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Verification of the criteria for evaluation of water and frost resistance of asphalt concrete

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ABSTRACT. *The paper presents the results of field investigation – condition survey of existing pavements and the results of laboratory tests on water and frost resistance of samples cored from the these pavements. The purpose of testing was to verify the criteria for evaluation of the resistance of asphalt concrete to the action of water and frost by way of comparing the results of field and laboratory tests, followed by evaluation of their reliability. The results of field and laboratory tests were subjected to comparative analyses. The output of these analyses includes conclusions and recommendations.*

KEYWORDS: *asphalt concrete, water and frost resistance, laboratory and field evaluation.*

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1. Introduction

Suitability and popularity of testing methods for determining the properties of asphalt mixes result from their reliability. Reliability in this context is understood as a consistency between the laboratory evaluation and the actual performance of the material. An additional factor to be taken into account for asphalt mix components is change of properties due to aging and external factors, such as constantly fluctuating weather conditions and trafficking (Jaskula, 2004).

Asphalt road pavements are designed for 20-30 years service life, which may include replacement of the wearing course. In most cases the purpose is to reinstate the functional performance of pavement, which has deteriorated due to normal wear, resulting in decreased friction and smoothness. Other types of surface distress, such as ravelling, potholes and certain types of cracking, resulting from the action of water and frost, should not occur. Therefore, the methods for evaluating the resistance of asphalt mixes to the action of water and frost should take into account long-term effects.

The research carried out in 2002 at the Gdansk Technical University involved visual evaluation of twelve pavement sections trafficked for between two and eight years and laboratory testing of samples cored from the wearing courses. Visual evaluation was carried out for the types of pavement distress which in the authors' opinion were related to the action of water and frost. It included rating of pavement condition according to SOSN[1]. The ratings ranged from 0 for pavements affected with surface distress (due to action of frost and water) to 1 for pavements showing very good surface condition. Visual evaluation was followed by drilling of samples for laboratory testing of asphalt mixes according to modified AASHTO T283 method. The values of Tensile Strength Ratio (TSR) and Resilient Modulus Ratio (RMR) were determined, which showed loss of tensile strength and lowering of modulus due to the action of water and frost. As the next step, the visual assessment ratings were correlated with the TSR and RMR values, as determined in the laboratory testing. This enabled proposing the minimum allowable values of RMR and TSR, as the preliminary criteria of TSR>80% and RMR>75%. These values were proposed for provisional use in design of asphalt mixes in Poland.

Currently in Poland, resistance of asphalt concrete to the action of water and frost is tested in laboratory conditions using AASHTO T283 method which was modified for Polish conditions or EN 12697-12 method. Finding of answers to the following two questions is indispensable for proper evaluation: Is the asphalt concrete, rated as good at the laboratory, performing well when incorporated in

[1] SOSN – System Oceny Stanu Nawierzchni = Pavement Condition Rating System. Method used in Poland for rating the condition of pavements on national roads.

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pavement? What values of TSR and RMR should be taken as criteria for evaluation of asphalt concretes? These issues have been addressed in the present paper.

2. Field testing

2.1. Identification of sections for testing

On the basis of consultations with the road administration, roadworks contractors and own observations twelve pavements were selected for testing, located in Gdansk and Gdynia[2] featuring varying severity of distress, attributable to the action of water and frost. The condition ratings ranged from heavily damaged to slightly damaged or even undamaged. As it has been established in the analysis of job mix formulas (JMF), almost in all cases, except for two, the wearing course was designed according to the Road and Bridge Institute (IBDiM) bulletin, issue No. 48[3], (Zawadzki, 1995). The two exceptions were designed according to the Polish Standard (PN-74/S-96022), issue from 1974. The age of pavements designed according to the IBDiM bulletin, ranged from 2 to 6 years, and according to PN-74/S-96022 were 5-8 years old. In all cases, with one exception where widening was designed as a separate construction, the pavements were placed as part of rehabilitation projects, which in most cases involved overlaying the existing pavement structures with two or three layers of new asphalt. The selected street pavements are presented in Table 1.

No.	City	Street name	AADT	Heavy loads	Age [years]
1	Gdansk	Góreckiego St.	2000	No	5
2		Brzegi St.	1000	No	8
3		Małomiejska St.	13000	Yes	4
4		Smoluchowskiego St.	15300	No	4
5		Kościuszki St.	22200	Yes	5
6		Kielnieńska St.	10000	Yes	6
7		Wysoka St.	24000	Yes	6
8		Stary Rynek Oliwski St.	12400	Yes	4
9		Grunwaldzka St.	45000	Yes	5
10		Kartuska St.	17400	Yes	2
11	Gdynia	Zwycięstwa Av.	53000	Yes	4
12		Wielkopolska St.	19600	Yes	4

Table 1. *List of tested street pavement sections of Gdansk and Gdynia.*

[2] Northern Poland, same climatic conditions for two cities

[3] IBDiM bulletin is a recommendation signed by General Director of Polish National Roads, always used since 1995 to 2002 year for main roads also in the cities

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2.2. Visual condition evaluation of selected street pavement sections

The survey condition was carried out according to the SOSN pavement condition rating system, issued in 1989.

Each of the street pavements listed in Table 1 was inspected for surface distress over 100 m long representative section. The following types of pavement distress were taken into account: patches and potholes, ravelling and stripping.

The surveyed parameters for the above types of pavement distress included severity and frequency of occurrence on the most heavily loaded traffic lane (Table 2), as per the SOSN guidelines.

Severity degree	Patches and potholes	Ravelling and stripping
M	Smooth patches, tightly joined with the pavement	Stripping and ravelling of up to five removed. grains per A4 sheet, forming holes larger than 5mm in diameter
S	Patches with small cracking at the interfaces with surrounding pavement	Stripping and ravelling of more than five removed grains per A4 sheet, forming holes larger than 5mm in diameter
D	Irregular patches with unsealed joints (cracking and spalling) and potholes	Ravelling/stripping all over the surface, very irregular texture, porous surface, ravelling may reach down throughout the whole wearing course thickness.

Table 2. *Severity of various types of pavement distress according to SOSN*

Patches/potholes and ravelling/stripping are rated according to the intensity and severity of distress. The ratings are given separately for each severity degree (if varying distress degrees have been noted on a single representative hectometre). Then the maximum value is taken and increased by 10% of the totalled ratings for different severity degrees and then multiplied by a factor to account for the traffic level.

The visual evaluation of pavement distress results in determining the pavement condition index S, taking a value between 0 and 1. The higher the value of pavement condition index S the better is the condition of pavement.

The evaluation criteria determine three levels of pavement condition:

– required level – pavements rated above that level require no remedial action for a few years on,

– warning level – rating below that level supports decision on remedial action,

– critical level – the condition has reached a level below which remedial action must be carried out without delay.

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Based on the above levels the condition of pavement has been rated in four classes according to the value of pavement condition index S.

Level 1 - acceptable	Class A -	Good condition, S > 0.95
	Class B -	Satisfactory condition, S value ranging between 0.66 and 0.95
Level 2 - warning	Class C -	Unsatisfactory condition, remedial action to be planned, S value ranging between 0.41 do 0.65
Level 3 - critical	Class D -	Bad condition – immediate remedial action needed, S< 0.41

The values calculated for representative points were used for determining the condition of pavement surface according to SOSN. The respective pavements were classified to one of the four pavement conditions classes (see Table 3).

No.	Street	Pavement condition index „S"	Condition class according to SOSN
1	Góreckiego	0.10	D
2	Brzegi	0.83	B
3	Małomiejska	0.07	D
4	Smoluchowskiego	0.58	C
5	Kościuszki	0.65	C
6	Kielnieńska	0.10	D
7	Wysoka	0.64	C
8	Stary Rynek Oliwski	0.44	C
9	Grunwaldzka	0.38	D
10	Kartuska - Auchan	0.48	C
11	Aleja Zwycięstwa	0.62	C
12	Wielkopolska	0.26	D

Table 3. *Determination of pavement condition class of the surveyed streets*

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2.3. Summary of visual evaluation according to SOSN

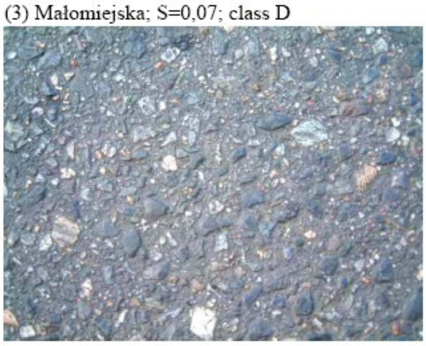
The pavement condition of the evaluated streets is compiled in Table 3 and shown in Fig. 1 and Fig. 2, giving the value of S (pavement condition index). The types of distress noted are attributed to the damaging effect of water and frost.

(1) Góreckiego; S=0,10; class D

(2) Brzegi; S=0,83; class B

(3) Małomiejska; S=0,07; class D

(4) Smoluchowskiego; S=0,58; class C



(5) Kościuszki; S=0,65; class C

(6) Kielnieńska; S=0,10; class D

Figure 1. *Pavements of tested streets in Gdansk and Gdynia, condition rating given under each photo, part 1*

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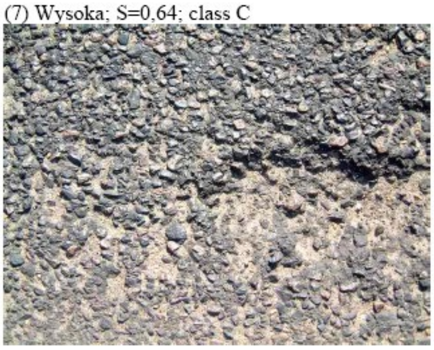
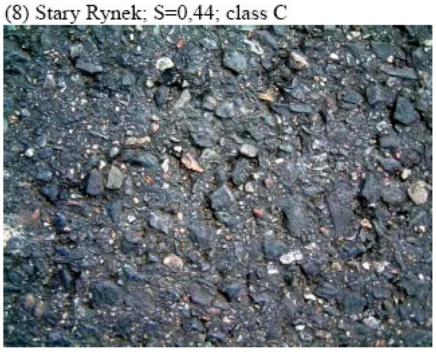
(7) Wysoka; S=0,64; class C

(8) Stary Rynek; S=0,44; class C



(9) Grunwaldzka; S=0,38; class D



(10) Kartuska; S=0,48; class C

(11) Aleja Zwycięstwa; S=0,62; class C

(12) Wielkopolska; S=0,26; class D

Figure 2. *Pavements of tested streets in Gdansk and Gdynia, condition rating given under each photo, part 2*

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As a result of visual evaluation:

– five out of the twelve surveyed pavements were rated in D class (bad condition, immediate remedial action required),

– six out of the twelve surveyed pavements were rated in C class (unsatisfactory condition, remedial action to be scheduled),

– one out of the twelve surveyed pavements was rated in class B (satisfactory condition),

– unfortunately, none of the evaluated pavement has been rated in A class (good condition).

3. Laboratory testing of asphalt concrete samples cored from the pavement

3.1. Sampling procedure

For each pavement section tested, from a representative hectometre, three 200 mm and two 100 mm in diameter samples were drilled. Wearing course was detached from the cores and subjected to testing.

3.2. Testing of physical and mechanical properties of asphalt concretes

The 100 mm cores were dried and immediately tested to determine: field bulk density, indirect tensile stiffness modulus (ITSM), indirect tensile strength (ITS) and condition of fractured surface by visual evaluation.

The 200 mm cores were heated up, pulverized and recompacted and tested to determine: specific density (before recompacting), aggregate composition and bitumen content, water and frost resistance according to modified AASHTO T283.

The test results consisting of physical and mechanical properties are given in Table 4.

In the following part of the paper two of the above tests are described in more detail, namely: visual evaluation of fractured surface and water and frost resistance according to AASHTO T283.

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Table 4. *Results of testing of asphalt concrete cores cut from the tested pavements and from job mix formulas (JMF)*

Street Ref. No.	Age of pavement [years]	Pavement condition value S	Data from	Mix properties										
				Specific density [g/cm^3]	Field bulk density [g/cm^3]	Air void content [%]	Marshall bulk density [g/cm^3]	Relative Density [%]	Indirect tensile strength [MPa]	Stiffness modulus at 20°C [MPa]	Bitumen content [%]	Content of grains <0.075 mm [%]	Stripping on fractured surface	Filler/ bitumen ratio
1	5	0,10	JMF	2,554	2,485	2,7	-	-	-	-	5,3	10,5	none	1,73
			Cores	-	-	-	2,442	-	-	-	5,2	9,0		
2	8	0,83	JMF	-	-	-	-	-	-	-	-	-	1,7	1,00
			Cores	2,431	2,370	2,5	2,384	99,4	0,93	2590	7,3	7,3		
3	4	0,07	JMF	2,592	2,514	3,0	-		-	-	5,1	6,5	1,8	1,83
			Cores	2,591	2,438	5,9	2,476	98,5	1,20	6572	5,1	9,4		
4	4	0,58	JMF	2,620	2,550	2,7	-		-	-	5,2	7,2	1,3	1,28
			Cores	2,627	2,530	3,7	2,540	99,6	1,30	3852	6,0	7,7		
5	5	0,65	JMF	2,560	2,460	3,9	-		-	-	5,0	5,8	1,2	1,25
			Cores	2,499	2,409	2,0	2,409	100,0	1,26	4436	5,1	6,4		
6	6	0,10	JMF	2,592	2,514	3,0	-		-	-	5,1	6,5	1,3	1,61
			Cores	2,570	2,518	2,0	2,484	102,1	1,64	5804	5,1	8,2		
7	6	0,64	JMF	2,538	2,458	3,2	-		-	-	5,1	8,8	1,2	1,75
			Cores	2,672	2,515	5,9	2,531	99,4	1,63	8942	5,1	8,9		
8	4	0,44	JMF	2,679	2,593	3,2	-		-	-	5,0	6,6	1,5	1,85
			Cores	2,694	2,544	5,5	2,545	100,0	1,35	6759	4,6	8,6		
9	5	0,38	JMF	2,643	2,553	3,4	-		-	-	5,0	6,5	2,2	1,88
			Cores	2,654	2,494	6,1	2,511	99,3	1,32	7536	5,0	9,4		
10	2	0,48	JMF	2,473	2,412	2,5	-		-	-	5,2	7,1	1,0	1,23
			Cores	2,561	2,525	1,4	2,478	101,9	1,32	3905	4,8	5,9		
11	4	0,62	JMF	2,560	2,480	3,1	-		-	-	5,1	5,8	none	1,64
			Cores	2,495	2,410	3,4	2,391	100,8	1,39	6101	4,3	7,0		
12	4	0,26	JMF	2,560	2,480	3,1	-		-	-	5,1	5,8	none	1,78
			Cores	2,515	2,433	3,3	2,412	100,9	1,29	5870	4,8	8,6		

3.3. Visual evaluation of fractured surface of pavement cores

The fractured surface is evaluated for the degree of stripping on detached samples in the Indirect Tensile Strength test. The percent of stripped grains was established according to the procedure developed at the Georgia Department of Transportation (USA), as described in NCAT REPORT No. 92-1, (Kandhal, 1992). The degree of stripping was rated in points corresponding to the ranges of total stripped surface area in percent, as measured on detached samples. The points were given according to Table 5, separately for coarse grains (> 5 mm) and fine grains (< 5 mm) according to the Georgia DOT Stripping Rating.

For the Georgia DOT Stripping Rating a condition rating criterion has been developed in South Carolina according to which stripping ratings in the range 2.5-3 mean dangerously high degree of stripping.

Value of **C**	Value of **F**
C = stripping of coarse grains (>5 mm) 1 = less than 10% 2 = 10 – 40% 3 = more than 40%	**F** = stripping of fine grains (<5 mm) 1 = less than 10% 2 = 10 – 25% 3 = more than 25%

Table 5. *Stripping degree represented by the stripping rating value*

The degree of stripping is determined from the following equation:

$$S = (C+F)/2 \qquad [1]$$

where: S – average stripping rating, C, F – values from Table 5.

For each sample the degree of stripping was determined in three independent visual evaluations. Then the average value was calculated to obtain the final rating. Table 6 presents a detailed visual evaluation record for the respective pavements.

Based on the data from Table 6 and according to the South Carolina criterion none of the wearing course samples showed high degree stripping in the middle of a sample. However, major stripping and ravelling attributed to the action of water and frost was noted on the surface of the wearing course.

Street No.	1	2	3	4	5	6	7	8	9	10	11	12
Average stripping rating	n.t.	1.7	1.8	1.3	1.2	1.3	1.2	1.5	2.2	1.0	n.t.	n.t.

Table 6. *Stripping ratings for the pavement cores*

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3.5. Evaluation of physical and mechanical properties of asphalt concrete using pavement cores

Asphalt mixes used for wearing courses of the selected pavements of Gdansk and Gdynia, comply with the requirements of the IBDiM (Zawadzki, 1995) concerning aggregate composition and bitumen content. However, in almost every mix the bitumen content approached the middle admissible limit (4.5-5,6%) while the content of filler approached the upper limit (5-7%), within the specified tolerances (+/-2%). This could have been the factor responsible for stiffening of the mix.

According to earlier experiences asphalt wearing courses designed according to the new guidelines of IBDiM (Zawadzki, 1995) have stiffness moduli at 20°C in the range of 3000-4000 MPa. The moduli of mixes tested in the present survey fall in the range 3000–9000 MPa (see Table 4 and Fig. 3), except for pavement No. 2 which was comply with the old Polish Standard PN-74/S-96022. The six pavements with the most stiff mixes, making up to 50% of the total number of tested pavements had the moduli in the range from 5800 MPa to 8900 MPa. Hence, for majority of pavements the asphalt mixes were excessively stiff.

In eight out of twelve pavements the air-void content in the wearing course material ranged between 1.4% and 3.9%. In four cases it ranged between 5.5 and 6.1%. Air-void content in a range of 5-6%, although higher than the maximum specified in the Polish standard is not dangerously high. Instead, it is quite typical for wearing courses constructed in USA and Europe. Nevertheless, it is worthwhile noting that excessive air voids content has a negative effect on the fatigue life and resistance to weather conditions (aging and action of water and frost). All the asphalt mixes incorporated in pavements were well compacted and had relative density between 99.4% and 100.9% out of the Marshall density.

From Fig. 5 a relationship between the filler/bitumen ratio and the air-void content can be figured out. Unfavourable proportion affected compaction and resulted in higher air voids content.

According to Fig. 4 the stiffness of asphalt concrete increases with the increase of filler/bitumen ratio[4].

[4] Filler/bitumen ratio (F/B) is a parameter recommended by SUPERPAVE. For mixes where maximum size of aggregate is less than 25 mm recommended value of F/B contains in the range 0,6-1,2.

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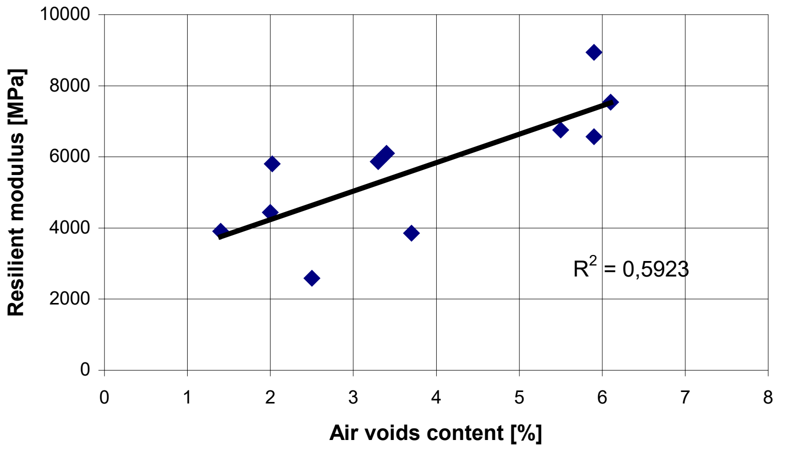

Figure 3. *Relationship between the resilient modulus and the air voids content.*

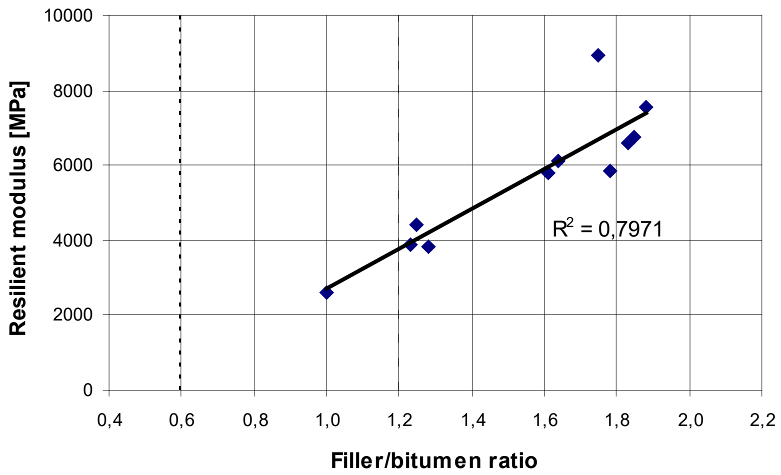

Figure 4. *Relationship between the resilient modulus filler/bitumen ratio.*

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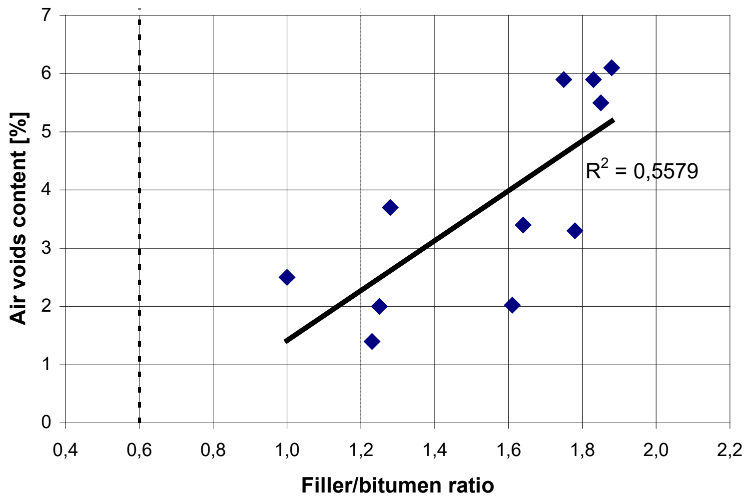

Figure 5. Relationship between air voids content and filler/ bitumen ratio

3.6. Resistance of asphalt concrete to the action of water and frost tested according to AASHTO T283

The tests were carried out according to the US standard AASHTO T283, modified for application in the Polish conditions (Judycki e*t al.,* 2001), (Judycki e*t al.,* 2002). The following is the modification introduced to the AASHTO T283 procedure. It was changed the method of aging of the loose mixture, testing temperature and resilient modulus test was added obligatory.

3.6.1. Samples

Pavement cores may be prepared for testing the resistance of asphalts to the action of water and frost according to AASHTO T283 in the three ways:

Testing of raw cores. Cores 100 mm in dia. after drilling from pavement are grouped in two series. The first series is conditioned (exposed to the action of water and frost) according to AASHTO T283. The second series is not conditioned. For both series the values of strength and modulus are determined, followed by determination of the tensile strength ratio (TSR) and the resilient modulus ratio (RMR). This is the procedure of AASHTO T283 test which requires testing of at least six samples (three conditioned and three unconditioned ones).

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Testing of recompacted cores. Drilled cores should preferably be larger in diameter than required for testing, for example D=150 mm or D=200 mm. The cores are split into separate layers and heated up. Cut grains are removed from the sides. Then the samples of D=100 mm are formed by Marshall compaction to obtain the air voids content in the range between 6% and 8% for all courses. Consequently, less energy is applied in compaction of the wearing course samples, which in Poland are typically designed with 4,5% or 5% air voids content. The purpose of increasing the air voids content is to promote the negative effect of water and frost during conditioning according to the AASHTO T283 procedure, even if the actual air voids content in the pavement material is about 4%. Then the samples are divided into two series and tested according to AASHTO T283.

Testing of samples fabricated by mixing aggregate obtained from the cores with new bitumen. The content and type of new bitumen should correspond to the parameters (mainly: penetration, viscosity) of old bitumen used in the pavement. The samples are compacted to obtain 6-8% air voids content. The samples are divide into two series and tested according to AASHTO T283.

The above methods were thoroughly reviewed for good and bad points. Upon analysis of the results as given in Table 7 second method was chosen, namely recompaction of pavement cores. Despite a thorough analysis there is still some uncertainty concerning preparation of samples as the recompaction process in high temperature could change the internal structure and improve bond between aggregate and bitumen.

3.6.2. Preparation of samples for testing and conditioning

First the wearing course material was detached from the cores, then the samples were heated up to 130°C in order to remove grains damaged in coring operation. Then the temperature was increased to 145ºC (higher than 135°C, as specified in AASHTO T283 to account for old age of asphalt), mix was pulverized and the samples were formed as for Marshall test (D=101 mm, H=63.5 mm). At least four uniform samples were prepared per each type of asphalt concrete cored from pavements. In total 48 samples were tested. Then samples was divided into control and conditioning group.

Control group (not subjected to conditioning) was kept in the laboratory, in room conditions until the time of the first test of sample.

Conditioning group of samples was subjected to laboratory conditioning which consisted of three stages: vacuum saturation of samples with water, one cycle of freezing and subjecting to an extended action of water at an increased temperature. Submerged in water at a temperature of 20°C samples were kept in a vacuum container at 200 hPa for 30 minutes. Next each saturated samples were placed in a plastic bag follows covered tightly with a plastic film and subjected to one freezing cycle (for 16 hours of minus 18°C). Thawing proceeded in a water bath of 60°C and storing them there for 24 hours without plastic bag and film.

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Evaluation of sample preparation methods:		
Method No. 1	Method No. 2	Method No. 3
100 mm raw cores tested after drilling	Recompacted asphalt mix from cores	Samples fabricated by mixing aggregate obtained from the cores by extraction of bitumen with new bitumen
Good points		
- easy preparation, - preparation time reduced to minimum, - condition evaluation of asphalts mixes, - maintains the original structure.	- maintains the original aggregate and bitumen content, - relatively short preparation time.	- maintains the original aggregate and bitumen content
Bad points		
- deterioration may have already started inside the sample (stripping, cracking of bitumen film), - only visual evaluation of sample interior, - the air-void content in samples cored from new and old asphalt pavements may be lower than 6%-8%, as required by AASHTO T283, reducing the effect of simulated water and frost action.	- bitumen properties may change due to reheating, - bond between bitumen and aggregate may be improved by heatng; this may result in change of resistance to water and frost action, - compaction to achieve 6% -8% air-void content changes the natural properties of the material, especially for wearing course, - unrealistic structure of material.	- time-consuming preparation, - foreign bitumen and partly filler, - pH and surface charge of aggregate may change, following flushing in organic solvents, - bitumen retained in pores will probably change the film thickness, - decreased adhesion of bitumen to aggregate due to old asphalt retained in the pores of aggregate, - compaction to achieve 6% -8% air-void content changes the natural properties of the material, especially for wearing course.

Table 7. *Good and bad points of the selected sample preparation methods*

3.6.3. Testing - resilient modulus and indirect tensile strength

After conditioning and immediately before testing all the samples were stored for 4 hours in a water bath at a temperature of 20°C. Each sample was subjected to non-destructive testing for resilient modulus at indirect tension, and destructive testing for indirect tensile strength.

Resilient modulus testing at indirect tension was performed in the Nottingham Asphalt Tester (NAT) during dynamic loading of the samples. The loading consisted in exerting a constant 240 kPa horizontal tension during 0.1 s, rest time of 2.9 s, and the cycle duration of 3 sec. Test was performed at temperature of 20°C.

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The indirect tensile strength testing was conducted in a Marshall testing press with piston travel of 50 mm/min. The load was transferred - through a 12 mm wide metal strip of 50.5 mm radius curvature. Testing temperature was 20°C.

For an evaluations the following values were calculated:

- resilient modulus ratio (RMR)

$$RMR = RM_1 / RM_2 \, x100\%, \tag{3}$$

- tensile strength ratio (TSR)

$$TSR = R_1 / R_2 \, x \, 100\%, \tag{4}$$

where: RM_1 and RM_2 – respectively: average values of resilient modulus after and before water and frost conditioning, R_1 and R_2 – respectively same for indirect tensile strength.

3.6.3. Results of tests carried out according to AASHTO T283

The average values of resistance to water and frost determined on asphalt samples after recompacting according to AASHTO T283 are presented in table 8 and Fig. 6.

Property	Asphalt concrete											
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
Resilient modulus, MPa, at T=20°C												
Unconditioned	4693	2252	9754	2997	3305	7291	9476	7415	7247	4018	4672	4855
After conditioning	2564	2014	5151	3187	3142	5728	5338	4391	5365	4148	4507	3962
Resilient modulus ratio RMR, %	*54,6*	*89,5*	*52,8*	*106,3*	*95,1*	*78,6*	*56,3*	*59,2*	*74,0*	*103,2*	*96,5*	*81,6*
Indirect tensile strength, MPa, at T=20°C												
Unconditioned	1,34	1,01	1,61	1,16	1,20	1,64	1,77	1,56	1,49	1,08	0,95	1,28
After conditioning	1,00	1,00	0,96	1,10	1,05	1,56	1,07	0,96	1,09	1,16	0,79	1,03
Tensile strength ratio TSR, %	*74,9*	*98,9*	*59,5*	*95,5*	*87,8*	*95,2*	*60,8*	*61,8*	*73,1*	*106,6*	*82,9*	*81,0*

1 – Góreckiego, 2 – Brzegi, 3 – Małomiejska, 4 – Smoluchowskiego, 5 – Kościuszki, 6 – Kielnieńska, 7 – Wysoka, 8 – Stary Rynek Oliwski, 9 – Grunwaldzka-Pomorska, 10 – Kartuska-Auchan, 11 – Aleja Zwycięstwa Gdynia, 12 – Wielkopolska Gdynia.

Table 8. *Average values of resistance to water and frost determined according to AASHTO T283*

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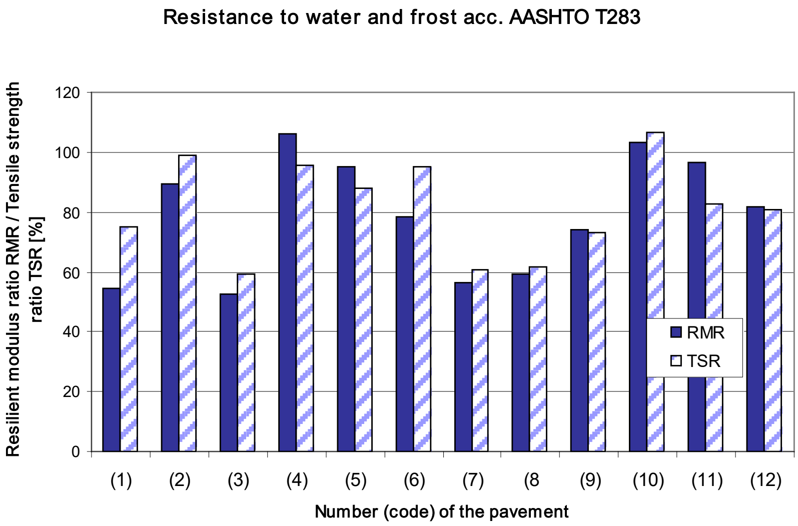

Figure 6. *Values of resilient modulus ratio (RMR) and tensile strength ratio (TSR) obtained in the test to determine water and frost resistance of asphalt samples after recompacting according to AASHTO T283*

3.6.4. Analysis of results

3.6.4.1. Comparison of RMR and TSR values

In Fig. 8 the relationship between RMR and TSR is presented with lines showing deviation between these values of +/-10% and +/-20%. Seven out of twelve results fall in the range of +/-10%, four in the range +/-20% and one more strongly deviates from the rest (street pavement No. 1). No regularity has been noted in the distribution of RMR and TSR values. Only what was observed seven out of twelve results of RMR were lower than TSR results for the same sample and three out of twelve results of RMR and TSR were almost the same.

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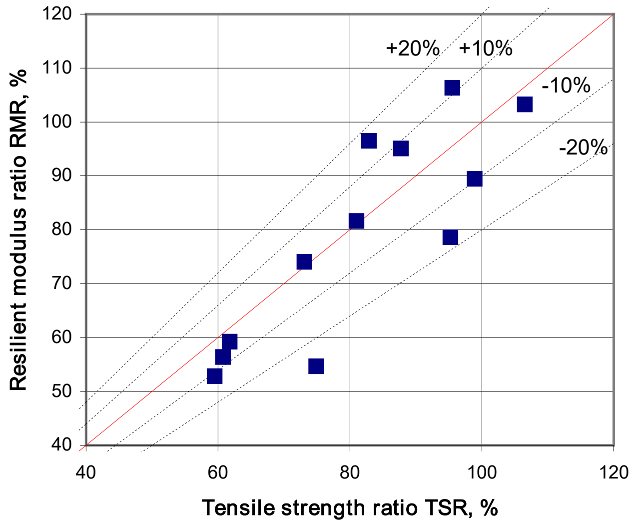

Figure 8. *Relationship between resilient modulus ratio (RMR) and tensile strength ratio (TSR).*

3.6.4.2. Resistance to water and frost related to the mechanical properties of asphalt concretes

Figures 9 and 10 relate the values of RMR and TSR to the values of resilient modulus and indirect tensile strength of asphalt concrete samples cut from the in service pavements. The values of RMR and TSR were determined on recompacted asphalt cores, tested in laboratory conditions. The moduli and strength values were determined on original cores drilled from the pavements.

From Fig. 9 and Fig. 10 we see that:

– **resistance to water and frost of asphalts decreases with increasing stiffness, R^2=0.58**,

– no relation has been found between indirect tensile strength and resistance to water and frost (TSR), R^2=0.05.

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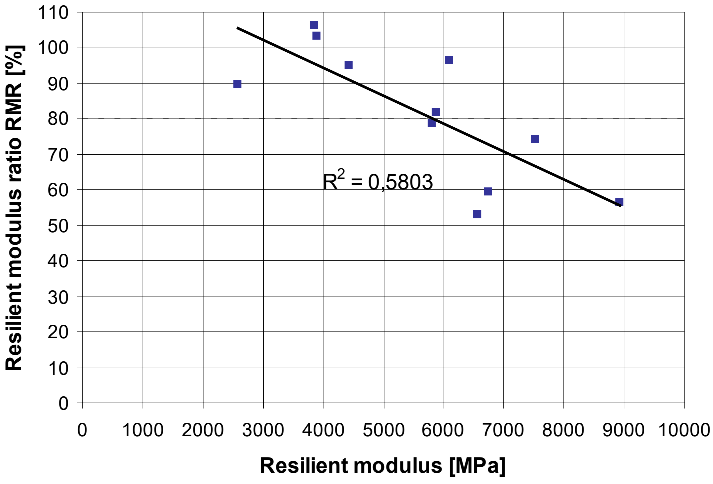

Figure. 9. *Relationship between RMR and resilient modulus determined on pavement cores (without recompacted).*

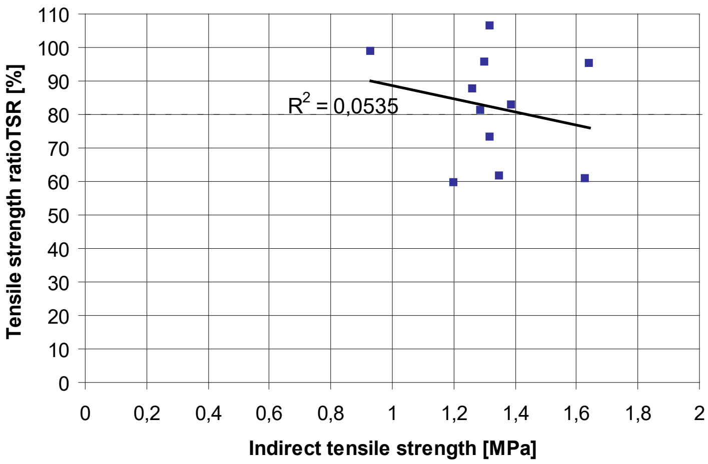

Figure. 10. *Relationship between TSR and indirect tensile strength determined on pavement cores (without recompacted).*

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3.6.4.4. Air voids content and measures of resistance to water and frost

Fig. 11 and Fig. 12 relate RMR and TSR to the air voids content, as determined on the tested asphalt cores.

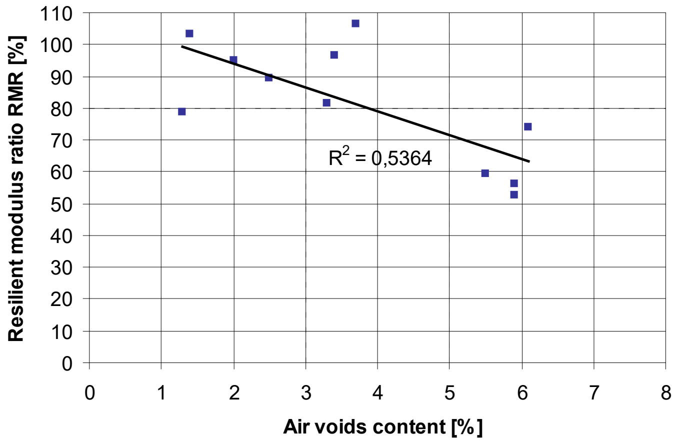

Figure 11. *Relationship between RMR and air voids content determined on asphalt cores*

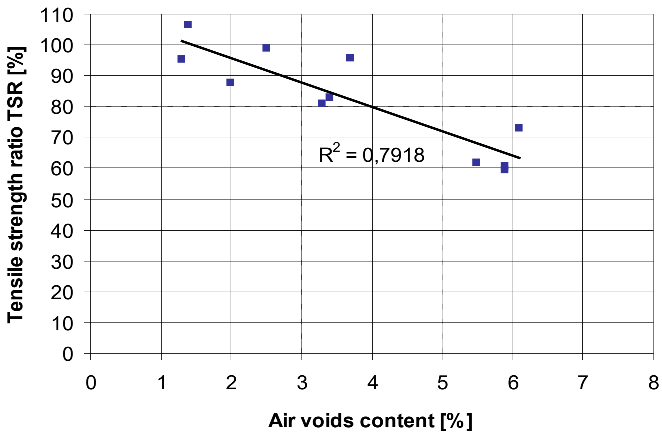

Figure 12. *Relationship between TSR and air voids content determined on asphalt cores*

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The test results confirmed that the air voids content in samples taken from the existing pavements has a significant effect on the resistance of asphalts concrete to the water and frost resistance according to the modified AASHTO T283. The relations between the values of RMR and TSR and the air voids content are described by correlation coefficients of $R^2=0.6$ and $R^2=0.8$ respectively.

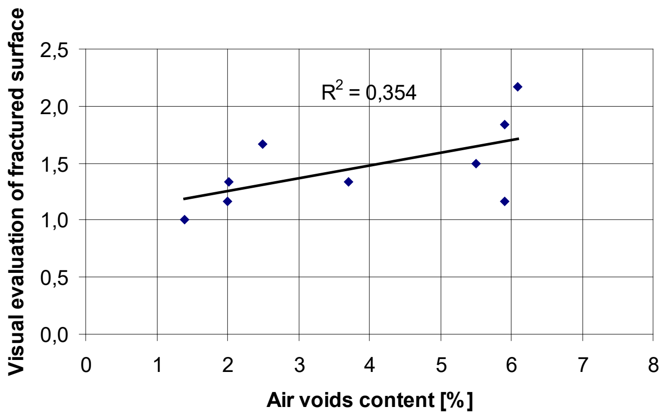

Figure 13. *Relationship between the fractured surface visual evaluation rating and the air-voids content*

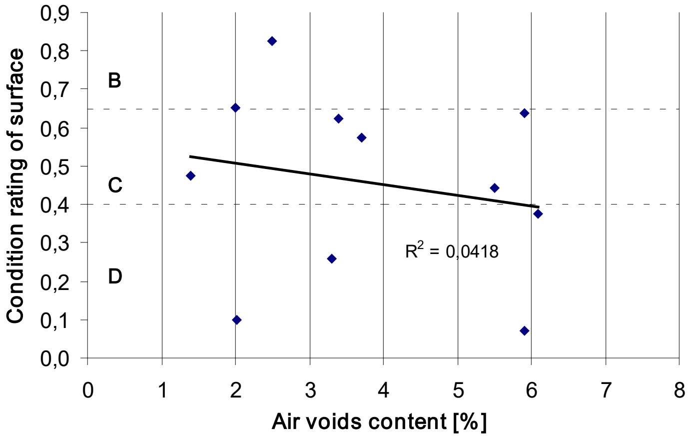

Figure 14. *Relationship between condition rating and air-voids content*

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The visual evaluation of fracture surfaces of drilled samples indicated that the air voids content has some effect on the internal structure of asphalt. However, the correlation coefficient between air voids content and stripping degree with the value of R^2=0.35 (Fig.13) is rather low.

As it can be seen from Fig. 14 there is no correlation (R^2=0.04). It could be attributed to the fact that air voids in all tested pavements were in the acceptable and rather narrow range from 1,5 to 6%.

3.6.4.5. Filler/ bitumen ratio and the measures of resistance to the action of water and frost

Figures 15 and 16 relate the values of RMR and TSR to the filler/ bitumen ratio (F/B).

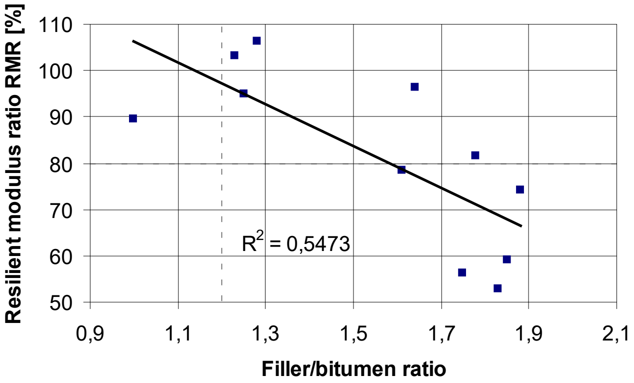

Figure 15. *Relationship between RMR and filler/ bitumen ratio*

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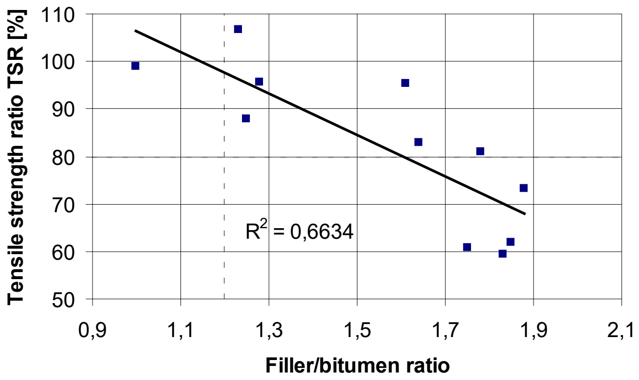

Figure 16. *Relationship between TSR and filler/ bitumen ratio*

According to Fig. 15 and Fig. 16 the increase of filler/bitumen (F/B) ratio lowers the resistance of asphalt concrete to the action of water and frost, as determined in laboratory conditions (RMR and TSR).

Fig. 17 presents the relationship between the condition rating of pavement surface according to SOSN and the F/B ratio. The condition of surface starts to deteriorate when F/B exceeds 1.5 and increases.

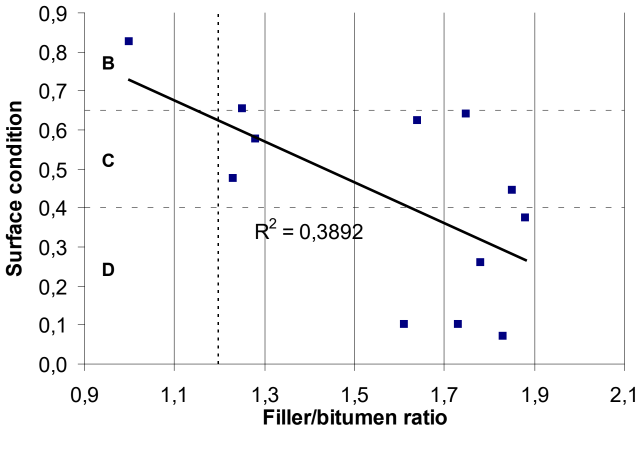

Figure 17. *Relationship between the condition rating according to SOSN and the filler/ bitumen ratio*

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3.6.4.6. Visual evaluation of pavement surfaces and the measures of resistance to the action of water and frost

A noticeable tendency can be observed from Fig. 18 and Fig. 19 (specially from fig.18) that the increase of RMR and less of TSR determined according to AASHTO T283 improves the resistance of asphalt to the damaging effect of water and frost. However, there was no clear consistency of results between surface condition rating and the condition rating carried out at the laboratory. Therefore, the laboratory method of AASHTO T283 for determining the resistance of asphalts to the action of water and frost does not fully represent the actual surface distress. The results could have been affected by the recompaction of samples for laboratory testing. Moreover, there may be other than water and frost adverse factors responsible for surface distress, such as repeating surface stresses due to traffic loading and cyclic thermal stresses.

For checking the reliability of the laboratory determination the limit resistance to water and frost, as represented by RMR and TSR, has been taken at 80%, and deterioration limit has been taken as equivalent to class D. Then the numbers of pavements have been calculated for:

– condition class D (Critical State) and RMR, TSR < 80% (resistance to water and frost was predicted accurately),
– condition class D, and RMR, TSR >80% (resistance to water and frost was not predicted accurately),
– condition class C, B (Warning State) and RMR, TSR < 80% (resistance to water and frost was not predicted accurately),
– condition class C, B, and RMR, TSR > 80% (resistance to water and frost was predicted accurately). The results are summarised in Table 11.

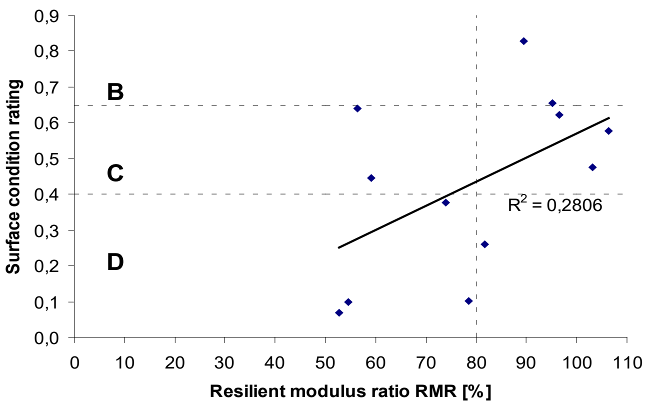

Figure 18. *Visual evaluation of pavements vs. resistance to the action of water and frost, represented by RMR.*

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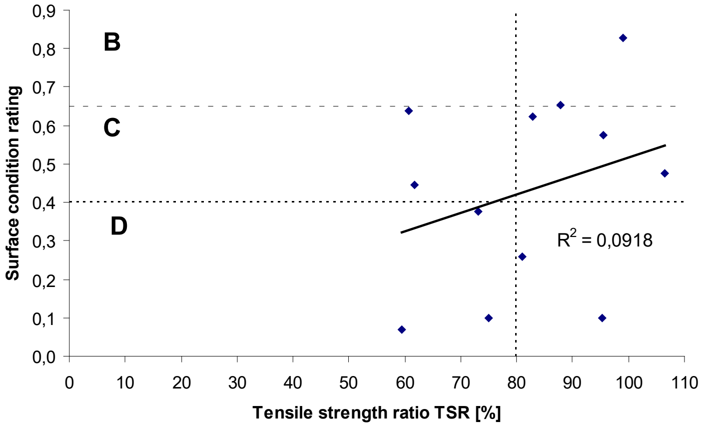

Figure 19. *Visual evaluation of pavements vs. resistance to the action of water and frost, represented by TSR.*

Pavement condition class	Resilient Modulus Ratio (RMR)		Tensile Strength Ratio (TSR)	
	<80%	>80%	<80%	>80%
D	4 accurate results	1 inaccurate result	3 accurate results	2 inaccurate results
C and B	2 inaccurate results	5 accurate results	2 inaccurate results	5 inaccurate results
Reliability	*9/12 (75%)*		*8/12 (66%)*	
Pavement condition class	Resilient Modulus Ratio (RMR)		Tensile Strength Ratio (TSR)	
	<75%	>75%	<75%	>75%
D	3 accurate results	2 inaccurate results	3 accurate results	2 inaccurate results
C and B	2 inaccurate results	5 accurate results	2 inaccurate results	5 inaccurate results
Reliability	*8/12 (66%)*		*8/12 (66%)*	
Pavement condition class	Resilient Modulus Ratio (RMR)		Tensile Strength Ratio (TSR)	
	<70%	>70%	<70%	>70%
D	2 accurate results	3 inaccurate results	1 accurate result	4 inaccurate results
C and B	2 inaccurate results	5 accurate results	2 inaccurate results	5 inaccurate results
Reliability	*7/12 (58%)*		*6/12 (50%)*	

Table 9. *Reliability of the laboratory method, verified on the basis of observed pavement condition for RMR and TSR levels of 80%, 75% and 70%.*

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It was found that if the admissible level of resilient modulus ratio (RMR) and tensile strength ratio are set at 80% than reliability of prediction of surface state condition is equal to 75% in case of modulus and 66% in case of strength.

Table 10 compiles water and frost resistance represented by the values of RMR and TSR, pavement condition index S, air voids content, filler/ bitumen (F/B) ratio, and age of pavement. The data are presented in the order of decreasing RMR. Among the data compiled in Table 10 worthwhile noting is that in one case with RMR>80% and TSR>80% one pavement (No. 12), which has been operated for 4 years has been rated in class D due to severe surface distress. The condition has been rated as unsatisfactory, and hence S=0.26. It is the third most heavily damaged pavement out of the twelve rated according to SOSN. This is the only case for which RMR and TSR criteria did not work. In the remaining cases the condition of pavement is consistent with the laboratory evaluation.

No.	Street No.	RMR [%]	TSR [%]	Surface condition	Air-void content [%]	F/B ratio	Age [years]	Limit of water&frost resistance
1	4	106.3	95.5	0.58	3.7	1.28	4	
2	10	103.2	106.6	0.48	1.4	1.23	2	
3	11	96.5	82.9	0.62	3.4	1.64	4	
4	5	95.1	87.8	0.65	2.0	1.25	5	
5	2	89.5	98.9	0.83	2.5	1.00	8	
6	12	81.6	81.0	0.26	3.3	1.78	4	Limit of 80% RMR. TSR
7	6	78.6	95.2	0.10	2.0	1.61	6	Limit of TSR>80%
8	9	74.0	73.1	0.38	6.1	1.88	5	RMR>75%
9	8	59.2	61.8	0.44	5.5	1.85	4	
10	7	56.3	60.8	0.64	5.9	1.75	6	
11	1	54.6	74.9	0.10	-	1.73	5	
12	3	52.8	59.5	0.07	5.9	1.83	4	

Table 10. *Data on the tested pavements, listed in the order of decreasing RMR.*

Taking the criteria of: lower value for RMR>75% and the same for TSR>80% the above pavement would be accompanied by pavement No 6. As both these pavements are severely affected with surface damage the criteria of RMR>75% and TSR>80% would fail twice.

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3.6.4.7. Visual evaluation of pavement surface vs. evaluation of fractured surface

As shown in Fig. 20 none of the samples has exceeded the maximum internal stripping level (index value below 2.5-3.0), notwithstanding poor visual condition rating due to distress caused by water and frost.

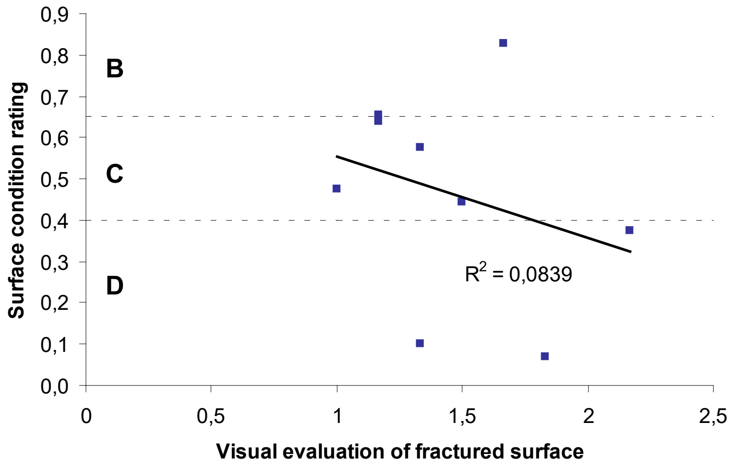

Figure 20. *Visual evaluation of the pavement surface and internal structure of asphalts*

4. Proposed criteria for determining the resistance of asphalt concretes to water and frost according to modified AASHTO T283

The AASHTO T283 method, modified for Polish conditions, has been analysed for reliability for various water and frost resistance criteria. Following the analysis, we propose the following provisional criteria:

– Resilient Modulus Ratio (RMR) - not lower than 75%,
– Tensile Strength Ratio (TSR) - not lower than 80%.

These requirements (RMR>75% and TSR>80%) are based on the results of the above described verification. Compliance with these criteria may eliminate premature pavement distress due to the action of water and frost, which is a frequent problem on the roads in Poland.

The requirement of TSR>80% is in compliance with the SUPERPAVE requirements. However, SUPERPAVE does not specify the requirements for RMR.

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The value of RMR has been reduced to 75% as the modulus testing is more demanding than tensile strength testing. In many cases in the earlier testing of resistance to water and frost carried out at the Technical University of Gdansk the values of RMR were below the values of TSR. Also in the tests carried out on the street pavements in Gdansk and Gdynia RMR was lower than TSR in 7 out of the total number of 12 cases (see Fig. 8).

Taking RMR at the equal level as for TSR (>80%) could result in rejecting mix designs, which actually could have shown good resistance to the action of water and frost. Moreover, it is worthwhile nothing that TSR criterion is more widely used internationally and there are very few publications comparing RMR and TSR.

5. Conclusions

The above described tests have yielded the following conclusions:

- The modified AASHTO T283 method is recommended for use in design of asphalt mixes in laboratory conditions to eliminate or at least largely reduce pavement distress caused by the action of water and frost. However, the method has some limitations.

- Field testing has shown that reliability of modified AASHTO T283 in predicting the resistance of asphalts to damage caused by water and frost ranged 66%-75% when compared to the visual evaluation rating according to SOSN. It means that the method did not work for the remaining 25%-34% of cases what may be explained by limitation of the method in question but also by the combined action of external factors, which were not been taken into consideration in this work, such as traffic, cyclic low-temperature induced stresses, salt used during the winter conditions occurring on roads in Poland.

- For evaluation of the resistance of asphalt mixes to the action of water and frost the authors recommend application of resilient modulus and indirect tensile strength.

- For predicting long-term resistance of asphalt mixes to the action of water and frost we propose taking the minimum requirement of RMR at 75% and TSR at 80%. This means that the designed asphalt mix when subjected to processes simulating long-term action of water and frost in laboratory conditions according to AASHTO T283 should retain 75% of the initial modulus and 80% of the initial tensile strength.

- The samples for testing the resistance to the action of water and frost should be compacted to achieve the air voids content in the range from 6% to 8%, irrespective of the air voids content in the job mix formula. For wearing courses asphalts the required air-void content may be obtained by reducing the number of blows of Marshall hammer and lowering the temperature during compaction to 135°C.

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- The purpose of increasing the air voids content to 6%-8% is to facilitate penetration of water to the interior of samples to intensify the damaging action of water and frost during conditioning of samples at the laboratory.

- Most of the asphalt concretes cored from wearing courses of the analysed street pavements of Gdansk and Gdynia showed excessive stiffness and low resistance to the action of water and frost.

- Excessive stiffness was caused by inappropriate value of filler/ bitumen ratio, much exceeding the upper limit of the 0.6-1.2 range recommended by SUPERPAVE. Mastic containing a high amount of filler and little bitumen is stiff and brittle, resulting in stiffness and low quality of the produced asphalt concrete.

- Strong correlation has been found between the filler/bitumen (F/B) ratio and the pavement condition. With F/B ratio greater than 1.2 the condition of pavement, rated according to SOSN, starts to deteriorate significantly. F/B greater than 1.2 significantly reduces the resistance of asphalt concrete to the action of water and frost.

6. Bibliography

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