  $J^*$  and is proportionate to zero shear viscosity  $\eta_{ZSV}$ . At temperatures up to 80 °C with large content of SW>1.5% and HL>0.15%, the mastic had a very high level of  $G^*/\sin\delta$ , indicating that phase angle  $\delta$  of the mastic was very low. Consequently, this indicated almost elastic material behaviour. The most disconcerting fact was the large increase of mastic stiffness, which was also recorded at 80 °C with the above-mentioned mastic composition – this was ascribed to the presence of synthetic wax crystallites in the bitumen. Consequently, compaction of the asphalt mixture with such configuration of ingredients in the mastic at approximately 80 °C could be impractical or impossible.

The above analysis has been conducted based on predicted values obtained by fitting of the second degree polynomial model. The results of the model of response surface for the analysed parameters are presented in table 4.

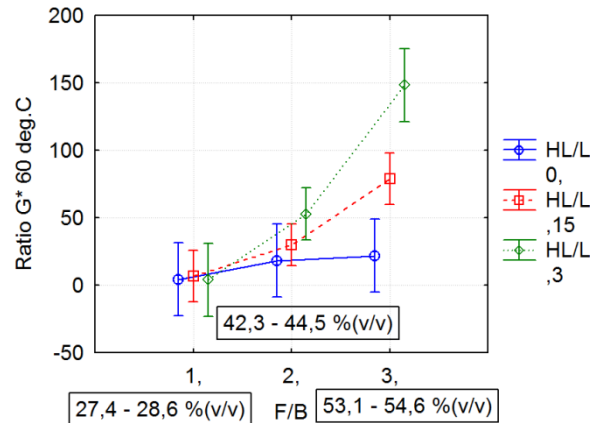
**Table 4.** Parameters of the response surface of the Box-Behnken design

Factors	Regression parameters of the second-degree polynomial model in the Box-Behnken design					
	$\eta^*40\text{ }^\circ\text{C}$	$T(\eta^*60\text{ }^\circ\text{C})$	$T(\eta^*80\text{ }^\circ\text{C})$	$G^*/\sin\delta\text{ }40\text{ }^\circ\text{C}$	$G^*/\sin\delta\text{ }60\text{ }^\circ\text{C}$	$T(G^*/\sin\delta\text{ }80\text{ }^\circ\text{C})$
	Pas	Pas	Pas	Pa	Pa	Pa
<b>mean</b>	2.625E+02	<b>2.926E+00</b>	<b>1.233E+00</b>	<b>-1.181E+05</b>	<b>4.348E+05</b>	<b>4.265E+00</b>
<b>(1)WAX (L)</b>	-4.906E+04	<b>3.014E-01</b>	2.874E-01	<b>4.436E+04</b>	<b>-2.305E+05</b>	<b>2.899E-01</b>
<b>WAX (Q)</b>	-1.765E+04	<b>-7.725E-02</b>	-5.333E-02	<b>-6.459E+03</b>	2.470E+04	<b>-6.860E-02</b>
<b>(2)HL/L (L)</b>	-6.178E+06	4.168E-01	-3.351E-01	<b>4.826E+05</b>	-3.329E+05	9.301E-01
<b>HL/L(Q)</b>	<b>9.802E+06</b>	-3.346E+00	-1.401E-01	<b>-4.636E+05</b>	-1.264E+06	-4.961E+00
<b>(3)F/B(L)</b>	2.681E+05	<b>6.766E-01</b>	<b>1.276E+00</b>	<b>1.204E+05</b>	-3.945E+05	6.313E-01
<b>F/B(Q)</b>	-9.449E+04	<b>-1.559E-01</b>	<b>-2.443E-01</b>	<b>-2.323E+04</b>	<b>7.403E+04</b>	<b>-1.348E-01</b>
<b>1L wz.2L</b>	<b>1.188E+06</b>	1.353E-01	3.436E-01	<b>-9.133E+04</b>	1.757E+05	-2.962E-02
<b>1L wz.3L</b>	6.297E+04	<b>9.504E-02</b>	1.048E-02	9.333E+02	<b>9.752E+04</b>	7.628E-02
<b>2L wz.3L</b>	<b>1.736E+06</b>	<b>9.250E-01</b>	7.126E-01	<b>-9.200E+04</b>	3.924E+05	<b>9.226E-01</b>
<b>R<sup>2</sup></b>	0.9	0.98	0.93	0.98	0.97	0.86

The results in table 4 indicate a very good fit of the model to the experimental data. The lowest value of factor  $R^2$  was 0.86. The common characteristic of all analyses, regardless of the temperature level, was the significant impact of the amount of filler in the mastic on its rheological properties in the model. The remaining ingredients usually demonstrated their significant impact in interaction with the f/b parameter, which indicates that they have an auxiliary role in the shaping of the mastic structure. Nevertheless, synthetic wax in most cases had an independent significant impact on the stiffness of the mastic. An interaction between synthetic wax and the amount of hydrated lime was observed as well. At temperatures lower than 60 °C, interactions between WAX and HL/L were significant, whereas at higher temperatures interactions between WAX and F/B and between HL/L and F-B were significant. The strong interaction above 60 °C between WAX and F/B indicated that synthetic wax acted as a fine-crystalline filler (in the form of crystallites) and complemented the filler phase.

The nature of mastic structuring and the amount of its ingredients were determined by assessing the changes of rigidity at the temperature that may be achieved by the asphalt mixture in the summer. This temperature is usually approximately 60 °C, and it is similar to the softening temperature of 50/70 asphalt (table 1). According to the references, the leading parameter strongly indicative of mastic

structuring was the  $G^*$  Ratio parameter [3]. It expressed the ratio of  $G^*$  of regular bitumen to  $G^*$  of the mastic with the particular composition of ingredients at 60 °C. The results are presented in figure 2.

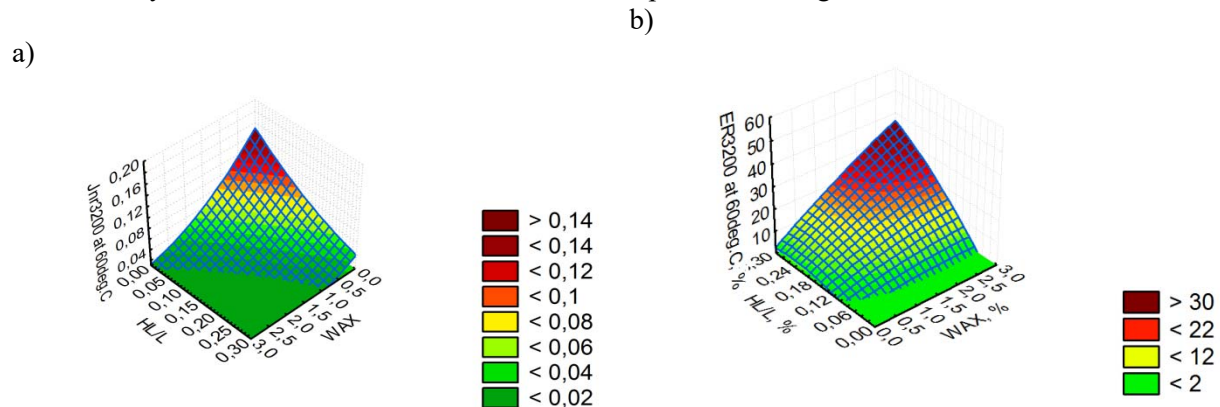


**Figure 2.** Impact of mastic composition on the  $G^*$  Ratio parameter at 60 °C

It should be noted that at a specific point around  $f/b = 2$ , there was probably a sudden rise of mastic stiffness, which means that there is a critical combination of the individual ingredients in the mastic. The specific content of ingredient combinations is currently assessed as part of mathematical model validation tests determining the critical level of their concentration with an addition of synthetic wax. Using the mathematical descriptions of the changes of rheological properties of the mastic by means of the Box-Behnken design enables optimising the  $f/b$  ratio in the asphalt and, eventually, determining the minimum amount of bitumen in the asphalt mixture. In figure 2, exceeding the 40% (v/v) or 2:1 (w/w) threshold (figure 2) of filler content in the asphalt may result in a dynamic decrease of mastic compliance and cause the asphalt mixture to have a very low workability. This is an initial assessment, but similar conclusions were drawn by Wilanowicz et al. [4] and Faheem et al. [3].

### 3.2. Impact of mastic composition on parameters of the MSCR methodology

The previous analysis of test results concerned the behaviour of the material in the linear visco-elastic range. However, an equally important matter is the behaviour of mastic in the non-linear visco-elastic range. These test results complement the analysis of the impact of mastic composition on mastic stiffness under high shear stress. The fitting of the regression model to the change of compliance  $J_{nr}$  and recovery  $ER$  at 60 °C under a stress of 3200 Pa is presented in figure 3.



**Figure 3.** Response surface specified for parameters: a)  $J_{nr}$  (1/Pa); b)  $ER$  (%) at  $f/b = 2$

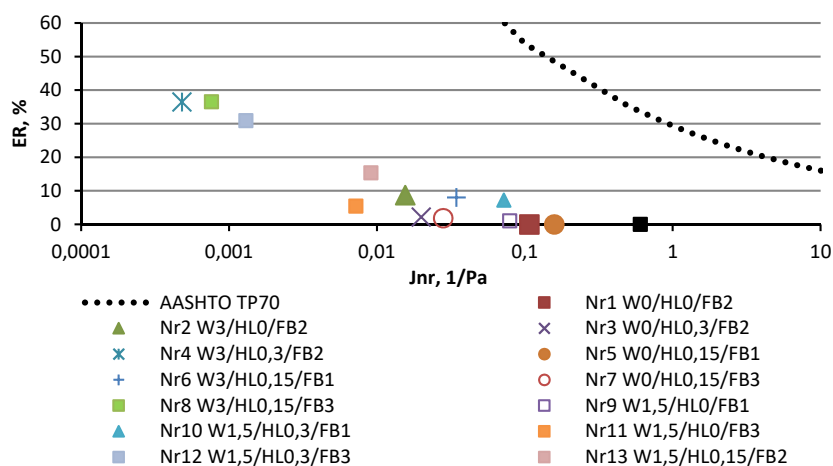
The results of the fitting parameters, in turn, are presented in table 5.



**Table 5.** Parameters of the response surface of the Box-Behnken design

Factors	Regression parameters of the second-degree polynomial model in the Box-Behnken design	
	Jnr <sub>3200Pa</sub>	ER <sub>3200Pa</sub>
	1/Pa	%
mean	3.268E-01	-6.750E-01
(1)WAX (L)	-9.401E-02	-3.961E+00
WAX (Q)	9.347E-03	-6.772E-01
(2)HL/L (L)	-2.948E-01	-2.922E+01
HL/L(Q)	2.496E-01	-8.772E+01
(3)F/B(L)	-1.633E-01	4.673E+00
F/B(Q)	2.516E-02	-2.211E+00
1L wz.2L	8.020E-02	2.848E+01
1L wz.3L	1.606E-02	4.433E+00
2L wz.3L	1.833E-03	3.210E+01
R <sup>2</sup>	0.96	0.98

Upon analysis of the test results in figure 3, it should be noted that at 60 °C the increase of the amount of component HL > 0.15 and WAX > 1.5% causes the mastic at ratio f/b = 2 to become a stiff body with a very low compliance Jnr. However, using the HL ingredient in amount > 0.06%, regardless of the amount of WAX involved in the experiment prevented the composite from having the elastic recovery determined based on ER. With both parameters used in the MSCR test, the increase of the amount of WAX and HL causes a very dynamic change of their value. It should be noticed (table 5) that the level of both Jnr and ER in the MSCR test also changed very quickly depending on the f/b ratio and the amount of WAX. As regard the ER parameter, all interactions between mastic ingredients played a very important role. The observations obtained above confirm that when designing the amount of bitumen in the asphalt mixture, it is necessary to consider the synergy between wax and filler composition. Finally, the results of Jnr and ER tests were plotted on the MSCR chart with a borderline required for correct classification of modified bitumens (figure 4).

**Figure 4.** Results of Jnr and ER tests plotted on the MSCR chart

It should be noted that the individual combinations of mastic ingredients resulted in very different rheological properties. Figure 4 shows certain groups of similarities between the results of mastic tests.

It can be inferred that two different mastic compositions can cause a similar mastic structuring effect. For instance, composition No. 4 (W0/HL0.3/FB2 (0% synthetic wax/0.3% hydrated lime/2 filler to bitumen ratio 2:1) is similar to composition No. 8 W3/HL0.15/FB3, which indicates that a specific amount of the WAX ingredient has an effect similar to adding a certain amount HL. Similarly, the high level (0.3) of the HL ingredient had the same effect on the mastic as the composition containing less HL (0.15) but having a higher f/b ratio, as in cases No. 3 and No. 7. As a result, the amount of free bitumen may be different depending on the amount of mixed filler and synthetic wax and may significantly affect the final properties of the asphalt mixture.

#### 4. Conclusions

The following conclusions were drawn based on the test results:

- the synergy between synthetic wax, the composition of mixed filler and the F/B ratio had a significant impact on mastic stiffness,
- the F/B ratio was found to be the most important parameter characterising the nature of mastic stiffness changes,
- synthetic wax (WAX), independent of other parameters, caused the stiffening of the mastic, indicating that it acted as a fine-crystalline filler complementing the mixed filler phase;
- the interaction between WAX and HL/L was observed at temperatures lower than 60 °C, whereas at higher temperatures, the most important element was the interaction between HL/L and F/B,
- the presence of synthetic wax in interaction with the filler causes a sudden decrease of compliance and increase of recovery according to the MSCR tests,
- the interaction of a large amount of synthetic wax and mixed filler causes the mastic to behave as an elastic material at 80 °C. In this situation, compacting the mixture made of such mastic can be difficult,
- the mastic stiffening effect of synthetic wax (WAX) may be substituted by the optimum amount of the mixed filler (HL) in the limestone filler (LM).

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