Asphalt mixture performance and testing

Study of the water sensibility of asphalt mixtures

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Abstract

Currently there are two European test methods for water sensitivity of asphalt mixtures at medium and high temperatures, but a respective correlation between them has not been established yet. There is not test method for water resistance of asphalt mixtures at low temperature. There are some evidences in scientific publications that both the chemical composition and low temperature properties of the binder are very important for the water resistance of asphalt mixtures. The low service temperatures are critical for the water resistance performance of the asphalt mixtures. Bitumen with different acid numbers and bitumen modified with organic and inorganic additives have been studied. The low temperature properties have been examined according to Fraass breaking point and BBR test methods. The binders were aged both short term according EN 12607-1 and long term according EN 14771. The acid number of all binders has been tested before and after short and long term aging according to CEN TC336, Working Group 2 Doc Number: N107-A1e. The water sensitivity of asphalt mixtures prepared with the above described bitumen, has been tested according to EN 12697-12, both at medium and low temperatures, before and after exposure at short and long term aging according to procedures, proposed in “Selection of Laboratory Aging Procedures for Asphalt – Aggregate Mixtures” by C. A. Bell, Y. AbWahab, M.E.Cristi, D. Sosnovske from Oregon State University. It was made an attempt to be defined the water sensitivity of asphalt mixtures prepared with bitumen with different acid numbers and different low temperature properties.

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1. INTRODUCTION

Most of the recognized and severe forms of pavement distresses like stripping, raveling, fatigue damage result in premature pavement failure which is related to moisture damage [1].

Moisture damage of asphalt pavement can take place due to three main reasons:

- Loss of cohesion of the bitumen (mastic) film;
- Failure of the adhesion between the aggregate particles and the bitumen (mastic) film;
- Degradation of aggregate particles due to freezing.[2]

Research of moisture damage of asphalt pavement has been active since many years. Nevertheless, identifying the mechanisms of adhesion in asphalt pavement materials is still a challenge [3, 4, 5]

Moisture damage is a combination of processes rather than just one single process. The understanding of the moisture damage process becomes more important by taking into account the micro mechanisms that affect the adhesion at asphalt aggregate interface and cohesion strength and durability of mastic [6, 7, 8].

The development and classification of a test procedure that truly simulates field conditions is an important consideration during the standardization process of moisture damage testing. At present there are two standards for testing the water sensitivity of hot asphalt mixtures on European Union (EU) level: EN 12697-11 [9] for loose mixture and EN 12697-12 [10] for compacted asphalt specimens.

In EN 12697-11 three different test methods are specified:

- Static test;
- Rolling bottle test;
- Boiling water stripping test

The first two of the above mentioned test methods are qualitative and subjective, but the third one is quantitative and with higher precision [9]. Nevertheless, there is a publication about correlation between rolling bottle test and the most widely used Indirect tensile strength ratio method, specified in EN 12697-12 [11], but nothing about correlation between boiling water stripping test method and indirect tensile strength ratio test method.

The main objectives of this study are to:

- Determine the low temperature properties of unmodified and modified bitumen with different acid numbers and the water sensitivity of asphalt mixtures prepared with them at medium and low temperature, where both the bitumen and asphalt mixtures are subjected to short-term and long-term aging;
- Determine if there are significant correlations between the results from bitumen properties tests and water sensitivity of asphalt mixtures.

2. MATERIALS AND TESTS

The tests have been carried out with six different bitumen that have been used in asphalt mixtures for wearing courses, as follows:

- bitumen A, grade - 70/100, with low acid number;
- bitumen B, consisting of bitumen A and 1,5 % poly-phosphoric acid (102%) (PPA);
- bitumen C, consisting of bitumen A and 4,5 % SBS;
- bitumen D, grade - 70/100, with high acid number;
- bitumen E, consisting of bitumen D and 1,5 % poly-phosphoric acid (102%)(PPA);
- bitumen F, consisting of bitumen D and 4,5 % SBS.

The bitumen have been tested according to the specifications given in EN 12591 and EN 14023. In addition, the stiffness and m-value at -16°C have been determined according to EN 14771, as recommended in EN 14023; also, a long-term aging has been carried out in Pressure Aging Vessel (PAV) at 100°C for 20 hours according to EN 14769. Additionally, the penetration index PI before and after short-term and long-term exposure has been calculated since this parameter characterizes the temperature sensitivity of bitumen [12]. The following formula has been used for parameter calculation:

$$PI = \frac{20-500A}{1+50A} \qquad A = \frac{LOGP-LOG800}{25-T} \qquad (1)$$

The acid number of bitumen before and after exposure to short-term and long-term aging has been tested by potentiometric titration in non-aqueous medium according to CEN Doc Number: N107-A1e [13].

The asphalt mixtures for wearing course have been prepared with the various bitumen included in the study using the same aggregate-andesite. The reasons for this were as follows:

- The siliceous aggregates are the most appropriate and most often used in asphalt mixtures for wearing courses because of their high polishing resistance. In our country the andesite is the most used aggregate in asphalt mixtures for wearing courses;
- The water sensitivity of asphalt mixtures depends on both bitumen and aggregate composition and properties. Using only one type of aggregate would help to eliminate the influence of the aggregate composition and would permit determination of significant correlations between bitumen properties and water sensitivity of asphalt mixtures at different temperatures, if there were such.

The asphalt mixtures were prepared in a laboratory mixer, equipped with a heater with thermostatic control according to EN 12697-35. Compaction has been carried out according to EN 12697-30. The asphalt mixtures recipe is as follows:

- Aggregate, grade 4/12.5 mm – 45%
- Aggregate, grade 0/4 mm – 47%
- Mineral filler (andesite) – 8%;
- Bitumen content – 5.7% to 100% of the aggregate (5.4 % to 100% of the mixture)

The aggregate particle size distribution is presented on figure 1.

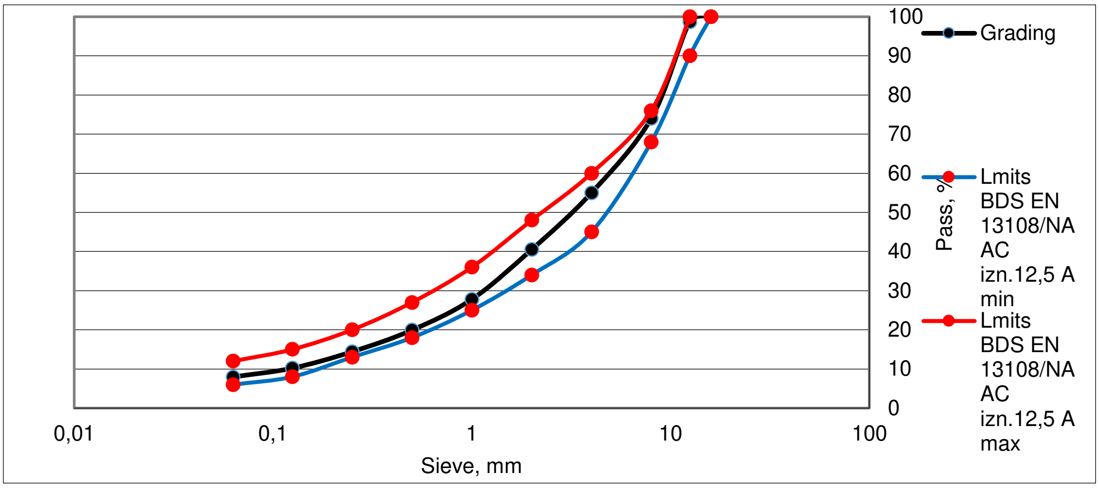

Figure 1: Particle size distribution curve

The conditions for preparation of the asphalt mixtures are presented in Table 1 below.

Table 1: Conditions for preparation of laboratory mixtures

№	Conditions	Bitumen A	Bitumen B	Bitumen C	Bitumen D	Bitumen E	Bitumen F
1	Mixing temperature, ºC	160	160	180	160	160	180
2	Compaction temperature, ºC	145	145	160	145	145	160
3	Number of impacts (per side)	75	75	75	75	75	75
4	Number of impacts (per side) for Water sensitivity determination	35	35	35	35	35	35

The asphalt mixtures have been tested for some of the characteristics included in EN 13108-1. The water sensitivity has been tested both for loose mixture and for compacted asphalt specimens according to EN 12697-11 and EN 212697-12 respectively. The water sensitivity, expressed by Indirect Tensile Strength Ratio (ITSR), test for compacted, asphalt specimens has been carried out at 15°C, as recommended in EN 212697-12 and at 0°C, since it has been demonstrated that ITS at 0°C correlates very well with low temperature properties of the bitumen [14] Short-term and long-term aging of asphalt mixtures have been carried out according to the procedures recommended by [15]. For short-term aging loose asphalt mixture is exposed to aging in a ventilated oven at 135ºC for 4 hours. For long-term aging loose asphalt mixtures as well as compacted asphalt specimens are exposed to aging in a ventilated oven at 85°C for 5 days.

3. RESULTS AND DISCUSIONS

The test results for the bitumen included in this study are presented in Table 2.

Table 2: Test results for the studied bitumen

№	CHARACTE-RISTICS	TEST RESULTS					
		Bitumen A	Bitumen B	Bitumen C	Bitumen D	Bitumen E	Bitumen F
UNAGED BITUMEN							
1	Penetration at 25°C- EN 426, dmm	83	46	56	78	45	57
2	Softening point- EN 1427, °C	46.9	61.6	87.3	46.8	62.7	83.0
3	Penetration index	-0.8	1.1	5.5	-1.0	1.3	5.1
4	Fraass breaking point- EN 12593, °C	-20	-21	-22	-20	-23	-23
5	Stiffness at -16 °C- EN 4771, MPa	179	174	172	153	131	96
6	m-value at -16°C- EN 14771	0.347	0.355	0.322	0.515	0.439	0.418
7	Acid number, %	0.11	7.92	0.32	2.98	9.37	2.90
SHORT-TERM AGED BITUMEN ACCORDING TO EN 12607-1 (RTFOT)							
8	Penetration at 25°C- EN 426, dmm	48	40	42	49	37	48
9	Softening point- EN 1427, °C	53.3	66.4	75.1	54.1	69.5	66.5
	Penetration index	-0.5	1.7	3.2	-0.3	2.0	0.2
10	Fraass breaking point- EN 12593, °C	-18	-15	-20	-16	-22	-20
11	Stiffness at -16°C- EN 4771, MPa	242	208	176	173	136	112
12	m-value at -16°C- EN 14771	0.331	0.355	0.324	0.4	0.439	0.426
13	Acid number, %	0.21	7.93	0.50	2.98	9.33	3.1
14.	Mass change, %	-0.24	-0.04	-0.02	-0.27	-0.31	-0.11
LONG-TERM AGED BITUMEN ACCORDING TO EN 14769 (PAV)							
15	Penetration at 25°C- EN 426, dmm	25	21	25	28	25	38
16	Softening point - EN 1427, °C	61.3	80.6	77.5	62.9	86.4	71.9
17	Penetration index	-0.2	2.4	2.3	0.3	3.5	2.4
18	Fraass breaking point- EN 12593, °C	-9	-8	-12	-6	-14	-13
19	Stiffness at -16°C- EN 4771, MPa	313	267	180	225	148	149
20	m-value at -16°C- EN 14771	0.300	0.355	0.321	0.343	0.420	0.400
21	Acid number, %	0.95	8.00	1.45	3.96	11.00	3.83

From the results in table 2 it follows that bitumen modified with inorganic and organic polymer additive have higher low temperature resistance and lower temperature sensitivity.

During aging the values of Fraass breaking point, stiffness and PI increase. Also during aging, the values of acid number increase. The velocity of this increase is highest for conventional bitumen and lowest for bitumen modified by PPA. This is probably because during aging, particularly during long-term aging, oxidation process occurs with formation of carboxylic acids and sulfoxides. Asphaltens are the bitumen fraction with the highest functional groups content. In bitumen modified by poly-phosphoric acid, the modifier reacts with the asphaltens [16] and the content of the free functional groups is lower.

The results for the degree of bitumen coverage for loose asphalt mixtures and water sensitivity at 15°C and 0°C for compacted asphalt specimens are shown on figures 2, 3 and 4 respectively.

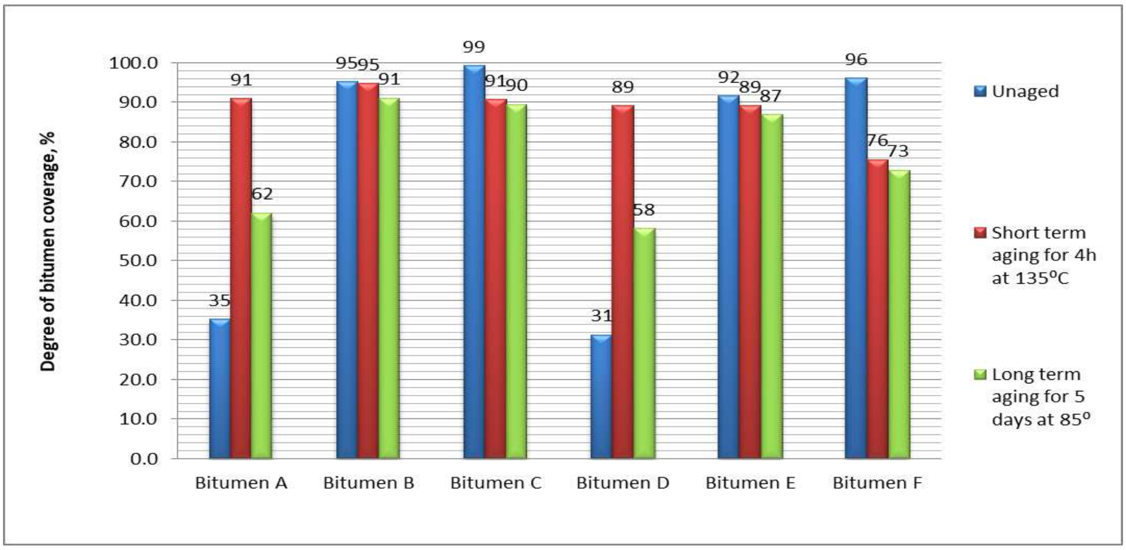

Figure 2: Degree of bitumen coverage for different in-laboratory loose mixtures

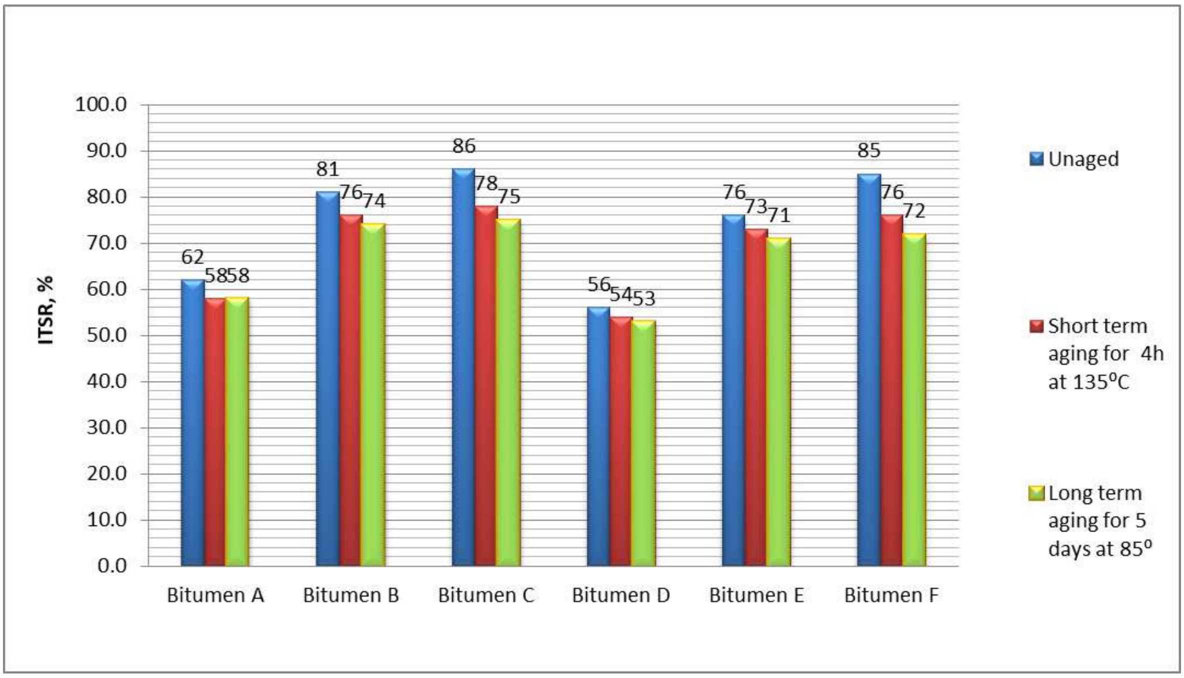

Figure 3: Water sensitivity at 15°C for in-laboratory compacted asphalt mixtures

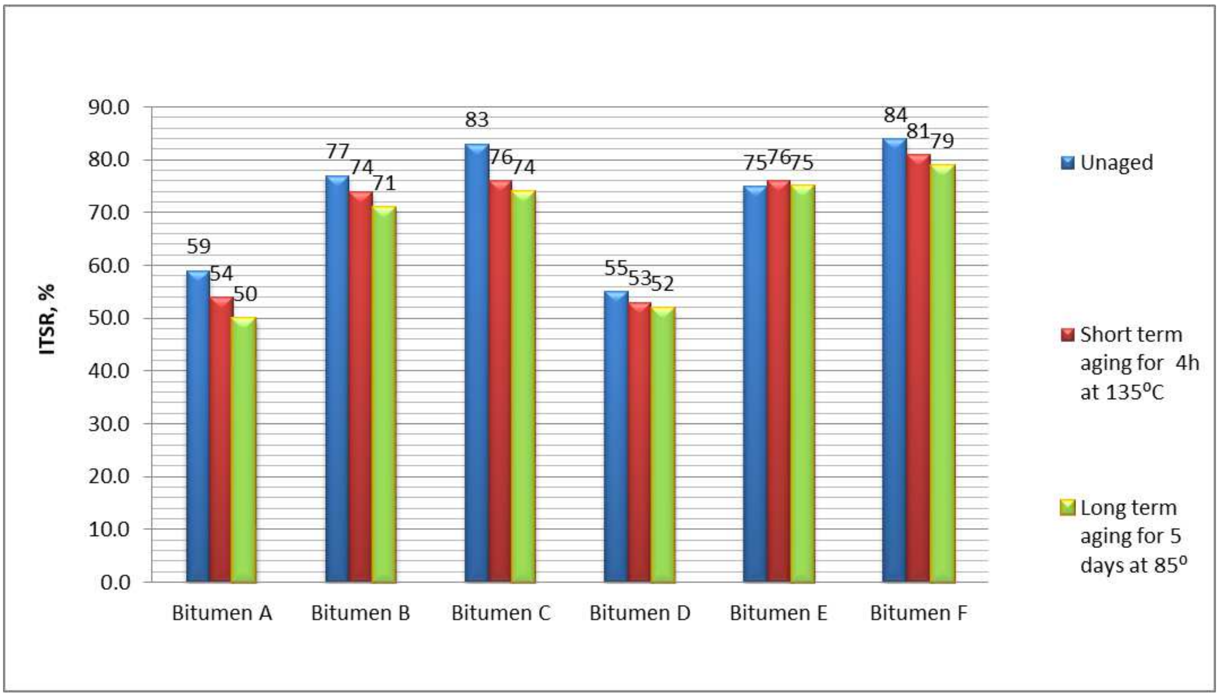

Figure 4: Water sensitivity at 0°C for in-laboratory compacted asphalt mixtures

From the results in table 3 and figures 2, 3 and 4 it follows that the asphalt mixtures with unmodified and modified bitumen with lower acid number are more water resistant. The asphalt mixtures with SBS modified bitumen are the most water resistant. Although the acid number of PPA modified bitumen is much higher, the asphalt mixtures prepared with them are more water resistant than those prepared with unmodified bitumen, which probably is phosphoric functional groups are bound to the bitumen's asphaltens.

The same refers to the degree of bitumen coverage of unaged and long-term aged loose asphalt mixtures. Since the test is carried out at high temperature (boiling water), the bitumen viscosity at high temperature is very important. As can be seen from table 2, the softening point of the bitumen modified by SBS after short-term aging is lower than the softening point of unaged bitumen, most probably because the bitumen-polymer heterogeneous systems are not very stable.

The univariate correlations have been calculated between the different characteristics of bitumen, which determine their behavior at low temperatures and their temperature sensitivity, as well as acid number and the degree of bitumen coverage and water sensitivity at 15°C and 0°C for in-laboratory asphalt mixtures prepared with different bitumen. In addition, the univariate correlations have been calculated between the degree of bitumen coverage and water sensitivity at 15°C and 0°C for in-laboratory asphalt mixtures prepared with different bitumen.

The high correlation coefficient could be an indicator of relationship between two characteristics. Bearing in mind that the typical limits of reproducibility for the various test methods for bitumen characteristics are from 5% to 10%, values R^2 over 0,80 for a pair of bitumen characteristics and degree of bitumen coverage and water sensitivity at 15°C and 0°C could be a reasonable limit indicating high correlation [17].

Correlation coefficient has been calculated using function PEARSON in Excel, which returns the Pearson product moment correlation coefficient, r, in a dimensionless index that ranges from -1.0 to 1.0 inclusive and reflects the extent of a linear relationship between two data sets.

The correlation coefficients between the bitumen characteristics and the degree of bitumen coverage and water sensitivity at 15°C and 0°C for in-laboratory asphalt mixtures are shown on figures 5, 6 and 7 respectively.

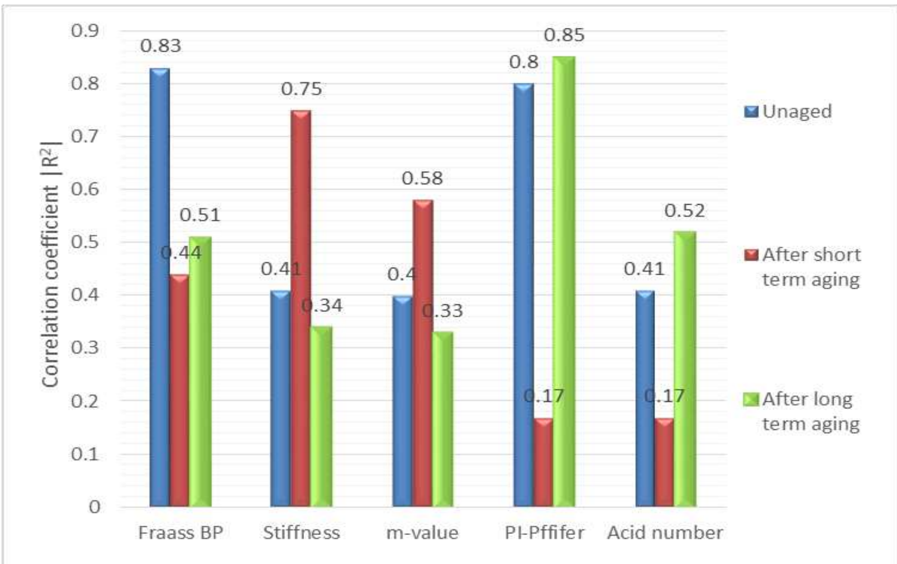

Figure 5: Correlations between degree of bitumen coverage of loose asphalt mixtures and bitumen characteristics

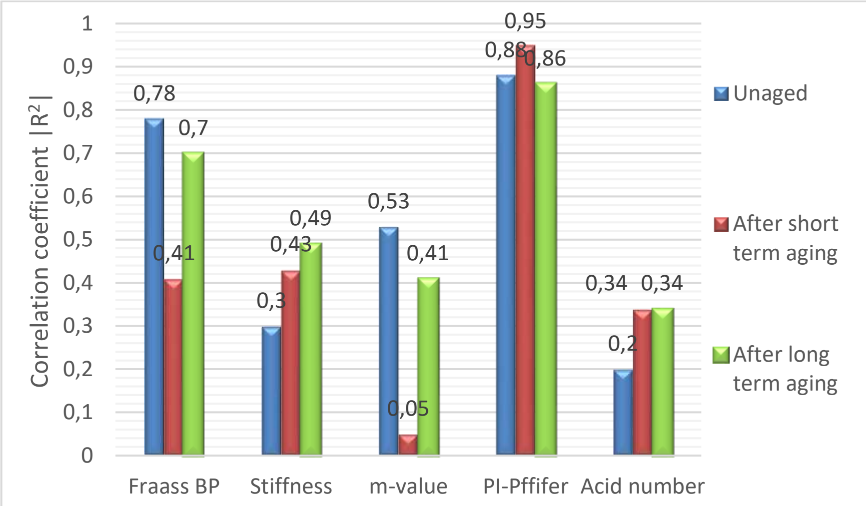

Figure 6: Correlations between water sensitivity at 15°C of compacted asphalt mixtures and bitumen characteristics

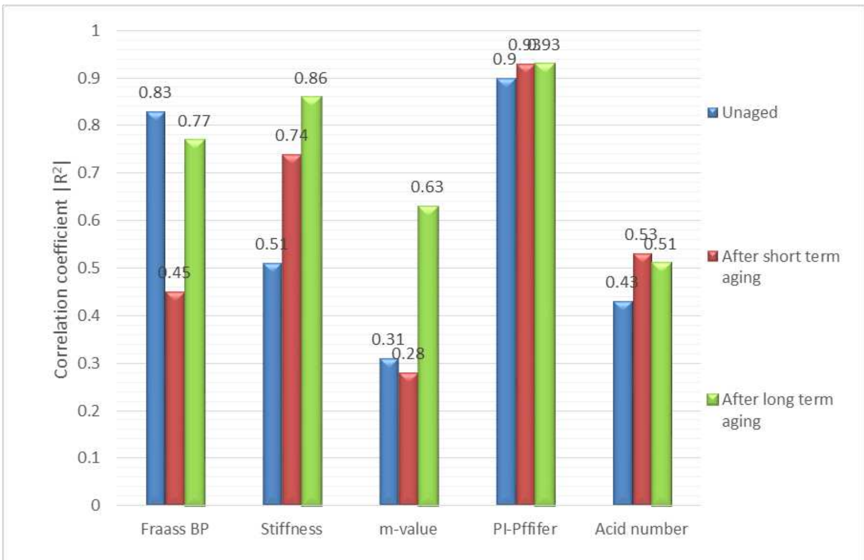

Figure 7: Correlations between water sensitivity at 0°C of compacted asphalt mixtures and bitumen characteristics

From the results shown in the diagram on figure 5 it follows that there is a high correlation between the degrees of bitumen coverage and Fraass breaking point before exposure to aging, stiffness at -16°C after long-term aging and PI before exposure to aging and after short-term and long-term aging.

From the results shown in the diagram on figure 6 it follows that there is a high correlation between the water sensitivity at 15°C and PI before exposure to aging and after short-term and long-term aging.

From the results shown in the diagram on figure 7 it follows that there is a high correlation between the water sensitivity at 0°C and Fraass breaking point before exposure to aging, stiffness at -16°C after long-term aging and PI before exposure to aging and after short-term and long-term aging.

The correlation coefficients between the degree of bitumen coverage and water sensitivity at 15°C and 0°C for in-laboratory asphalt mixtures are shown on figures 8.

Figure 8: Correlations between the degree of bitumen coverage and water sensitivity at 15°C and 0°C of in-laboratory asphalt mixtures

From the results shown in the diagram on figure 8 it follows that there is a high correlation between the degree of bitumen coverage and water sensitivity at 15°C before exposure to aging and after long-term aging and high correlation between the degree of bitumen coverage and water sensitivity at 0°C before exposure to aging.

4. CONCLUSIONS

Based on the test results from this study, the following conclusions can be drawn:

- Asphalt mixtures prepared with bitumen with lower acid number are more water resistant;
- There is a correlation between the water sensitivity at 0°C and bitumen stiffness at -16°C after long-term aging, which is performance related characteristic of the bitumen, describing the behavior of bitumen at low temperatures. This means that the water sensitivity at 0°C of long-term aged asphalt mixture could be used to predict the asphalt mixtures behavior at low temperatures in presence of water;
- In order to confirm the correlations it is advisable to extend this study by increasing the number of bitumen and testing different types of asphalt mixtures.

REFFERENCES

[1] Kim, Y. R., Lutif, J. S., et al., Evaluation of Moisture Damage Mechanisms and Effects of Hydrated Lime in Asphalt Mixtures through Measurements of Mixture Component Properties and Performance Testing. Journal of Materials in Civil Engineering, Volume 20, 2008, pp.:659–667;
[2] Brown, E. R., Kandhal, et al., Performance Testing for Hot Mix Asphalt. National Center for Asphalt Technology (NCAT), Report (2001) 05, 2001, Alabama;
[3]Renken, P. 1992. Untersuchungen zum Haftverhalten zwischen Bindemittel und Gestein, Straße + Autobahn, 1/1992, Kirschbaum Verlag, Bonn.

[4] Renken, P., Wistuba, M., Grönniger, J. et al. Adhäsion von Bitumen am Gestein. Verfahren der quantitativen Bestimmung auf Grundlage der Europäischen Normung. Schlussbericht zum Forschungsprojekt des Instituts für Straßenwesen der TU Braunschweig, erschienen in: Forschung Straßenbau und Straßenverkehrstechnik, Bundesministerium für Verkehr, Bau und Stadtentwicklung, Heft 1043, 2010.
[5] CEN, Comité Européen de Normalisation. Activity Report of the CEN Ad-hoc Group „Adhesion/Durability". Forschungsbericht 2009/TC/012-N090, 2009, Brüssel.
[6] Little, D. N., Jones, D. R. Chemical and Mechanical Processes of Moisture Damage in Hot-Mix Asphalt Pavements, Moisture Sensitivity of Asphalt Pavements, A National Seminar. February 4–6. , 2003
[7] Valdes G., Miró, Ret al., Assessment of the adhesive capacity of asphalt binders in the aggregate-binder bonds by means of new methodology, Journal of Construction, volume 14(1) , 2015, pp.69-76;
[8] Cho D. and Kim K., The Mechanisms of Moisture Damage in Asphalt Pavement by Applying Chemistry Aspects, Journal of Civil Engineering, volume 14 (3, 2010, pp.333-342;
[9] EN 12697-11, Bituminous mixtures - Test methods for hot mix asphalt - Part 11: Determination of the affinity between aggregate and bitumen, 2012;
[10] EN 12697-11, Bituminous mixtures - Test methods - Part 12: Determination of the water sensitivity of bituminous specimen, 2018;
[11] Grönniger J, Wistuba M. et al., Adhesion in Bitumen-Aggregate-Systems. New Technique for Automated Interpretation of Rolling Bottle Tests, Road 2 Materials and Pavement Design, Volume 11(4), 2010, pp.2-23,
[12] Wang D., Tetteh-Wayoe, H., et al., Low Temperature Properties of Asphalt Cements and Mixtures used in the C-SHRP Lamont Test Road in Alberta, Alberta Transportation and Utilities, 1992, pp.5-6.;
[13] CEN TC336, Working Group 2 Doc Number: N107-A1e – 2018 Round Robin. Determination of acid number of bitumen Potentiometric titration method, 2018,
[14] Pangarova D., Nikolov A., Study of the low temperature characteristics of binders and the asphalt mixtures produced with them, E&E Congress, 2016;
[15] Bell C.A., Wahab Y. Ab., Cristi M.B., Sosnovske D., "Selection of Laboratory Aging Procedures for Asphalt-Aggregate Mixtures", SHARP-A-383,1994, p.1;
[16] Stanley T., The Use of Phosphoric Acid to Stiffen Hot Mix Asphalt Binders, FHWA-HRT-14-086, 2014
[17] [Kalman B., Tušar M., et al., "Recommendations for modified binder usage in pavement", SPENS, D 15, 2010, pp. 86-90.