STUDY ON THE PLASTIC DEFORMATIONS OF THE ASPHALT MIXTURES

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ABSTRACT

The temperatures during the last summers were unusually high for relatively long periods of time and this combined with an increase of the traffic resulted in a number of ruts on the asphalt pavements in our country.
Asphalt mixtures were tested in order to predict their plastic deformation behavior using two methods. The first is the standard test method EN 12697 – Part 22 "Wheel Tracking". The asphalt mixtures were compacted with a sector compactor. The second method is through determination the cohesion of the asphalt mixtures. The cohesion is determined by testing the compressive strength and the shear stress.
The investigated asphalt mixtures were produced with the same mineral material and gradation, but different binders. The binders used were neat bitumen; polymer modified bitumen and modified bitumen. The standard physical and mechanical properties of the binders were tested as well as their viscosity by dynamic shear rheometer. The test results suggested that asphalt mixtures have different cohesion value, depending on the binder type, when tested under the same conditions. Based on the results obtained it is concluded that the cohesion determining method can identify future plastic deformation in asphalt pavements.
Road sections were constructed using the same binders, which are periodically observed for developing plastic deformations.

Keywords: asphalt mixtures, cohesion, plastic deformation, shear stress

INTRODUCTION

The temperatures during the last summers were unusually high for relatively long periods of time and this combined with an increase of the traffic resulted in a number of ruts on the asphalt pavements in our country. Ruts occurred at a road section paved with asphalt concrete right after opening it to traffic, which depth increased with the time. The investigation proved that the ruts occurred only in the wearing course. Another road section executed with polymer modified asphalt concrete has been in service for 10 years without having any deformations. One of the factors determining the resistance of the asphalt pavements to permanent deformations is the binder. The bitumen binds the mineral materials and must ensure a good bonding between them for a long period of time at a wide temperature interval. The strength and the durability of the bitumen film depend on the rheological properties of the binder, determining its behavior at different temperatures, shear stresses and shear rates. The aim of this study is to investigate the possible relations between the rheological properties of binders and the resistance of the asphalt samples produced with these binders to permanent plastic deformations.

2. TEST METHOD

a) The binders were tested according the test methods presented in table 1.

b) The following rheological characteristics of the tested binders were determined:

- shear stress (τ_r) at different shear rate D_r at 60 ^oC; the measurements were carried out with a rotary viscometer. Maximum Newtonian (η_0) and structural viscosity (η_τ) were calculated from graphical relationship shear stress and shear rate (1)

- complex modulus G*/sinδ, ASTM 7175 - 08 (2)

c) The asphalt concrete mixes were tested according to methods presented in table 4;

d) The resistance to permanent deformation of asphalt mixes was tested according wheel tracking test at 50 ^oC EN 12697-22, method B – in air (3) . Two slabs were produced from each asphalt sample with the help of a sector compactor.

e) The cohesion of bitumen in the asphalt concrete mixture is determined by the compressive strength -R and the simple shear strength τ_s at temperature 60 ºC. The compressive strength is determined according to ASTM D1074 (4). The shear strength is determined according TPA -80 (5) with the help of a shearing frame.

These characteristics are related through Mohr’s circle (strength theory) to the following parameters of shear:

$$\sin\varphi = 1 - \frac{2\tau_s}{R} \qquad\qquad c = \frac{\tau_s}{\cos\varphi}$$

φ – angle of internal friction of the asphalt concrete mixtures, degrees
C – cohesion of the asphalt concrete mixtures, Pa
R – compressive strength at 60 ºC, Pa
τ_s – simple shear strength at 60 ºC, Pa

Following the calculation of φ and C, the shear strength of the asphalt mixture is obtained from:

$$\tau_{mix} = \tau_s . tg\varphi + c$$

3. Experimental Results

Binder properties are given in Table 1.

Table 1 : Binder Properties

No	Properties	Test method	Unmodified bitumen BV 50/70	Modified bitumen		
				With thermoplast	With thermoelastoplast	
			A	Pmb25/55-60 B	PmB 35/55-55 C	PmB45/80-65 D
1	Penetration at 25 °C, 0,1 mm	EN 1426	59	40	56	66
2	Softening point "ring and ball", °C	EN 1427	52.1	83.9	57.3	88.9
3	Fraass breaking point, °C	EN12593	-14	-13	-18	-23
4	Elastic recovery, %	EN13398	-	-	63	92
5	Stability in hot storage, difference on softening points, °C	EN13399	-	-	1.5	0.2
6	Loss on heating for 5 h at 163, °C	EN12607-2	0.5	0.15	0.27	0.41
7	Penetration after heating as a % from original/initial (No. 1)	EN 1426	72	69.5	73.5	77.1
8	Plastic interval, °C	line 2-3	66.1	96.9	75.3	111.9
9	η_τ at 60 °C, Pa.s x 10^2		2.45	3,80	3,91	19.8
10	η_0 at 60 °C, Pa.s	EN13702-2	2,27	3,15	2,75	8,07
11	η_0 at 135 °C, Pa.s		0.47	0.4	0.89	1,97

It is obvious that polymer modification increases the softening point, the structural viscosity and the plastic interval. This indicates that the asphalt mixtures produced with these binders would have better resistance to permanent deformations. The elastic recovery of bitumen C and D is outperforming the requirements in the specification for modified binders (6). The modified binders C and D also have lower Fraas Breaking Points than the reference bitumen, indicating a reduction in the tendency for embrittlement at lower temperatures.

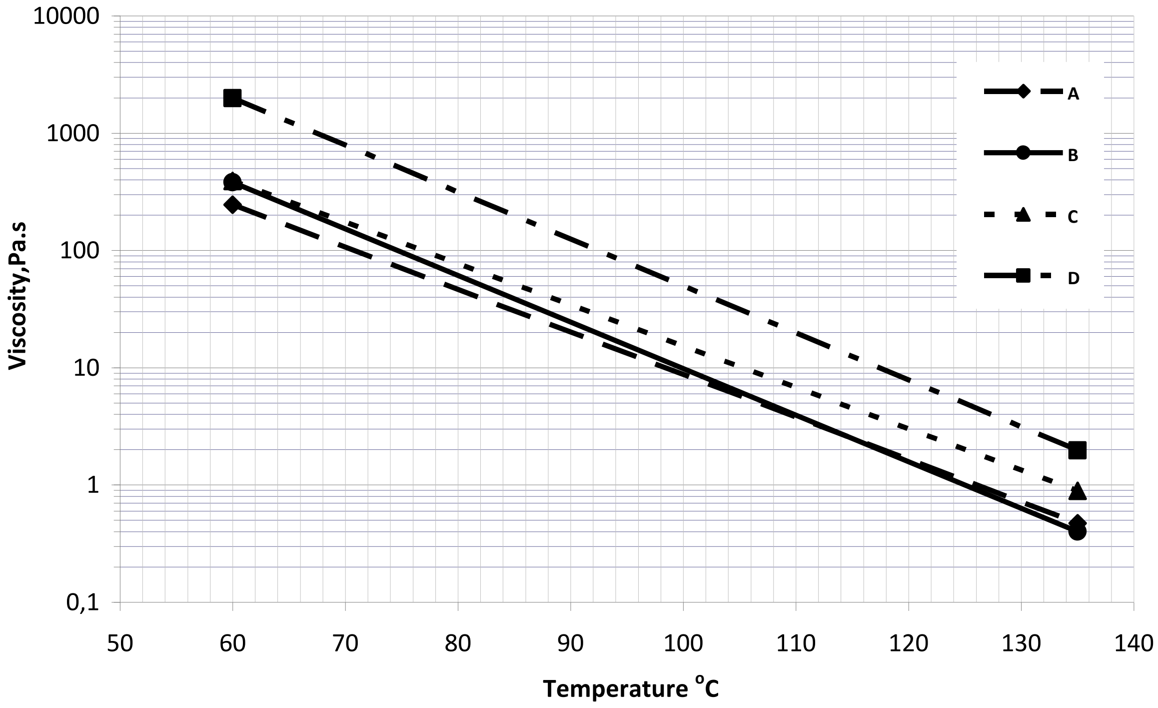


Figure 1: Relationship between temperature and viscosity

Viscosity values at 60 °C of (η_τ) (at low stress and deformation rates) and (η_0) are evaluated acc. to (4) and reported in Table 1. With the standard binder, the relative difference between the two viscosities is much smaller than that of modified binders; this corresponds to the stronger Newtonian behavior of the reference binder. This is the result of the change or destruction of the polymer structure or network in the modified binder during the test at higher shear rate; after deformations this structure is restored with time and the initial properties are again found.

The relation between viscosity and temperature was studied in order to be found the most proper temperature at which the asphalt mixtures to be produced and compacted. At temperature, which relates to the mixing, laying and compaction procedures of the asphalt concrete mixture, the viscosity of C and D PMB bitumen is higher than that of non-modified bitumen and binder B is with lower viscosity than that of non-modified bitumen. This demonstrates the necessity of working at different temperature during mixing, in order to provide sufficient coating of the mineral materials components. The exact temperatures for each of them were determined according to the diagram in Fig. 1.

Results from DSR tests are presented in Table 2, Figures 2,3 and 4.

Table 2 : Rheological properties determined according to SHARP

Characteristics \ Binder sample designation	A	B	C	D
Complex shear modulus, G*, (kPa)	3.0	6.85	4.44	9.21
Phase angle, (δ^o)	83.3	78.6	72.1	57.0
SHARP criterion G*/sin(δ), (kPa)	3.02	6.98	4.67	11.0

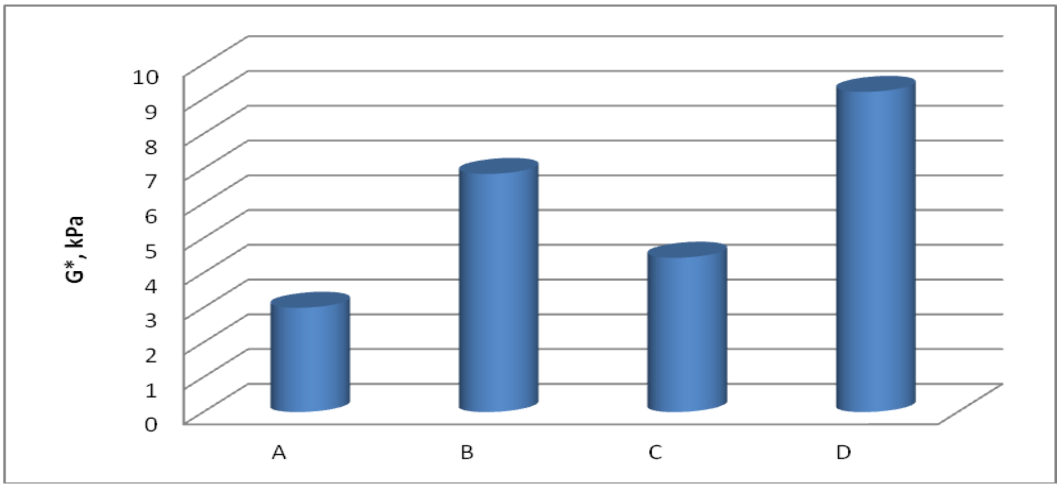


Figure 2: Relationship between complex shear modulus and binder type

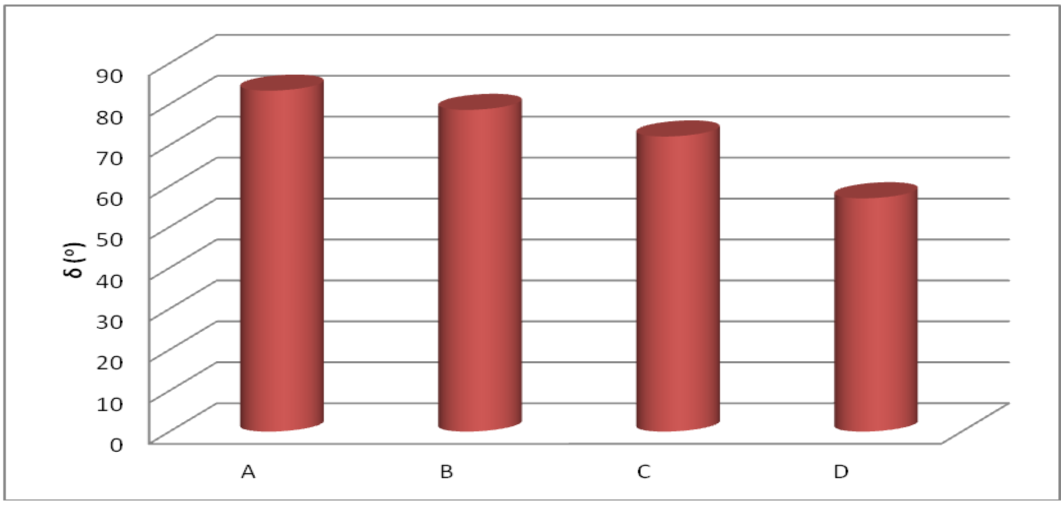


Figure 3: Relationship between phase angle and binder type

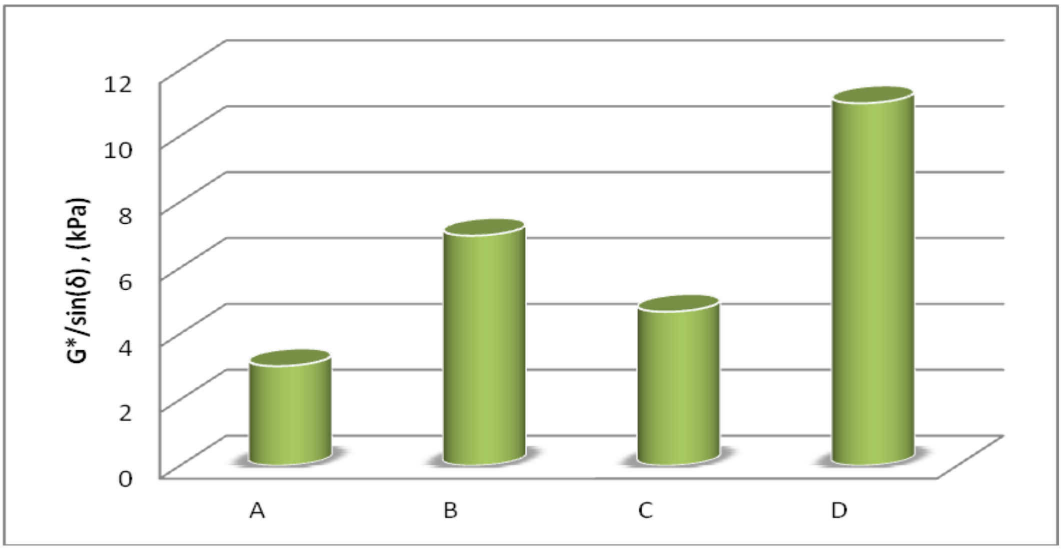


Figure 4: Relationship between SHARP criterion and binder type

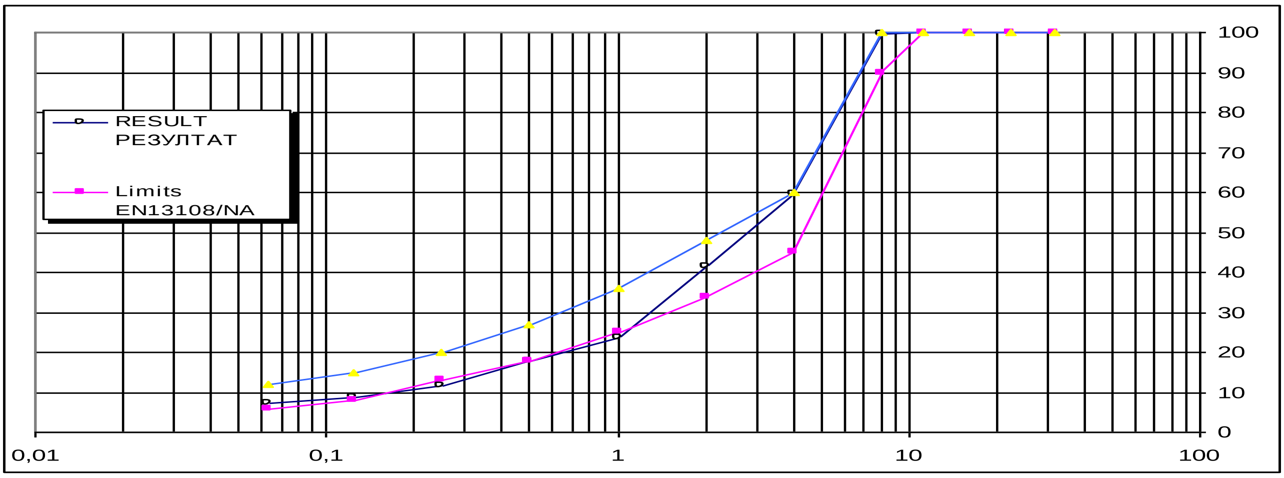
As expected the complex modulus is higher in modified binders. Maximum complex modulus is achieved with the binder D with the highest content of polymer in it. It can be observed that the binder, which is modified with thermoplastic polymer has a high complex shear modulus, but has a higher phase angle in comparison with the binders modified with plasto-elastic polymers. Asphalt mixtures produced with binders with high complex modulus tend to be more resistant to plastic deformations.

Asphalt samples were prepared according to the following recipe:

Table 3 : Aggregate gradation and mix design

Sieve (mm)	Mineral aggregates				Sieve (mm)	RESULT	Limits EN13108/NA AC 8	
	sand	4-8	0-5	Filler			min.	max.
	13,0	43,0	41,0	3,0		100,0		
11,2	13,0	43,0	41,0	3,0	11,2	100,0	100	100
8	13,0	42,5	41,0	3,0	8	99,5	90	100
4	12,9	4,3	39,6	3,0	4	59,7	45	60
2	11,8	2,5	24,3	3,0	2	41,6	34	48
1	4,9	1,6	14,1	3,0	1	23,7	25	36
0,5	4,7	1,2	9,1	3,0	0,5	17,9	18	27
0,25	1,1	1,1	6,6	2,9	0,25	11,7	13	20
0,125	0,2	1,0	5,0	2,6	0,125	8,8	8	15
0,063	0,1	0,9	3,9	2,3	0,063	7,2	6	12

The binder content in the asphalt mixture is 6,5 % by weight of the aggregates.



This fine grade mixture design aims at decreasing the angle of internal friction of the mineral aggregates. Thus the influence of the binder cohesion will be distinguished in a greater extent.

The results of the physical and mechanical tests of asphalt mixtures are presented in Table 4.

Table 4 : Physical and mechanical properties of asphalt mixtures

No	Properties	Test method	Asphalt mixtures with:			
			Unmodified bitumen BV 60 A	Modified bitumen with		
				Pmb 25/55-60 B	PmB 35/55-55 C	PmB45/80-65 D
1	Bulk density	EN 12697-6	2.472	2.475	2.474	2.483
2	Compressive strength Pa x 10^5	ASTM D1074	3.3	4.3	4,6	6.6
3	Shear strength , (τ_s) Pa x 10^5	TPA-80	0.48	0.58	0.62	0.86
4	Cohesion, (C), Pa x 10^5		0.681	0.849	0.908	1.277
5	Average rut depth in mm	EN12697-part 22	5.83	1.95	2.0	1.63

The asphalt mixtures were prepared with similar bulk density in order to be correctly compared their physical and mechanical properties

The compressive strength, the shear strength and the cohesion of the asphalt mixtures produced with polymer modified bitumen proved to be higher than those of the asphalt mixtures produced with reference bitumen, which is a tendency for their better resistance to permanent deformation. This is also proved by the results from the wheel tracking test , according to EN 12697-22, method B – in air. The ruts at mixtures produced with polymer modified bitumen are 3 times less deep.

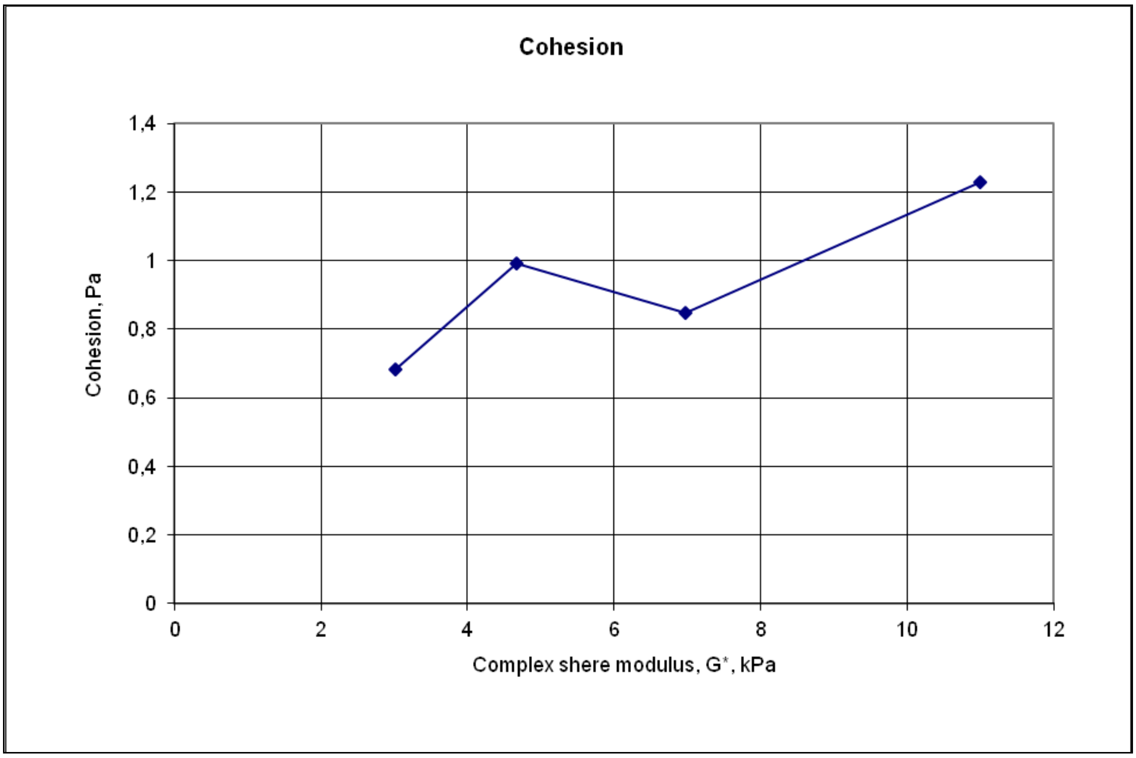


Figure 4: Relationship between complex shear modulus and cohesion

On fig 4 is shown the correlation between the complex modulus and the cohesion of the asphalt mixture. On figure 5 is shown the correlation between the complex modulus and the ruts' depth. The results from the tests show a tendency that with the increase of complex modulus the cohesion of asphalt mixtures increase and the ruts' depth is minimized. Due to the lack of sufficient number of values and dispersing of the results, it is practically impossible to be approximated a correlation with mathematical expression (7).

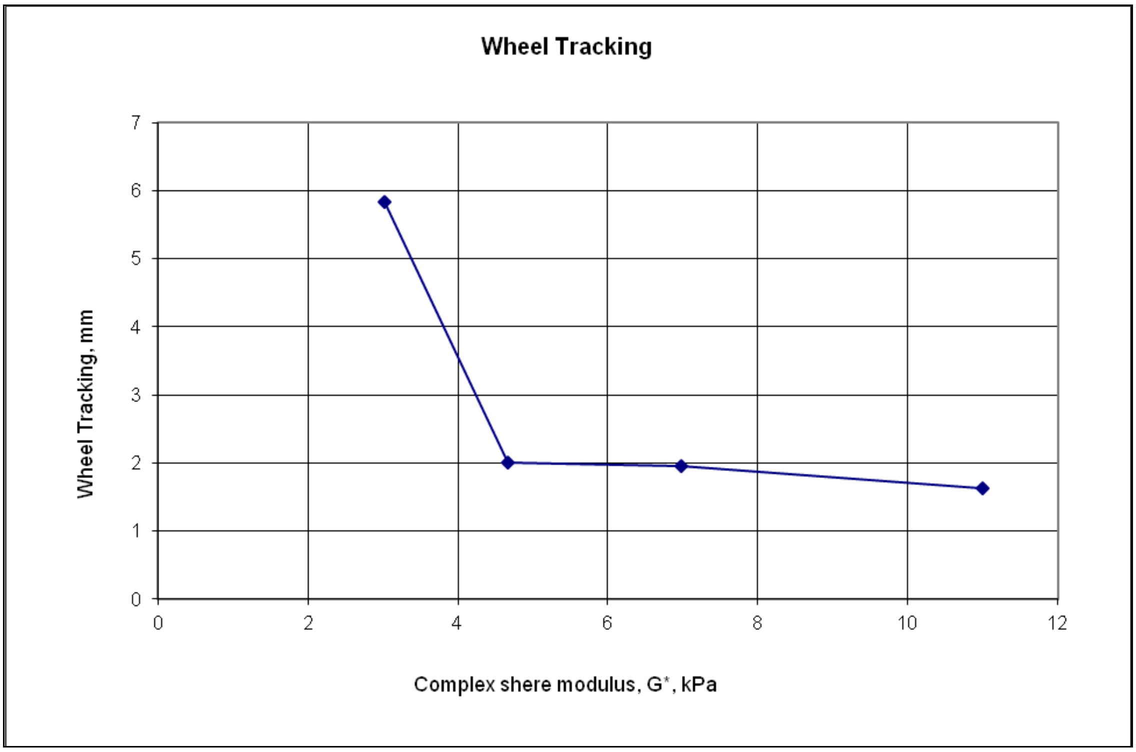


Figure 5: Relationship between complex shear modulus and rut depth in mm

It was studied the correlation between viscosity and cohesion of the binder in the asphalt mixture.

The correlation turned to be of a linear type and it could be described with a linear function, using a regression analysis.

By regression analysis, an empirical relationship of the form:

$$c = A \log \eta - B$$

has been established between the viscosity of bitumen at 60 ºC and the cohesion of asphalt mixture, where:

η – viscosity, Pa.s
C – cohesion, Pa
A and B – coefficient; A = 0,92 and B = 2.44 for the tested bitumen and asphalt mixes respectively.

The following equation is obtained for the shear strength:

$$\tau_{mix} = \tau_s .tg\varphi + A \log \eta - B$$

The correlation between the shear strength of asphalt mix (τ_{mix}) and the viscosity is in line with the fact that the viscosity of the binder is an important factor in the development of mix resistance to permanent deformation.

4. CONCLUSIONS

Polymer modified binders have better cohesion and asphalt mixtures produced with them show good resistance to permanent deformation.

Tendency for a relationship between the viscosity of the binder and the cohesion of the asphalt mixture produced with it was observed. It appears that the viscosity at 60 ^{o}C could be considered a characteristic, which could predict the binder resistance to permanent deformations. Further investigations will be carried out in order to prove this relationship also with different types of asphalt mixtures.

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