

FOUNDATION FOR DEVELOPMENT OF THE BIAŁYSTOK POLYTECHNIC

**Analysis of matter and technological solutions for
construction layers of surface based on chosen national road
sections within podlaski district**

**Evaluation of the efficiency of using Chemcrete as an
additive to the binding layer of the surface construction**

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Order no GDDKiA-O/BI-LD-I-5/07/03/03**

Białystok, July 2004

1. Aim of the report

The aim of this report was to compile matter and technological research pertaining to the mineral-asphalt mixtures used for construction layers of surface based on chosen research methods and evaluation of technical condition of the following road sections:

- road no 8 – section Szypliszki – Szwajcaria,
- road no 61 – modernized section Pańnica – Stawiski – Grajewo,
- road no 65 – modernized section Białystok – Bobrowniki,
- road no 19 – Kuźnica Białostocka circular road.

This report applies to the efficiency evaluation of using Chemcrete as an additive to the binding layer of the road surface construction. Results of examination of binding agents, mineral-asphalt mixtures and construction of road surface of various road sections within podlaski district built using modified binding agents and, for comparison unmodified binding agent with Chemcrete, were analyzed herewith.

2. Laboratory research of modified and unmodified bitumen.

2.1 Elastic and tenacious attributes of binding agents.

Road asphalt type 35/50 and 50/70, and modified binding agents with chemcrete (asphalt type 35/50 + 2% chemcrete, asphalt type 50/70 + 2% chemcrete) were examined in a laboratory.

The following laboratory tests were performed in order to determine elastic and tenacious attributes of binding agents:

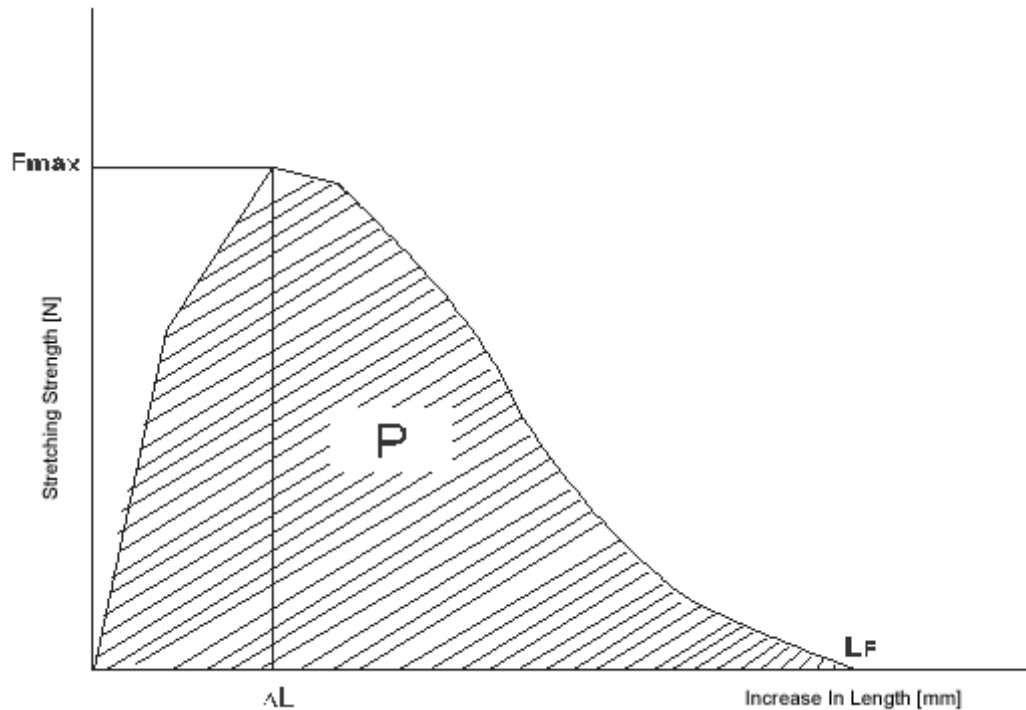
- determination of base asphalt attributes,
- determination of asphalt after technological ageing using the TFOT (Thin Film Owen Test) method,
- determination of asphalt after technological TFOT ageing and usage ageing using the PAV (Pressure Ageing Vessel) method.

Laboratory asphalt binding agent ageing methods TFOT and PAV are widely known and described in Polish and foreign literature.

Asphalt binding agents were submitted to the following laboratory tests:

- penetration in temperatures: 5C, 15C, 25C,
- softening temperature PiK (TpiK),
- fragility temperature according to Fraass,
- dynamic viscosity using Brookfield apparatus in temperatures: 60C, 90C, 110C, 135C,
- ductility with stretching speed of 50 mm / min in temperatures: 5C or 7C, 15C, and 25C,
- maximum ductility with stretching speed of 50 mm / min in temperatures: 5C or 7C, 15C, and 25C,

- flow abilities with stretching speed of 50 mm / min in temperatures: 5C or 7C, 15C, and 25C.
- Ductility testing with simultaneous maximum ductility ability to evaluate ductility was performed using a modified ductilometer.



Pic. 2.1 Graph showing ductility volume in ductility function within asphalt binding agent test in modified ductilometer.

In the test the ductility volume in function of elongating a sample of binding agent was determined, a maximum ductility volume was determined, and misshaping ability was calculated. The flow ability was mathematically defined by a following equation:

$$P = \int_{L=0}^{L_F} F * dL$$

where:

- P – flow ability [N*mm],
- ΔL - total elastic ductility [mm],
- LF – asphalt ductility, when F>0, [mm],
- F – ductility volume, [N],
- L – elongation of asphalt sample, [mm].

In the geometric picture the flow ability is indicated by the area on the graph of the ductility and ductility volume function from zero volume point to FF (Pic. 2.1).

Determination of dynamic viscosity in Brookfield apparatus was done according to norm ASTM D4402. According to that method the viscosity was determined using a turning mandrel submerged in thermostative sample of asphalt binding agent. The test was performed using various turning speeds and various measuring mandrels.

Some results of the tests performed on original binding agents are shown in table 2.1, after technological ageing - in table 2.2, and after usage ageing - in table 2.3.

Table 2.1 Attributes of asphalt binding agents before ageing.

Attribute	Type of binding agent			
	35/50	35/50+chem.	50/70	50/70+chem.
Penetration [0.1 mm]				
5 °C	5.6	5.8	6.4	6.7
15 °C	23.7	24.5	28.6	28.8
25 °C	48	64.3	67.2	78.9
Softening temperature [°C]	53.6	52.5	50.9	46.5
Fragility temperature [°C]	-13	-14	-15	-17
Viscosity				
60 °C	912.2	812	299.1	229.9
90 °C	22.9	20.9	11.5	8.8
110 °C	3.8	2.88	2.4	1.57
135 °C	0.8	0.62	0.4	0.39
Ductility [mm]				
5 °C	No result	No result	65.1	94.5
7 °C	49.7	52.3	-	107.2
15 °C	113.1	199	>1000	>1000
25 °C	>1000	>1000	>1000	>1000
Maximum ductility volume [N]				
5 °C	No result	No result	139	87
7 °C	108	98	-	61
15 °C	32	25	20	13
25 °C	2	4	1	2
Flow ability [Nxmm]				
5 °C	No result	No result	3923.8	2807.4
7 °C	2771.2	2553.8	-	2184.2
15 °C	1263.9	988.9	1179.5	755
25 °C	412	457.7	309	367.6

Table 2.2. Attributes of asphalt binding agents after technological ageing TFOT

Attribute	Type of binding agent			
	35/50	35/50+chem.	50/70	50/70+chem.
Penetration [0.1 mm]				
5 °C	4,7	5.2	5,9	7,6
15 °C	19,5	19.5	23,6	20,3
25 °C	37,2	28.6	51,3	50,4

Softening temperature [°C]	60,5	68.8	53,3	55.1
Fragility temperature [°C]	- 7	-9	- 8	- 10
Viscosity				
60 °C	2145,7	No result	462,37	726
90 °C	45,13	46,2	14,1	17,8
110 °C	7,3	8,6	2,8	3,3
135 °C	1,22	1,2	0,59	0,7
Ductility [mm]				
5 °C	36,2	No result	202	40
7 °C	-	No result	-	-
15 °C	70	51.7	765	235
25 °C	>1000	92	>1000	>1000
Maximum ductility volume [N]				
5 °C	212	No result	181	167
7 °C	-	No result	-	-
15 °C	57	70	29	29
25 °C	8,7	21	2,7	2,9
Flow ability [Nxmm]				
5 °C	5697	No result	5750	3718
7 °C	-	No result	-	-
15 °C	1889	2208	1421	1196
25 °C	422	854.7	157	161

Table 2.3. Attributes of asphalt binding agents after technological ageing TFOT and usage ageing PAV.

Attribute	Type of binding agent			
	35/50	35/50+chem.	50/70	50/70+chem.
Penetration [0.1 mm]				
5 °C	4,3	4.7	5,6	
15 °C	11,6	11.2	12,2	14,9
25 °C	26,4	23.0	31,6	28,8
Softening temperature [°C]	65,5	75.5	57,9	65.0
Fragility temperature [°C]	- 6	- 8	- 7	- 9
Viscosity				
60 °C	-		-	-
90 °C	101,7	319.1	35,1	55,8
110 °C	13,5	32.5	5,8	7,6
135 °C	2	14.5	1,1	1,4
Ductility [mm]				
5 °C	No result	No result	No result	No result
7 °C	No result	No result	No result	No result
15 °C	40.0	15.2	62	62,3
25 °C	107	66.2	>1000	300
Maximum ductility volume [N]				
5 °C	No result	No result	No result	-
	No result	No result	No result	-

7 °C	110	119	87	88
15 °C	23	35.5	11.5	19
25 °C				
Flow ability [Nxmm]				
5 °C	No result	No result	No result	-
7 °C	No result	No result	No result	-
15 °C	2721	1525.3	3005	3003
25 °C	947	1125.4	646	1094

The results of the tests performed on asphalt binding agents show a beneficial improvement of attributes of the binding agents when modified with chemcrete. Stiffening of the binding agent can be observed after technological ageing of the modified agent in comparison to base asphalt in higher temperatures (lower penetration in 25C, higher dynamic viscosity in 60C, higher value of softening temperature). An increase in flow ability can also be noticed after modification of asphalt. Such binding agent behaviors allow for the assumption that it will function much better as road surface.

It must be noted that the laboratory test results, despite stiffening of the binding agent, do not show any worsening in low temperature attributes.

2.2. Attributes of asphalts in tests with dynamic load.

Dynamic tests of binding agents were performed using a dynamic rheospectrometer RDS-2, manufactured by Rheometrics company. Sample, placed between two parallel rifled plates with diameter of 25 mm was subjected to forced vibrations. The bottom plate made sinusoidal vibrations with stabile misshaping. The turning point, registered by the point sensor, is moved by angle of δ in a phase. The viscosity of described materials causes their flow to oscillate at an angle of δ in a phase, in comparison to applied tension.

Based on the tests performed the following was determined:

- compound module (G^*),
- elasticity module when cutting (G'),
- depreciation module, fictitious integrant of compound module (G''),
- phase movement angle δ ,

Based on the obtained results the binding agent stiffness ration (W_D) in temperature function for frequency $\omega = 5$ rad/s, that is frequency coinciding with the frequency of road surface charge by cars, was calculated. The coefficient (W_D) was calculated using the following equation:

$$W_D = G^*_x / G^*_{60C}$$

where:

G^*_x – value of compound module in temperature value x, equal to subsequently: 40 °C, 23 °C,

G^*_{60C} – value of compound module in temperature 60 °C.

Compound module determined by dynamic charge equals to:

$$G^* = G' + G'' \bullet i$$

where:

G' – actual part of compound module, complaint in phase with the charge, it is part of the energy recycled and stored (elasticity module when cutting),
 G'' – fictitious component of compound module, it is energy diffused due to internal friction (depreciation module).

The equation for compound module in trigonometric function is as follows:

$$G^* = |G^*_{(i\omega)}| (\cos\delta + i \sin\delta)$$

Value of the phase angle movement gives the assumption that elasticity or ductility have more effect on the behavior of the matter. Depending on the type and hardness of the asphalt and the temperature and angle δ frequency, it varies between 0^0 and 90^0 .

The following binding agents were submitted to dynamic testing:

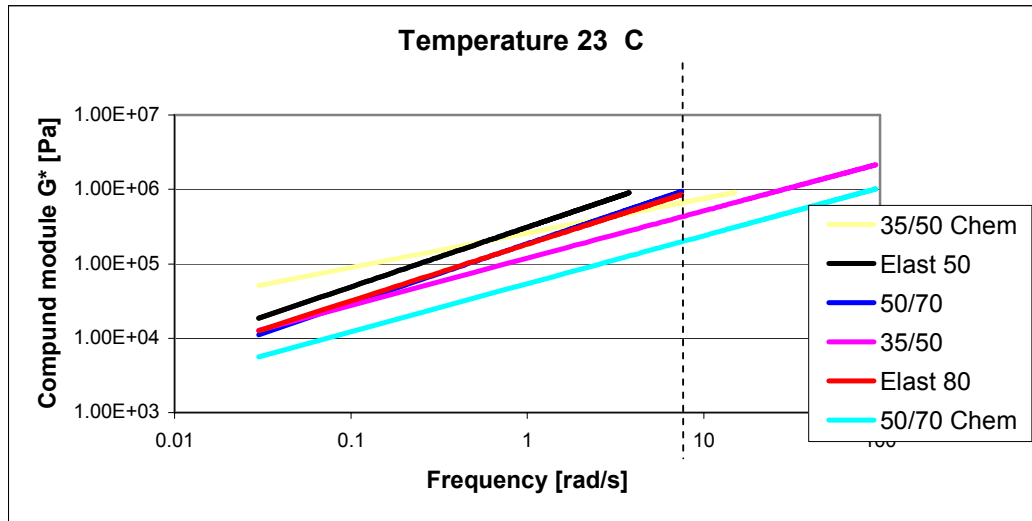
- road asphalts type 35/50 and 50/70,
- asphalts modified with 2% chemcrete: type 35/50 Chem., 50/70 Chem.,
- asphalts modified with elastomere SBS: type Elast. 50, Elast. 80.

The analysis of results obtained during the testing of binding agents under dynamic charge was conducted in three binding agent attribute groups: dynamic module, stiffness coefficient and tangent of the phase movement angle.

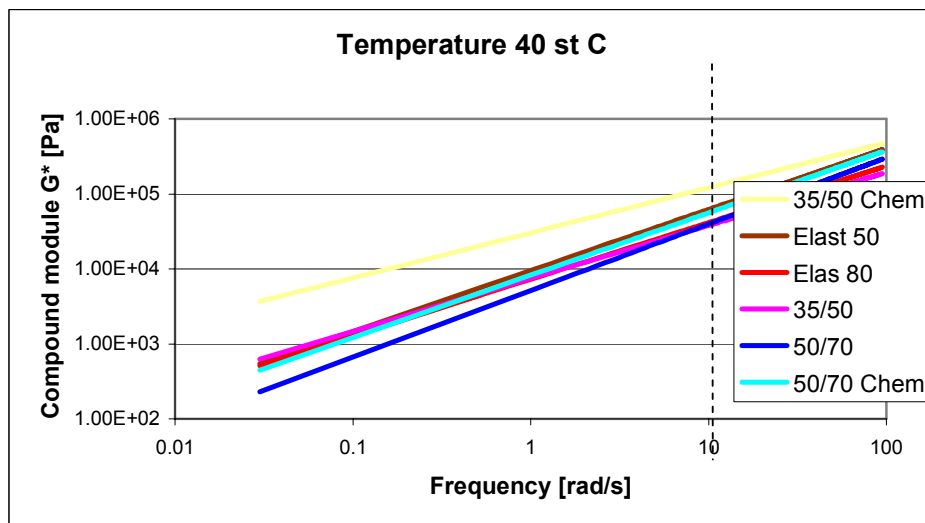
Dynamic module

Based on the tests the values of compound module in the frequency function and temperature function are shown in pictures: 2.2, 2.3, 2.4 and 2.5. Based on the isotherms of the compound module the following conclusions can be drawn:

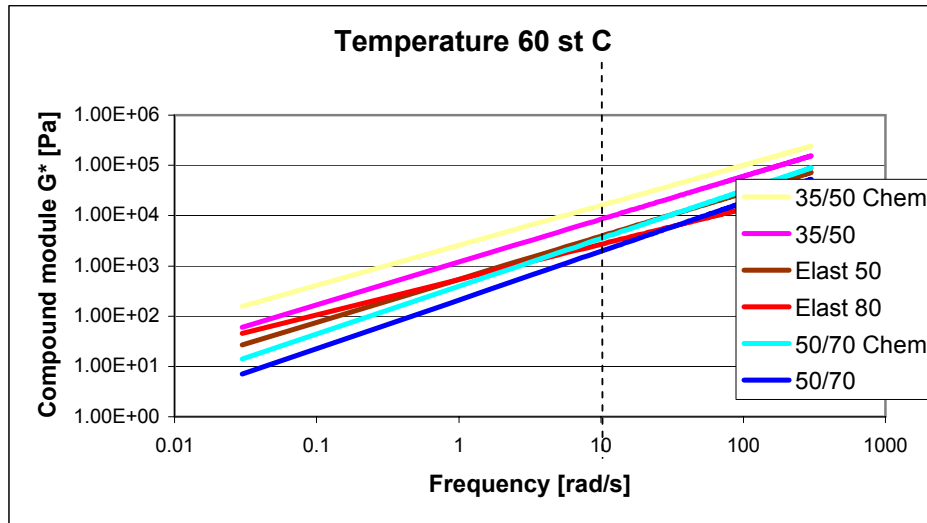
- in moderate temperatures (23^0C) asphalt type 35/50 modified with Chemcrete is characterized by a more beneficial, smaller inclination of the graph, which indicates lower susceptibility to temperatures. This binding agent, with the frequency of 10 rad/s (simulation of conditions “in situ”), shows a lower G^* value from modules of asphalts modified with elastomere, which can indicate lower susceptibility of asphalt with Chemcrete to ageing cracks.
- In high usage temperatures of 40 and 60C binding agents type 35/50 modified with Chemcrete obtained the best and highest values; they are followed by three groups of binding agents: Elast. 50, 35/50 and Elast. 80, further followed by agent type 50/70 modified with Chemcrete; unmodified asphalt type 50/70 obtained lowest and most disadvantageous values. Binding agents modified with Chemcrete and elastomere are characterized, in comparison to unmodified binding agents, by a lower beneficial inclination of isotherms of the module in the charge frequency function, which indicates their very low susceptibility to temperatures.



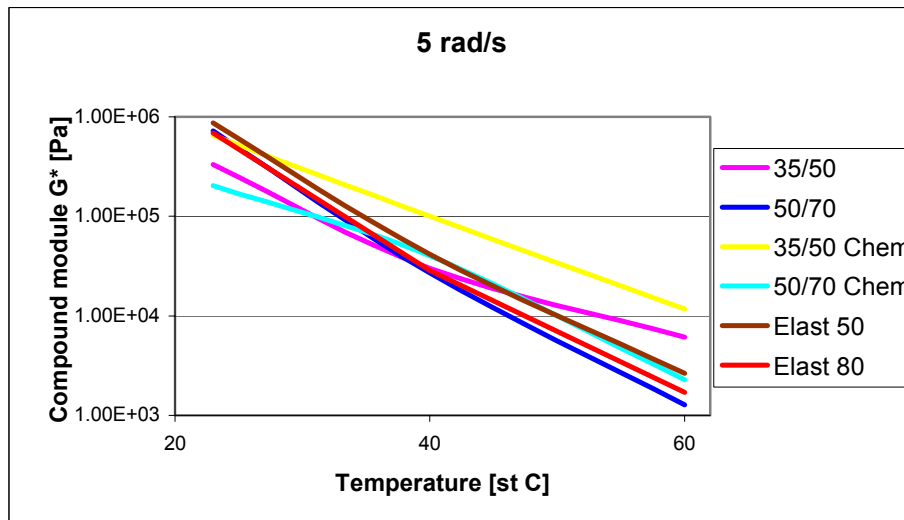
Pic. 2.2. Compound modules of binding agents in frequency function with testing temperature of 23 °C.



Pic. 2.3. Compound modules of binding agents in frequency function with testing temperature of 40°C.



Pic. 2.4. Compound modules of binding agents in frequency function with testing temperature of 60 °C

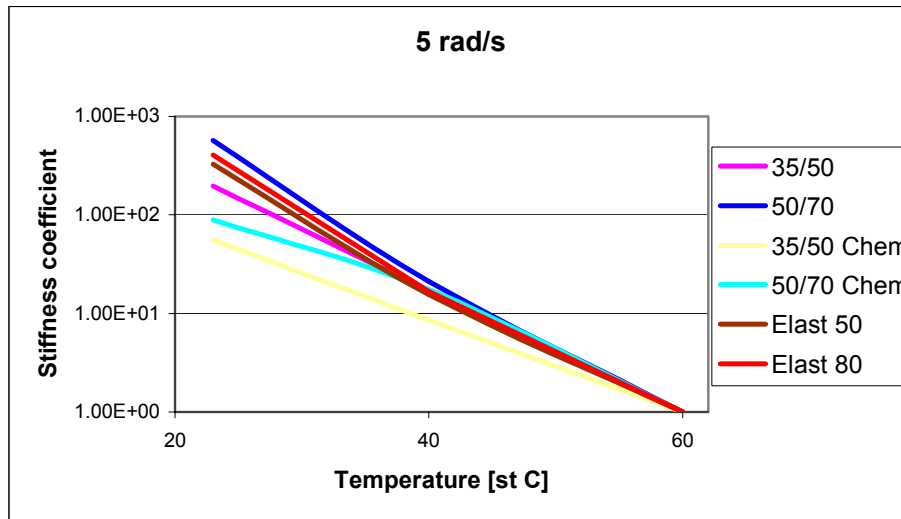


Pic. 2.5. Binding agent compound modules in testing temperature function

Stiffness coefficient W_D

A more detailed evaluation of rheological behavior of binding agents can be conducted based on the ration of stiffness represented by the stiffness coefficient. Ratio of stiffness in comparison to the stiffness represented by compound module in temperature of 60°C shows speed of change from viscose state to elastic viscose state and elastic state. The graph showing changes of the W_D coefficient in temperature function, with frequency of 5 rad/s is shown in picture 2.6. From the curves we can conclude that binding agents modified with Chemcrete (type 35/50 Chem., 50/70 Chem.) have a lower variation of the W_D coefficient in comparison to other asphalts tested. Binding agent type 35/50 modified with chemcrete has the most beneficial attributes in positive temperatures, indicating a slow accumulation of elastic characteristics within the agent in dropping temperatures. Binding

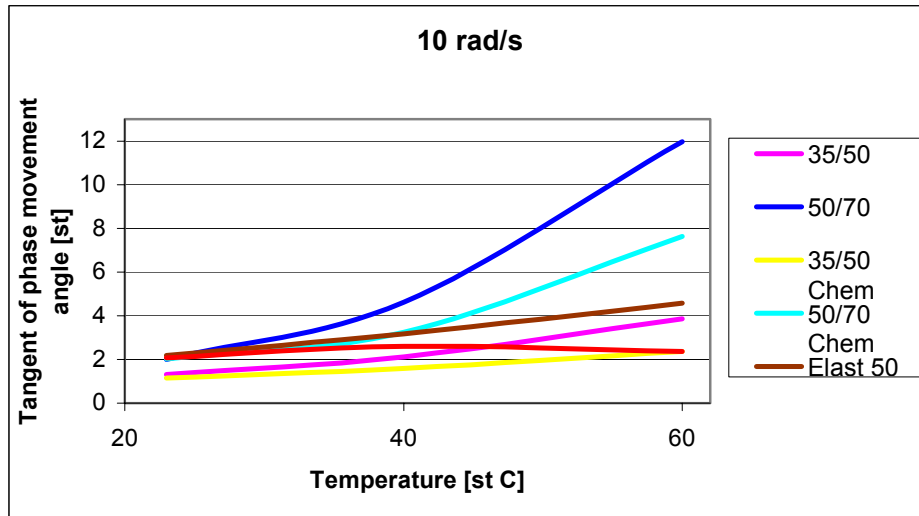
agents modified with elastomere in positive temperatures stiffness much faster than those modified with Chemcrete, although slower than asphalt type 50/70.



Pic. 2.6. Binding agent stiffness coefficient

Tangent of phase movement angle

Tangent of the phase movement angle is a measurement of ductility element. For ductile materials $\text{tg}\delta = \infty$, for elastic materials $\text{tg}\delta = 0$, for elastic and viscose materials $\text{tg}\delta$ has a value of > 0 and does not reach infinity. The relationship between $\text{tg}\delta$ in temperature function for analyzed asphalt binding agents is shown in picture 2.7. Small variations in the value of $\text{tg}\delta$ in positive temperatures shows positive behaviors of binding agents type 35/50 modified with Chemcrete and Elast. 80. This indicates low susceptibility to temperatures and the ability to keep elastic viscosity on an appropriate level (large range of elasticity – small value $\text{tg}\delta$) in high usage temperatures. When comparing the level of plasticity of binding agents due to increase in temperature, tested binding agents can be divided into the following groups: least susceptible to high temperatures binding agents type 35/50 Chem., then Elast. 80., 35/50, Elast. 50, 50/70 Chem., and most susceptible to high temperatures unmodified asphalt type 50/70.



Pic. 2.7. Relationship between $\text{tg}\delta$ and temperature for tested asphalt binding agents (testing frequency 10 rad/s).

Summating results of laboratory testing of asphalt binding agents it can be concluded that binding agents modified with Chemcrete (type 35/50+ Chem.) show improved attributes of elasticity and viscosity in comparison to unmodified binding agents. The comparison between agents modified with Chemcrete and thermoplastic elastomere also shows more beneficial attributes of binding agents modified with Chemcrete used in asphalts with organometallic salts.

3. Laboratory testing of mineral-asphalt mixtures with binding agents modified with Chemcrete

3.1. Study of characteristics of mineral-asphalt mixtures

The analysis of characteristics mineral-asphalt mixtures with binding agent modified with Chemcrete (with asphalt type 35/50 and 50/70) based on studies of samples of the said mixtures in a laboratory. Similar materials were used to create these samples as during construction of an experimental field road section. They were the following: calcium powder, crushed sand 0/2, grit 2/5, grit 5/10, grit 8/11, grit 11/16, grit 16/25 from granodiorite, road asphalt D 35/50. The amount of asphalt (with a 2% additive of Chemcrete) was 4.5% (same as the amount of asphalt in a mixture included in the binding layer of the field road section no 8). Tests of concrete asphalt with asphalt type 50/70 modified with Chemcrete and with unmodified asphalt type 35/50 were also performed for comparison.

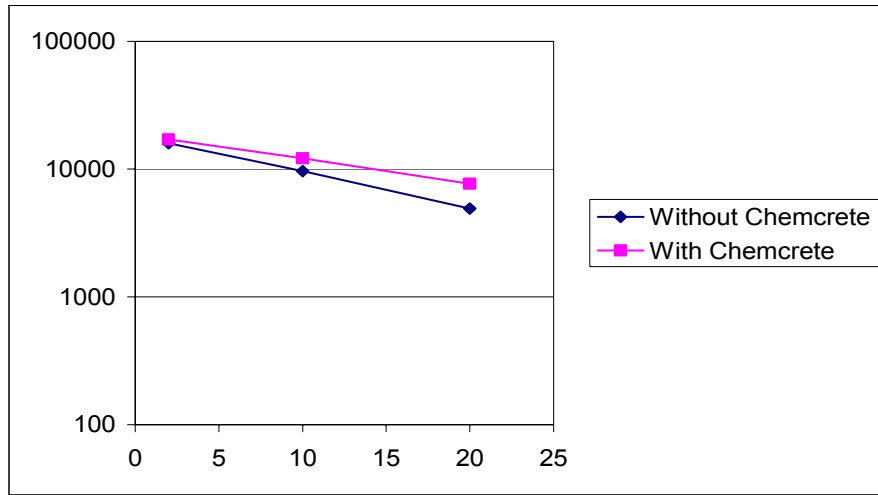
Results of the tests of various technical characteristics are shown in table 3.1.

Table 3.1

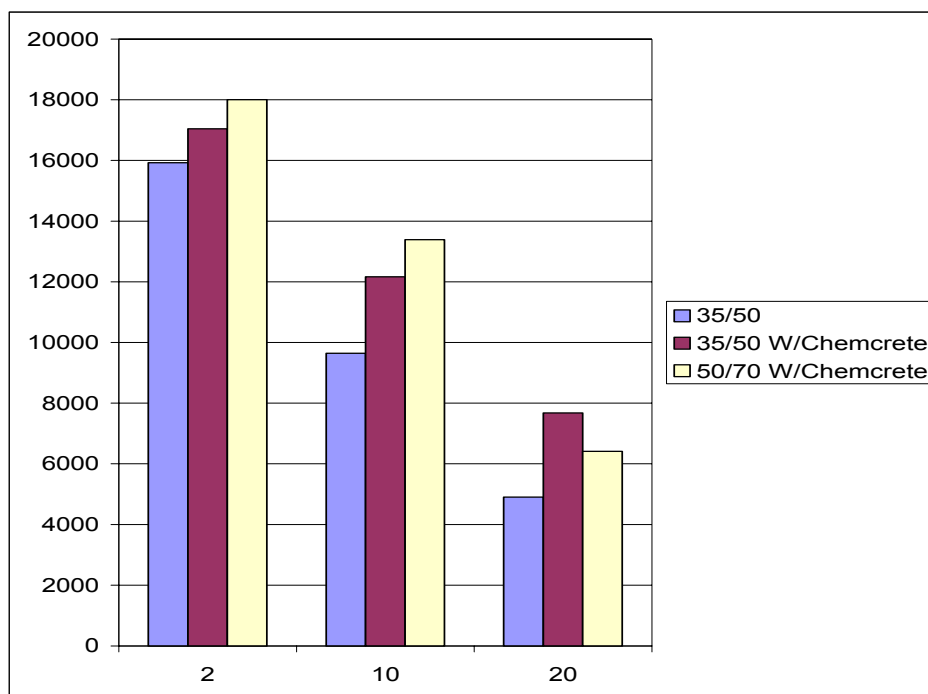
Attributes of mineral-asphalt mixtures with binding agents modified with Chemcrete – mineral-asphalt mixture was created in a laboratory.

Attributes	Concrete asphalt mixture 0/20 with asphalt type 35/50		Concrete asphalt mixture 0/20 with asphalt type 50/70+2%Chem
	35/50	35/50+2%Chem	
Stability [kN]	13.0	17.5	18.0
Misshaping [mm]	4.3	4.8	4.0
Module of stiffness creep [MPa]	19.6	22.2	25.0
Module of elastic stiffness [MPa]			
2 °C	15925	16701	18004
10 °C	9645	12167	13372
20 °C	4908	7680	6417

When comparing the results of tests of modified and unmodified mixtures (Table 3.1) it should be noted that the mineral-asphalt mixture with asphalt type 35/50 modified with Chemcrete attains most beneficial attributes. In a temperature of 20C this mixture attains the best stiffness from all concrete types tested. When the temperature drops the change in the stiffness module occurs slower than in the asphalt concrete with unmodified binding agent (Pic. 3.1). Such behaviors of the asphalt concrete in the top layer of a road is beneficial because it decreases the risk of occurrence of low-temperature cracks in that layer.



Pic. 3.1. Change in the elastic stiffness module in relation to temperature of asphalt concrete with binding agent type 35/50 and binding agent type 35/50 modified with Chemcrete.



Pic. 3.2. Elastic stiffness module of asphalt concrete with binding agent

Laboratory test results of tests performed on mineral-asphalt mixtures shown above allow for a following conclusion: asphalt concrete used for a binding layer with binding agent modified with Chemcrete is characterized by more beneficial technical attributes than unmodified mixtures.

It should be noted that asphalt concrete with binding agent type 35/50 with Chemcrete attains better technical attributes that asphalt concrete type 50/70 also with Chemcrete.

3.1. Study of fatigue stability

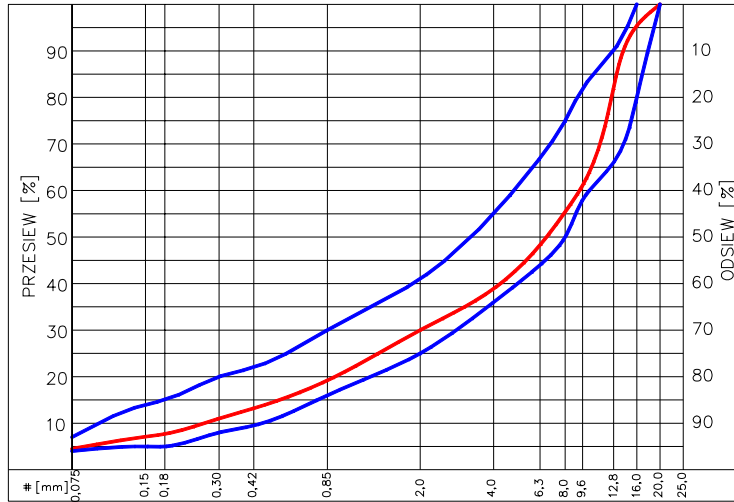
3.1.1. Materials

The following materials were used to create testing samples of asphalt concrete 0/20 for binding layer:

- Calcium powder MOWAP - Barcin
- Crushed sand 0/2 - Szumowo
- grit 2/5 - Siemianówka
- grit 5/10 - Siemianówka
- grit 8/11 - Siemianówka
- grit 11/16 - Siemianówka
- grit 16/25 - Siemianówka

- road asphalt D 35/50 - Gdańsk.

The grading curve of designed mineral mixture is shown in pic. 6.3. The amount of asphalt (asphalt with 2% Chemcrete) was 4.5%. The composition of a tested mineral-asphalt mixture corresponded with the composition of a mixture in the binding layer of a field section of road no 8 – Szypliszki – Szwajcaria.



Pic. 3.3. Graphic representation of grading curve BA 0/20 binding layer

Table 3.3
Grain disposition of the mineral mixture

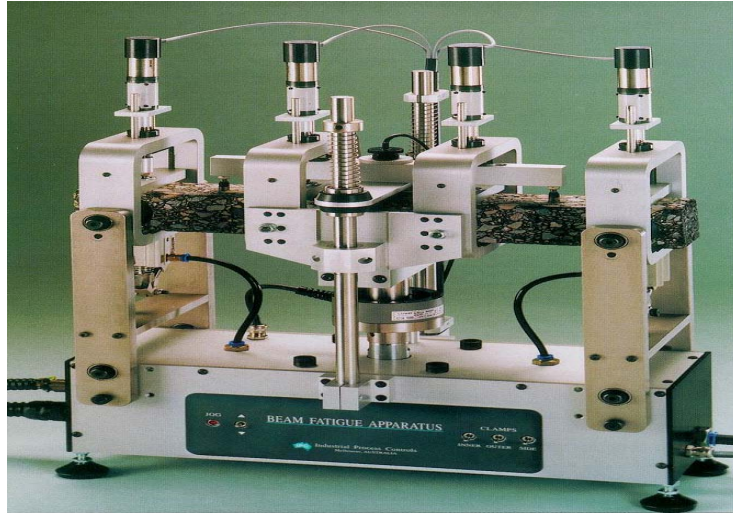
Size of sieve eyelet [mm]	20	16	12,8	9,6	8,0	6,3	4,0	2,0	0,85	0,42	0,30	0,18	0,15	0,075
Ordinates of limiting curves	100	100	90	82	75	67	55	41	30	22	20	15	14	7
	100	80	66	58	50	44	36	25	16	9	8	5	5	4
Curve of mixture grain disposition	100	95,4	82,0	61,1	55,4	48,3	38,9	30,0	19,2	13,2	11,0	7,7	7,1	4,5

3.2.2. Test methodology

In order to compare fatigue stability of asphalt concrete with Chemcrete and asphalt concrete without Chemcrete it was submitted to a beam fatigue test.

Testing methods

In order to compare fatigue stability of asphalt concrete with Chemcrete and asphalt concrete without Chemcrete it was submitted to a beam fatigue test. In the said test cubocoidal beam fatigue samples with the dimensions of 50x60x400 mm were submitted to cyclical four-point beaming. Haversine $[1/2x(1-\cosx)]$ load with the frequency of 10 Hz, with various misshaping amplitudes of 300, 400, and 500 $\mu\text{m/m}$ was used.



Pic 3.4. Beam Fatigue Apparatus

Creation of samples for beam fatigue testing

Plates with the thickness of 7 cm were created in a laboratory. They were condensed with a pneumatic compactor until a completely flat surface was reached, which assured attaining of a required condensation value for the mass and dimensions of a particular sample. The said plates were then cut with a diamond saw into cubocoidal beams with the dimensions of 50x60x400 mm.

Testing temperature

The beam fatigue tests were conducted in 10C. The temperature was attained and kept on that level using a curing chamber.

3.2. Test results

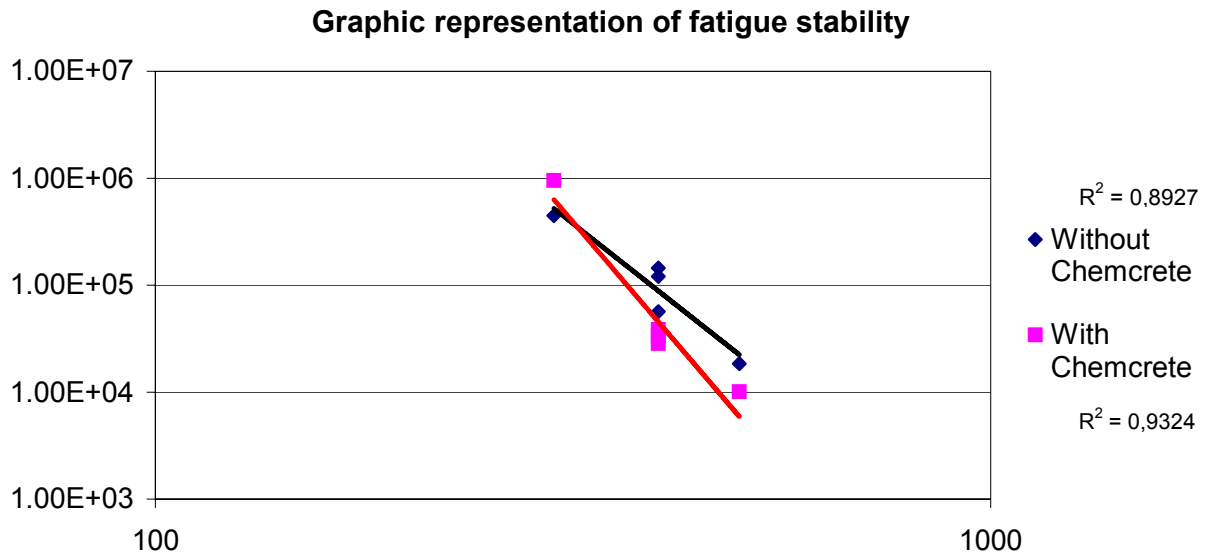
Test results are shown in tables 3.4, 3.5 and on pic. 3.5.

Table 3.4
Test results according to Marshall

	BA/20 in bind.ag. w/out	BA/20 in bind.ag. w/ chemcrete	
	after 24 hrs	after 24 hrs	after 5 days
Stability [kN]	18,1	20,3	21,3
Flow [mm]	3,4	3,2	3,7
Free space %	5,7	6,0	6,0
Condensation volume [g/cm ³]	2590		

Table 3.5
Beam Fatigue Test results

		BA/20 in bind.ag. w/out	BA/20 in bind.ag. w/ chemcrete
Initial stiffness module E_{50} [MPa]	300 μ m/m	15165	13855
Number of cycles [thousands]		446.660	953.570
<hr/>			
Initial stiffness module E_{50} [MPa]	400 μ m/m	13730	12473
		14121	14011
		12193	12763
Number of cycles [thousands]	400 μ m/m	120.740	28.530
		144.430	33.270
		56.450	38.620
<hr/>			
Initial stiffness module E_{50} [MPa]	500 μ m/m	12558	12408
Number of cycles [thousands]		18.400	10.090



Pic. 3.5. Graphic representation of fatigue stability

Picture 3.5 shows that with large deflection values, asphalt concrete samples with asphalt type 35/50 attain better fatigue stability than samples with modified binding agent. Fatigue stability of samples with a mixture with Chemcrete is better than the fatigue stability of a standard mixture with smaller deflections from 300 $\mu\text{m/m}$. This means that road surfaces (deflections of surfaces under the wheels of heavy load vehicles are much smaller than 300 $\mu\text{m/m}$) layers with Chemcrete will operate much longer without fatigue cracking. It should also be noted that with larger deflections, usually occurring in bridge-like structures, mineral-asphalt mixtures with Chemcrete should not be used.

4. Analysis of test results of mineral-asphalt mixtures with binding agents modified with Chemcrete – testing of road section samples

Laboratory test results of tests conducted throughout construction of binding layers (1999) and samples taken from road surfaces a year later (2000) of road No 8, section Szypliszki – Szwajcaria, and test results of tests conducted throughout construction and after construction was completed of road no 61, section Piątnica – Stawiski (2000), and section Stawiski – Grajewo (2001) were analyzed.

4.1. Road No 8, section Szypliszki – Szwajcaria

The following test results were analyzed:

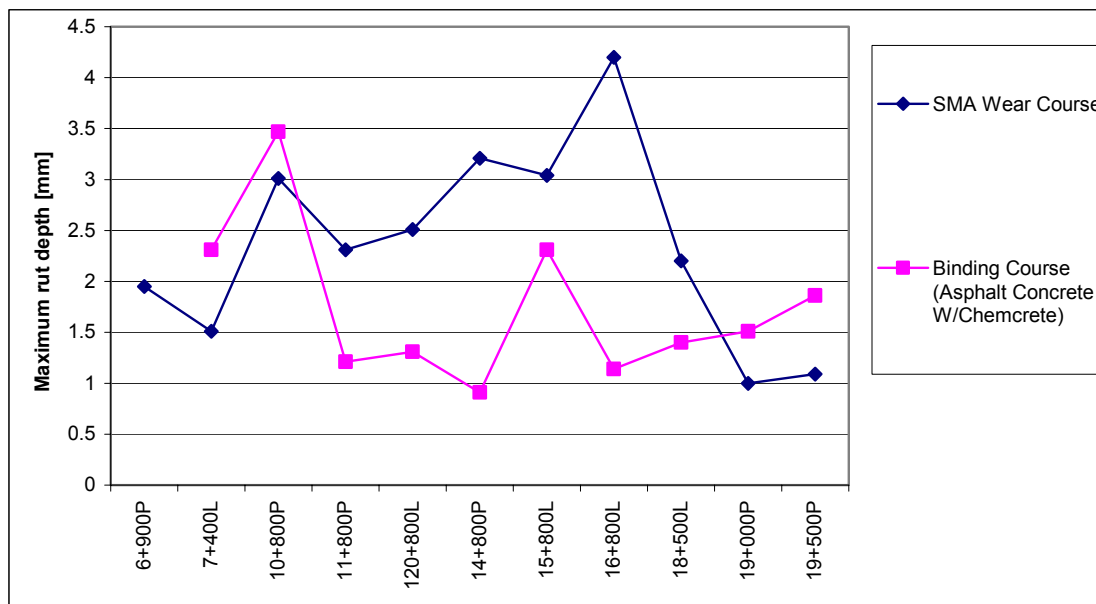
- test of composition and technical characteristics of mineral-asphalt mixture of binding layer dated 8.09.1999,
- same as above dated 30.06.2000,
- rutting tests on samples taken from road surface dated 18.07.2000,
- same as above dated 11.08.2000,
- same as above dated 8.11.2000.

In terms of composition and normative characteristics the mineral-asphalt mixture used in the binding layer (asphalt concrete 0/20 mm) complies with all requirements, and the deviations fall within allowed limits.

In terms of functional characteristics it is possible to evaluate the susceptibility of the mineral-asphalt mixture to permanent deformation. Rutting tests on samples taken from the surface of the abrasive layer, binding layer and substructure layer were conducted in the Road Laboratory of GDDKiA. The tests were conducted compliant with the British standard BS 598 Pt110:1996 using a small Wessex rutting meter. The maximum rut depth and the speed of enlargement of the rut are the results of the conducted tests. Criteria according to the Specification for Highway Works (MCHW1) Clause 948, which sets the maximum depth of a rut to 10.5 mm and the speed of enlargement to 7.5 mm/h for one sample tested, and 7.0 mm and 5.0 mm/h respectively for more than one sample tested, were used for the said tests. A test of samples taken from the abrasive layer made from SMA 0/12.8 mm (11 locations) and samples from binding layer made from asphalt concrete 0/20 mm with Chemcrete modifier (9 locations) was also conducted. The following average values of maximum rut depth and maximum enlargement speed were obtained:

- abrasive layer – 2.53 mm and 0.92 mm/h,
- binding layer – 1.78 mm and 0.65 mm/h.

Given results should be evaluated as follows: abrasive layers and binding layers are resistant to rutting.



Pic. 4.1. Graphic representation of rutting of the abrasive layer and binding layer.

In pic. 4.1 a graphic representation of rutting of the abrasive and binding layers of the analyzed road section is shown on one graph. The picture indicates that the binding layer with Chemcrete modifier has a higher resistance to permanent deformation than the SMA mixture, which is widely considered to be a material of high resistance to rutting.

4.2. Road No 61, sections Piątnica-Stawiski and Stawiski – Grajewo

The following test results were analyzed:

- test of composition and technical characteristics of mineral-asphalt mixture of bitumen layers – section Piątnica-Stawiski, dated 21.12.2000,
- test of composition and technical characteristics of mineral-asphalt mixture of bitumen layers – section Stawiski-Grajewo, dated 4.12.2001,

The analysis of laboratory tests results conducted on a large amount of samples taken directly from the surface is included in the laboratory opinions attached to the reports from the said tests. The conclusions contained within those reports are correct, and can be summarized as follows:

- the composition of mineral-asphalt mixtures for almost all samples is compliant with all requirements and the deviations fall within allowed limited,
- tests results from the rutting test of the SMA 0/11 mm abrasive layer, binding layer made from asphalt concrete 0/20 with Chemcrete and substructure layer made from asphalt concrete 0/25 mm indicate that all tested layers are resistant to rutting according to the criteria specified by Specification for Highway Works (MCHW1),
- when comparing tested mixtures in terms of resistance to permanent deformation it should be noted that the binding layer made from asphalt concrete 0/20 with Chemcrete is superior to the layer from the SMA mixture and has similar characteristics as the coarse-grained substructure layer.

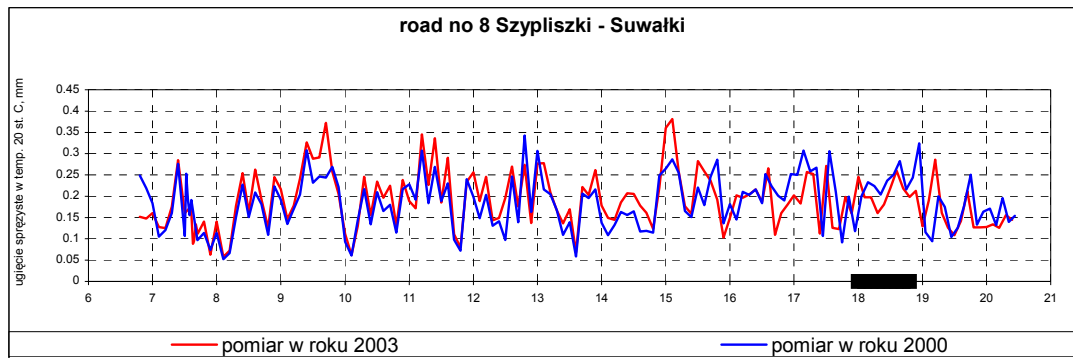
5. Study of the surface elastic deflection cap

The test results of tests of the elastic deflections conducted on sections of roads no 8 and no 61, which contain the Chemcrete modifier in their binding layer and tests conducted on section of roads no 65 and no 19 were analyzed.

The test on the structure was conducted using a falling weight deflectometer.

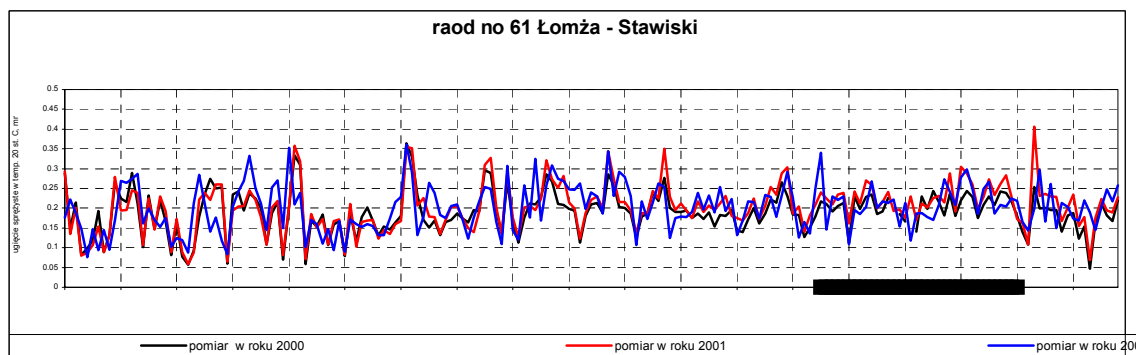
The deflection tests were conducted in 2000 and 2003 (road no 8), and in 2000, 2001 and 2003 (road no 61), and for comparison in 2003 on roads no 65 and no 19.

Results of elastic deflections brought down to reference temperature of 20C are shown in pic. 5.1 and 5.2 (roads no 8 and no 61 according to the former kilometer scale). The location of tested sections, which were thoroughly analyzed are shown in the pictures as well.



Pic. 5.1. Graphic representation of elastic deflections - section of road no 8 with a binding layer modified with Chemcrete

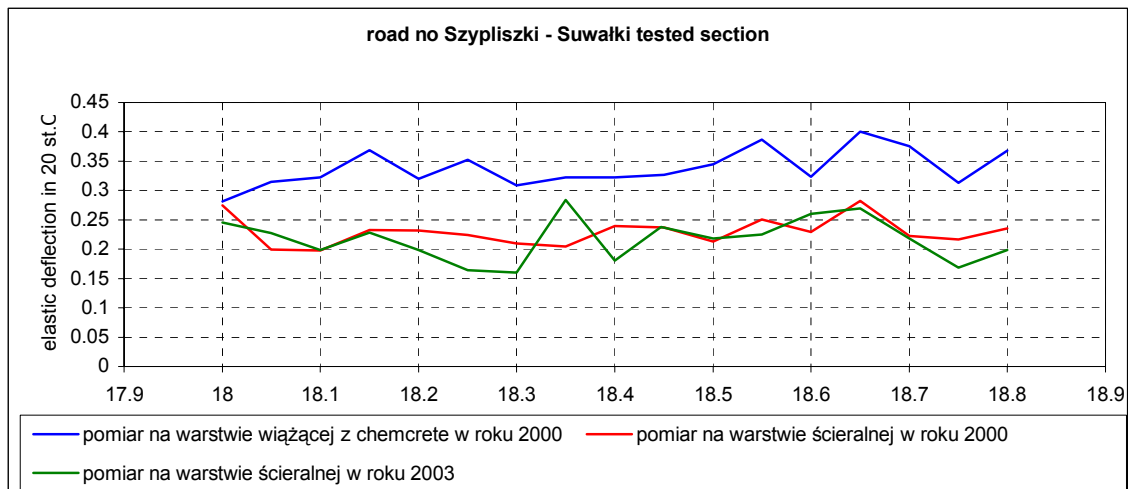
(Legend: — - measurement taken in 2003, — - measurement taken in 2000)



Pic. 5.2. Graphic representation of elastic deflections – section of road no 61 with binding layer modified with Chemcrete.

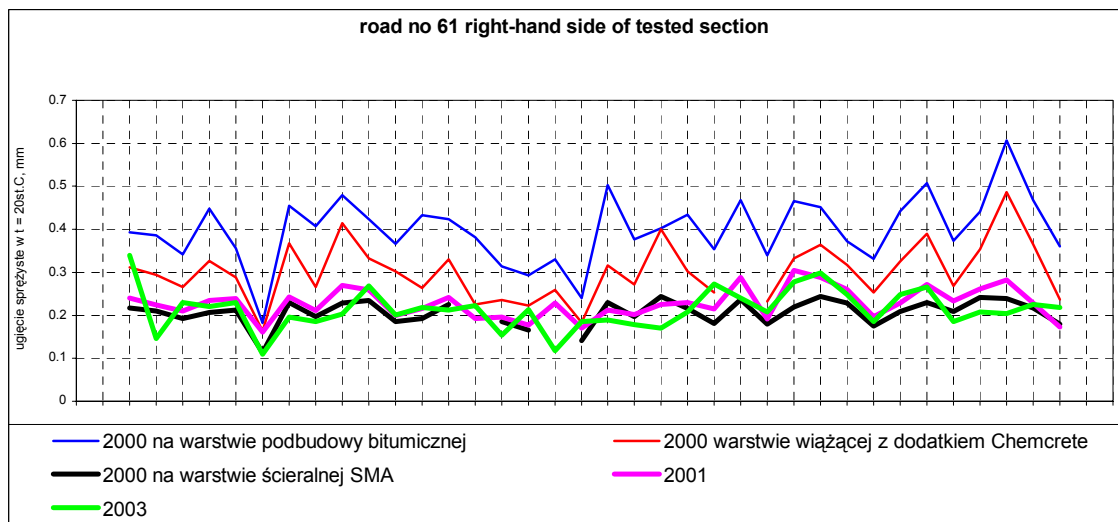
(Legend: — - measurement taken in 2000, — - measurement taken in 2001, — - measurement taken in 2001)

It can be concluded from pic. 5.1 and 5.2 that, despite a large charge of heavy-load vehicles the surfaces of both roads are in a good condition in terms of load capacity (very small elastic deflections, approximate to deflection characteristic for half-stiff structures). It can be observed on the tested sections (new surface structure) that with time the structural stiffness increases (smaller elastic deflections). This is probably due to a stiffening effect of the binding agent modified with Chemcrete (normal oxidizing of the modified binding agent). The above conclusion are supported by graphs for tested sections shown in pic. 5.3 and 5.4.



Pic. 5.3. Graphic representation of elastic deflections in tested section of road no 8

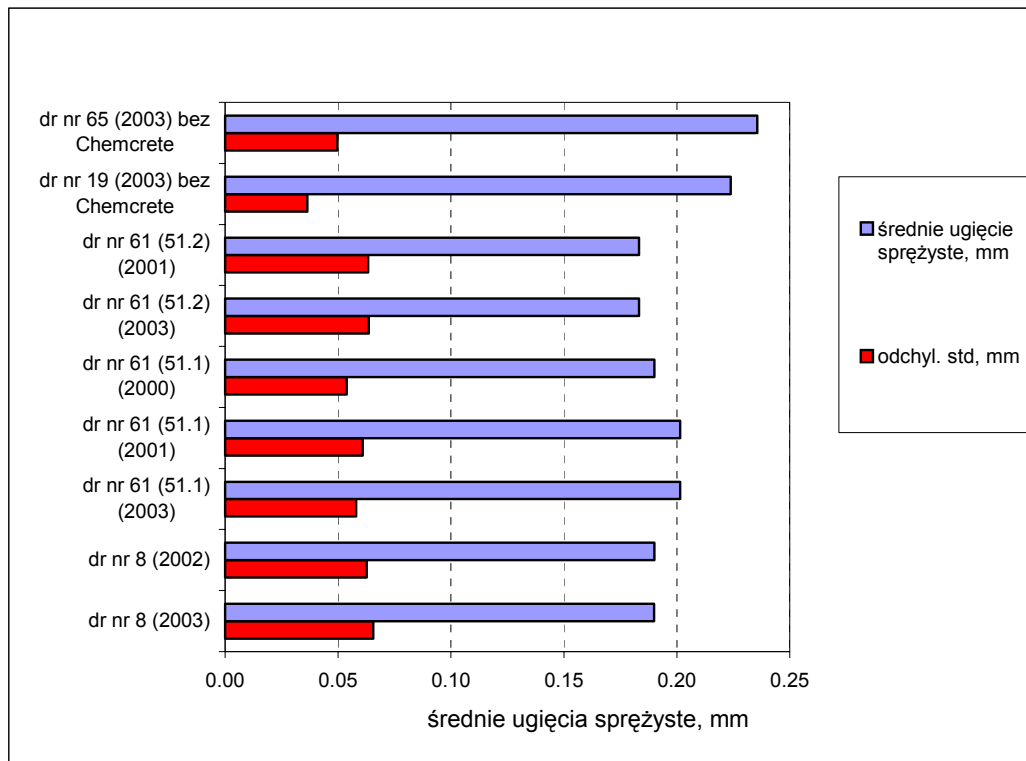
(Legend: — - measurement in binding layer with Chemcrete taken in 2000, — - measurement of abrasive layer taken in 2000, — - measurement of abrasive layer taken in 2001)



Pic. 5.4. Graphic representation of elastic deflections in tested section of road no 61

(Legend: — - 2000 of bitumen substructure layer, — - 2000 of binding layer with Chemcrete, — - 2000 in SMA abrasive layer, — - 2001, — - 2003)

Interesting conclusion can be drawn from the comparison of elastic deflections. In pic. 5.5 the average values of elastic deflections for particular tested sections are shown and, for comparison, deflections of road surfaces which include a binding layer with a binding agent modified with Chemcrete (road no 19 – circular road of Kuźnica and road no 65 – Białystok-Bobrowniki). The stiffening effect of modified binding layer for the whole structure is visible in the geophone indications located in the proximity of the load axis.



Pic. 5.5. Comparison of average elastic deflections in tested surfaces of road sections

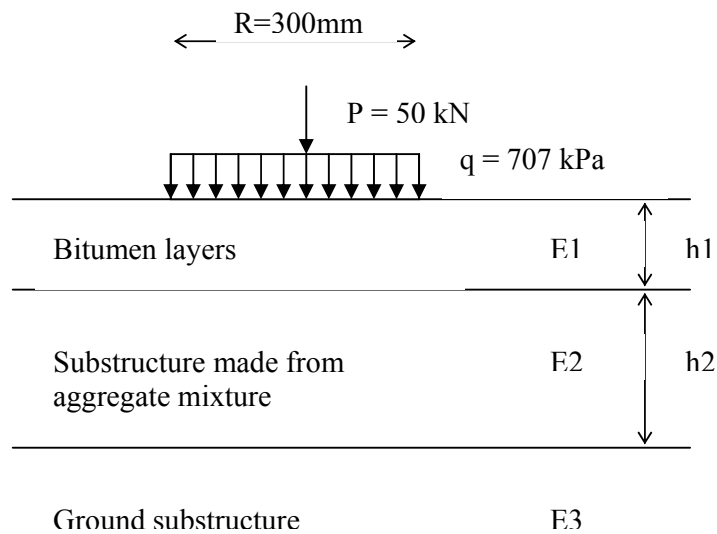
(Legend: line 1: road no 65 (2003) w/out Chemcrete, line 2: road no 19 (2003) w/out Chemcrete, footnote: average elastic deflections mm, ■ - average elastic deflections mm, ■ - standard deviation mm)

6. Mechanistic analysis of road surface structures

6.1. Identification of elasticity modules of surface structures of various road sections.

For tested sections structure calculation models were used where the thickness of layers correspond with average values obtained based on bore-holes conducted on the surface structures. For identification of surface modules and surface structure foundation results of surveys of the deflection cap in tested sections were used. The calculation was obtained (using computer software “ELMOD”) for various representative points. Location of the representative points was determined based on the comparison of the shape of deflection cap (measured at the particular point) with the average cap for each particular homogeneous section (tested). Points with a cap statistically most approximate to the approximate average cap were used for testing.

The calculation model is shown in pic. 6.1. Thickness of the structure layers in the model is set as the average based on the measurement of thickness obtained through boring in tested sections and from archives.



Pic. 6.1. Calculation model of road surface substructure.

Calculated elasticity module values are shown in table 6.1. .

Table 6.1
Elasticity module values obtained from calculations made by ELMOD computer software

road	Representative point location	E1	E2	E3	Temp. Of meas.
		MPa	MPa	MPa	°C
19	2.300 P	2530	261	166	28
65	178.750 P	6264	462	175	11
8	18.100 P	4545	359	242	21
61	171.900 L	5871	448	101	19

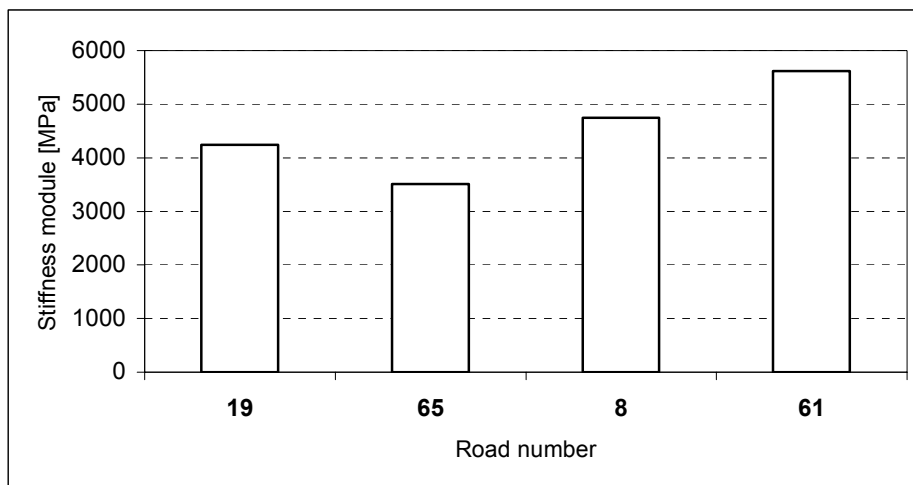
Obtained values of bitumen layer modules for various temperatures where brought down to modules in equivalent temperatures of 10C and 20C (according to

the procedure described in “LTPP Guide to Asphalt Temperature Prediction and Correction”).

Coefficients determining the increment of bitumen layers in relation to temperature change were determined based on the results of tests of elastic stiffness modules in the NAT apparatus. Calculation results are shown in tables 6.2 and in pic. 6.2.

Table 6.2
Values of elastic stiffness modules of bitumen layer in relative temperatures of 10C and 20C

Road	Representative point location	E1 in 10 °C	E1 in 20 °C
		MPa	MPa
19	2.300 P	8075	4238
65	178.750 P	6681	3506
8 (Chem.)	18.100 P	7354	4748
61(Chem.)	171.900 L	8704	5620



Pic. 6.2. Stiffness modules of bitumen layers in relative temperature of 20C

From the comparison of the stiffness module values shown in table 6.2 and in pic. 6.2 we can see that thanks to the binding layer made from asphalt concrete with Chemcrete modified asphalt higher module values were obtained in 10C, average of 8.8%, and in 20C by 33.9%.

6.2. Analysis of fatigue durability of typical surface structure configuration and their modification when Chemcrete is added.

For the analysis the surface structure corresponding with the KR4 vehicle load (load mostly occurring on main roads of podlaski district) was used. A

configuration of layers and types of materials used in these layers were assumed as typical for those currently used in structural solution in the north-eastern part of Poland. Calculations were made considering climatic conditions given in the Catalog.

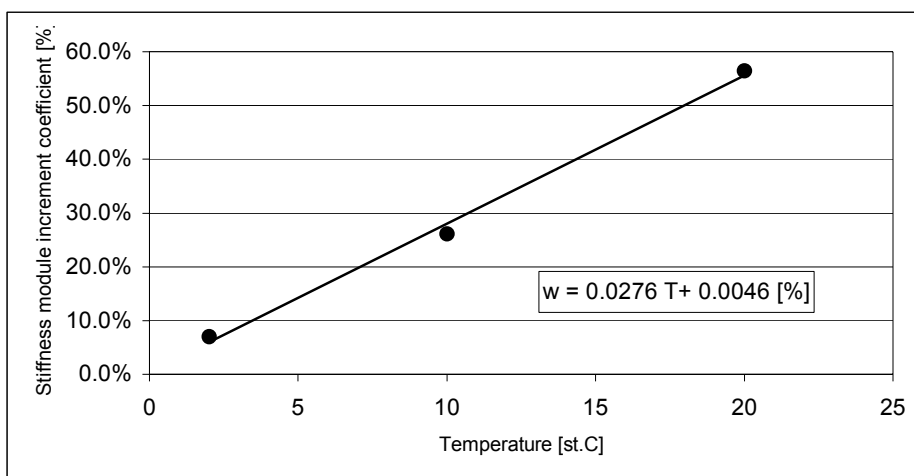
Values of the stiffness module of asphalt concrete with Chemcrete were determined considering the percentile increment of the stiffness module of the binding layer with modifying additive. The percentile coefficients of increment were determined based on the test results of elastic stiffness module tests conducted on samples according to the Brazilian method in three different temperatures (Table 6.3).

Table 6.3

Determination of stiffness module increment in relation to temperature

Elastic stiffness module – asphalt concrete with asphalt type 35/50				Elastic stiffness module – asphalt concrete with asphalt type 35/50 with Chemcrete			
Temp	2 ⁰ C	10 ⁰ C	20 ⁰ C	Temp.	2 ⁰ C	10 ⁰ C	20 ⁰ C
A1	18995	9223	5202	B1		10811	6576
A2	15114	9534	5824	B2	15676	11808	7476
A3	15519	10191	4352	B3	16698	12652	7728
A4	15874	9494	4412	B4	17018	12726	8293
A5	16139	10958	6044	B5	16895	12027	7871
A6	15640	9203	4769	B6	17276	12428	7660
A7	15825	9130	4451	B7	19328	12504	7793
A8	15968	10113	5071	B8	15648	12288	8131
A9	14251	8963	4050	B9	17824	12258	7590
average	15925	9645	4908	average	17045	12167	7680
				Increment coefficient	7.0%	26.1%	56.5%

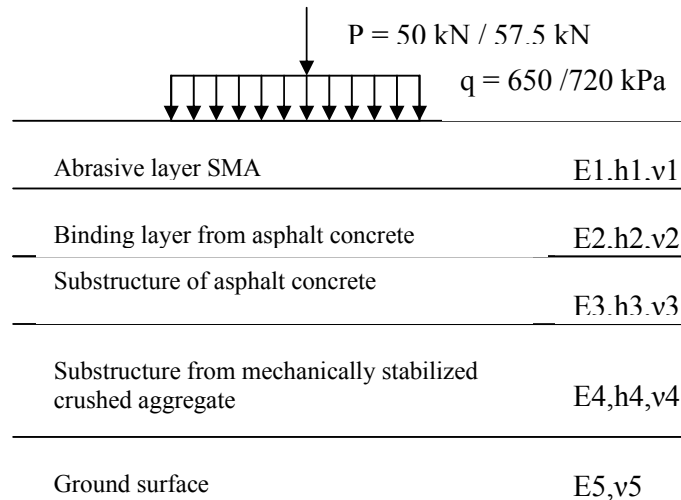
Graphic representation of percentile coefficient of stiffness module increment in relation to temperature is shown in pic. 6.3.



Pic. 6.3. Graphic representation of percentile coefficient of stiffness module increment in relation to temperature.

For temperatures characteristic for the particular seasons: winter $-2\text{ }^{\circ}\text{C}$, spring and autumn $10\text{ }^{\circ}\text{C}$, summer $23\text{ }^{\circ}\text{C}$ from pic. 6.3 stiffness module coefficients were determined with used modification of bitumen layers with Chemcrete. They amount to, respectively: -5.0% , $+28.1\%$ i 63.9% .

The surface structure shown in pic. 6.4 was submitted to mechanistic analysis.



Pic. 6.4. Calculation model of road surface structure

Structure layer thickness, stiffness module values (binding layer without Chemcrete and with the modifier added) and the results of calculations of fatigue durability are shown in table 6.4. The value of the Poisson coefficient was determined as follows:

- Bitumen layers – winter $\nu=0.25$, spring and autumn $\nu=0.30$, summer $\nu=0.40$,
- Substructure from mechanically stabilized crushed aggregate - $\nu=0.3$,
- Ground surface - $\nu=0.30$.

Volume proportions of mineral-asphalt mixtures compliant with the Catalog of Typical Surface Structures Susceptible and Half-stiff (asphalt concrete with partially enclosed structure to the substructure layer: asphalt volume 10.0% , empty space volume 8%) were assumed for the calculations.

Deflection calculations for the analyzed structures were conducted using computer software BISAR 3.0.

Table 6.4.

Fatigue durability calculation results

Basic data					
	Layer thickness	season	Without Chemcrete		With Chemcrete
E1 abrasive layer module [MPa]	h1 = 5cm	Summer	2800		
		Spring + autumn	10300		
		Winter	19300		
E2 binding layer module [MPa]	h2 = 8 cm	Summer	3000	4918	
		Spring + autumn	10100	12934	
		Winter	18800	17849	
E3 bitumen substructure layer module [MPa]	h3 = 10 cm	Summer	3000		
		Spring + autumn	9600		
		Winter	18100		
E4 substructure from crushed aggregate layer module [MPa]	h4 = 20 cm		400		
E5 ground layer module E5 [MPa]			100		
Calculation results					
	season	Oś 100 kN	Oś 115 kN	Oś 100 kN	Oś 115 kN
Stretching deflections on the bottom of bitumen layers [μm/m]	Summer	130.8	148.5	124.8	141.9
	Spring + autumn	66.0	75.1	64.6	73.7
	Winter	42.8	48.8	43.0	49.0
Crushing deflections on the top of the ground layer [μm/m]	Summer	365.4	418.8	345.9	396.6
	Spring + autumn	214.9	246.6	209.6	240.6
	Winter	155.6	178.6	156.4	179.5
Fatigue durability of bitumen layers Nf1 [mln axis]		3.5	2.3	4.0	2.6
Durability in terms of deflections in the ground layer Nf2 [mln axis]		9.9	5.4	12.4	6.7
Fatigue durability of surface structure [mln axis]		3.5	2.3	4.0	2.6
Percentile increment of fatigue durability due to the usage of Chemcrete in the binding layer – criteria for fatigue durability for asphalt layers				14.3%	13.1%
Percentile increment of fatigue durability due to the usage of Chemcrete in the binding layer – criteria for structural deformations of the surface				25.3%	24.1%

It can be concluded from table 6.4 that using a modified binding agent in the binding layer causes an increase in the fatigue durability of asphalt layers in the structure by 14.3% in relation to the fatigue durability of structures without the modifier (axes 100 kN). A larger increment if durability is obtained from the structural deformation criteria of surfaces (misshaping of the ground layer) by

approximately 25%, which is caused by a greater effect of modified binding layer on the complete structure (significant effect for weak load ground layers).

6.3. Analysis of fatigue durability of structures of lower durability surfaces

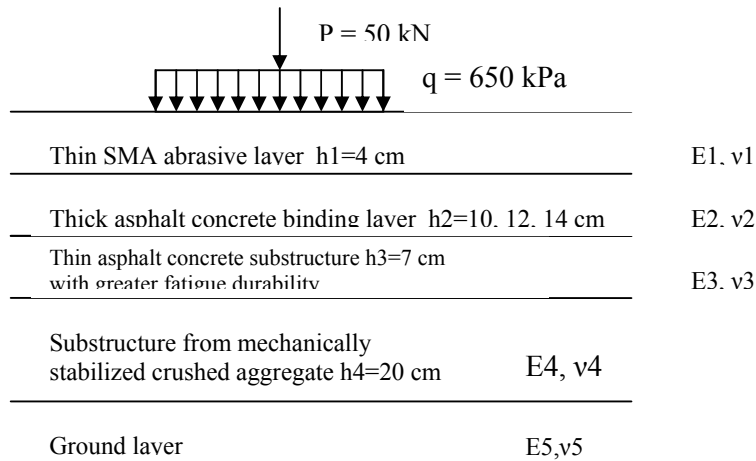
Apart from the material characteristics of materials used in the structure, the following have an effect on the longevity of road surfaces: type of layers, their thickness and set-up in the surface structure. Traditional solutions with typical surface layers from asphalt concrete, whose thickness increases and stiffness decreases with depth do not correspond with the new surface concepts of a much extended longevity, in comparison to traditional surfaces. Experiences of French, British, Dutch, and especially American researchers indicate that there are huge potential possibilities in the asphalt surfaces. Roads built using new methods prove the thesis that there is a possibility for construction of susceptible road surfaces with long longevity, which comply with the 50-year requirement for load layers. Proposed concept of road surface construction called “perpetual” has the following characteristics:

- All layers of the surface are susceptible, made from specially chosen mineral-asphalt mixtures,
- Thin abrasive layer is made from a mineral-asphalt mixture resistant to rutting, it is durable, air and watertight and rough (rock-like materials resistant to polishing, e.g. SMA mixture),
- Binding layer, thicker than the one currently used in Poland (over 10 cm), characterized by high resistance to permanent deformation,
- Much thicker substructure layer, with a lower stiffness level and a greater fatigue life.

The binding layer constructed according to this concept, which has a great effect on the longevity of the surface structure should be given special distinction. It should be characterized by increased stability (hardened layer with high resistance to rutting), as well as high durability.

It seems possible that most of the requirements set forth for structure binding layers with extended longevity can be fulfilled by using mineral-asphalt mixtures modified with Chemcrete to construct them.

An analysis of road surface structure compliant with the requirements of the “perpetual” surface, with a binding layer with Chemcrete is shown in pic. 6.5.



Pic. 6.5. “Perpetual” type surface structure

For the substructure layer asphalt concrete with Multiphalte 60/70 asphalt with stiffness module 5164 MPa (calculated using computer software SPDM 3.0 for the following data: asphalt volume 12%, aggregate volume 83%, empty space volume 5%, temperature 10C) was assumed. The Poisson coefficients were assumed for all layers, and equal to 0.35. The calculation of deflections and fatigue durability was made for temperatures characteristic for particular seasons: winter -2 °C, spring and autumn 10 °C, summer 23 °C. Two variants connected with the bearing capacity of ground layer were assumed: variant I – ground layer with elasticity module of 100 MPa, variant II – ground layer with the elasticity module of 50 MPa. The fatigue durability calculation results are shown in table 6.5.

Table 6.5

Results of calculation of fatigue durability for “perpetual” type of structure

	Layer thickness	Basic data	
E1 abrasive layer module [MPa]	$h_1 = 4$ cm	summer	2800
		spring + autumn	10300
		winter	19300
E2 binding layer module [MPa]	$h_2 = 10, 12, 14$ cm	summer	4918
		spring + autumn	12934
		winter	17849
E3 bitumen substructure layer module [MPa]	$h_3 = 7$ cm	summer	1630
		spring + autumn	5160
		winter	10900

E4 substructure from crushed aggregate layer module [MPa]	h4 = 20 cm	400							
E5 ground layer module E5 [MPa]		Variant I		Variant II		100	50		
Calculation results									
		Typical structure according to the Catalog (Pic. 6.4)		“perpetual” structure thickness of binding layers with Chemcrete [cm]					
				10		12		14	
Stretching deflections on the bottom of bitumen layers [μm/m]				I	II	I	II	I	II
	summer	130.8	156	171	137	151	121	13	4
	spring + autumn	66.0	91	101	79	88	69	77	77
	winter	42.8	62	68	54	60	47	52	52
Crushing deflections on the top of the ground layer [μm/m]									43
	summer	365.4	411	564	361	494	320	6	27
	spring + autumn	214.9	266	362	231	313	201	2	20
	winter	155.6	202	273	175	235	153	4	4
Fatigue durability of bitumen layers Nf1 [mln axis]	3.5		14.3	10.4	22.3	16.1	34.0	24.4	24.4
Durability in terms of deflections in the ground layer Nf2 [mln axis]	9.9		5.4	1.3	9.7	2.4	17.1	4.3	4.3
Fatigue durability of surface structure [mln axis]		In relation to fatigue durability of bitumen layers of a typical structure (lower value with Nf1i Nf2)	54	-63	177	-31	389	23	23

It can be concluded from table 6.5 that there is a possibility for construction of surfaces with extensive longevity. With the same thickness of bitumen layers (23 cm – typical structure, and 23 cm for extensive longevity surfaces – 4 + 12 + 7 cm) it is possible to obtain over two and a half times greater increment of fatigue durability of the surface structure (increment by 177%).

The capacity of ground layer has a significant effect on the fatigue durability of the structure. With a low capacity ground layer it is possible to design structures with layers of required durability by increasing the thickness of the layer modified with Chemcrete (in the analyzed sample in variant II with the binding layer 14 cm thick).

7. Conclusions

Based on the tests and analysis conducted the following conclusions can be drawn:

- Due to climatic conditions of podlaski district a mixture with a large amount of mastics should be used in the abrasive layer (especially SMA and MNU mixtures – mixtures with non-perpetual grain for thin layers)
- Adding Chemcrete to the asphalt mixture has a positive effect on its viscose elastic attributes; the binding agent hardens in relation to the basic binding agent in positive usage temperatures (especially in very high temperatures), simultaneously there is a lack in hardening in negative temperatures.
- Mineral-asphalt mixtures with binding agent modified with Chemcrete show an improvement in relation to standard mixtures in terms of technical characteristics in resistance to permanent deformation, at the same time not worsening but actually improving the fatigue durability.
- Road surface structure with binding layer containing a binding agent modified with Chemcrete as a whole shows improved hardening and, consequently, has an improved durability and extended longevity.
- Surface structure with higher fatigue durability should contain the following layers: thin abrasive layer made from SMA (MNU), stiff thick binding layer made from asphalt concrete with modified binding agent, e.g. modified with Chemcrete (thickness over 12 cm – best would 14 cm), relatively thin elastic substructure layer made from mineral-asphalt mixture of asphalt concrete type with a not very hard binding agent (thickness of about 7 cm).

