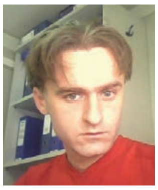
Primljen / Received: 6.11.2013.
Ispravljen / Corrected: 4.1.2014.
Prihvaćen / Accepted: 17.1.2014.
Dostupno online / Available online: 10.3.2014.

Influence of grading on the thin-layer asphalt concrete properties

Authors:



Ivica Androjić, PhD. CE
Osijek-Koteks d.d.
ivica.androjic@osijek-koteks.hr

Gordana Kaluđer, mag.ing.aedif.
Kombel d.o.o.
gordana.kaludjer@kombel.hr

Filip Kaluđer, mag.ing.aedif.
Ured ovlaštenog inženjera građevinarstva
Belišće
kaludjer_filip@hotmail.com

Professional paper

Ivica Androjić, Gordana Kaluđer, Filip Kaluđer

Influence of grading on the thin-layer asphalt concrete properties

Results obtained by laboratory testing of samples for preparation of the thin-layer asphalt surfacing BBTM (béton bitumineux très mince), labelled BBTM 11B PmB 45/80-65, are presented in the paper. The testing was conducted to determine dependence of variable asphalt mix grading on the realisation of physical and mechanical properties of samples - stability, stiffness, density, voids content, and percent voids filled with asphalt. Test results obtained show that even minimum variations in the mineral mix grading have a significant impact on each tested property of the asphalt mix.

Key words:
grading, physicomechanical properties, thin-layer asphalt concrete BBTM

Stručni rad

Ivica Androjić, Gordana Kaluđer, Filip Kaluđer

Utjecaj granulometrijskog sastava na svojstva tankoslojnih asfaltbetona

U radu su prikazani rezultati laboratorijskih ispitivanja uzoraka mješavina za izradu tankoslojnih asfaltnih zastora BBTM (Beton Bitumineux Tres Mince) oznake BBTM 11B PmB 45/80-65. Ispitivanjima se nastojala odrediti zavisnost varijabilnog granulometrijskog sastava asfaltne mješavine na ostvarivanje fizikalno-mehaničkih svojstava uzoraka: stabilitet, krutost, gustoća, udio šupljina te ispunjenost šupljina bitumenom. Dobiveni rezultati ispitivanja pokazuju da i minimalna odstupanja u granulometrijskom sastavu mineralne mješavine imaju značajan utjecaj na svako ispitano svojstvo asfaltne mješavine.

Ključne riječi:
granulometrijski sastav, fizikalno - mehanička svojstva, tankoslojni asfaltbeton BBTM

Fachbericht

Ivica Androjić, Gordana Kaluđer, Filip Kaluđer

Einfluss der Kornzusammensetzung auf die Eigenschaften von dünnschichtigem Asphaltbeton

In dieser Arbeit werden die Resultate von Laborversuchen an Proben von Asphaltmischungen für dünnschichtige Beläge der Bezeichnung BBTM - Concrete Bitumineux tres mince BBTM 11B PmB 45/80-65 dargestellt. Durch die Prüfungen sollte die Einwirkung der variablen granulometrischen Zusammensetzung auf die physikalischen und mechanischen Eigenschaften der Proben (Stabilität, Steifigkeit, Hohlraumdichte und Hohlraumdichte mit Bitumen gefüllter Hohlräume) bestimmt werden. Die Resultate haben gezeigt, dass sogar kleine Variationen in der Kornzusammensetzung der Mineralmischung die geprüften Eigenschaften der Asphaltmischung bedeutend beeinflussen.

Schlüsselwörter:
Kornzusammensetzung, physikalische und mechanische Eigenschaften, dünnschichtiger Asphaltbeton BBTM

1. Introduction

A very thin asphalt surfacing, made as an asphalt mixture by hot process, is a bituminous layer that improves the existing properties of pavement structure in terms of strength and deformability, while simultaneously it is less than 50 mm in thickness [1]. According to the French standard, a very thin asphalt surfacing (asphalt mixture label: BBTM – béton bitumineux très mince) is the layer 20-25 mm in thickness, with the absolute minimum of 15 mm at each point of the layer [2]. In maintenance procedures, it is used as a layer of the pavement structure, whereas in rehabilitation procedures it is referred to as the layer for coating the existing surfacing for better separation of functions between the new surfacing and the existing one.

The thin asphalt surfacing extends the lifespan of pavement structures damaged by rutting, mesh and thermal cracks, and affected by material fatigue under the traffic load and temperature changes [3]. It contributes to the aesthetic appearance of the final layer of the pavement structure and, while not being a structural layer, it contributes to the strength and water resistance, ride comfort, and noise reduction [3, 4]. Numerous positive international examples, in which this type of asphalt surfacing is used for wearing layers of rehabilitated or maintained roads, testify to their applicability regardless of climatic or geographic position [5-12]. However, there are certain requirements that must be met so that this layer can be considered a proper surfacing of the pavement structure. The basic pavement structure must provide a sufficient carrying capacity, and should be characterized by an appropriate flatness and longitudinal and transverse profiles. With the thin asphalt layer, it is not possible to make flatness corrections without jeopardizing the durability of the layer. A bituminous binder must be applied on the asphalt surfacing that is to be improved with a thin asphalt layer. This binder is applied to ensure better connectivity among layers. The existing procedures for dimensioning very thin asphalt surfacings relate to the determination of the upper and lower wearing layer of the pavement structure whose surfacing is made of well-complex aggregate, and to which a thin layer of asphalt is set. The exact thickness of this asphalt layer will depend on the traffic load to which the road is exposed, on the binder of the hot asphalt mixture, and on its stiffness and strength [13]. Two classes of very thin asphalts - Type 1 and Type 2 - are defined in French standards [2]. Type 1 mixtures are produced in two gradations – 0/10 mm with missing 2/6 mm fractions, and the 0/6 mm gradation, with the fraction discontinuity of 2/4 mm. These mixtures contain up to 17 % of voids. Type 2 mixtures are open texture mixes that ensure better slip resistance and friction, and are acceptable for humid climates [14]. These mixtures are produced with polymer binders only, and contain 18-25 % of voids.

Since very thin asphalt surfacing layers are non-structural, there are no special projects for making hot asphalt mixtures to be prepared from. This mixture is characterized by variable grading. The asphalt mixture consists of the mineral mixture of uneven grain size, and bituminous binder by which this aggregate is connected with the mixture. The mineral mixture makes 95 % of the weight of the asphalt mixture, and it is very important to determine the proper grading, but also the shape and texture of grains. Researches [15-17] have shown that the size, shape and texture of the grain have an effect on properties of the hot asphalt mixture. Flat and elongated grains during mixing, compaction and traffic load affect the appearance of ruts - a smaller share of crushed grains in the mineral mixture of the asphalt mixture affects deformable properties [18, 19]. The workability of the asphalt mixture can be improved by using well-graded mineral mixtures, which will have an impact on water resistance properties, including durability of this layer. Mixtures with smaller NMAS (nominal maximum aggregate size: the nominal maximum size of aggregate grain is defined as the ten percent transience out of total) are less permeable than those with larger NMAS values [3, 20, 21]. The following requirements are applied for aggregate used in making hot asphalt mixtures with very thin layers: a minimum of 50 % of the grain must be crushed, the minimum angular index is 2.5, the maximum LA is 40, the index of grain is less than 18, the minimum polish is 50, and the maximum water absorption amounts to 1.5 %. Requirements for bituminous binder are the classes 40/50 and 60/70 for South Africa and Europe, with the possibility of adding 0.3 to 1.5 % of improvers, and with the possibility of using polymer bituminous binders [22, 23]. In the Republic of Croatia, the use of very thin asphalt surfacings is only in its beginnings, although there are standards for the preparation of hot asphalt mixtures for these layers.

During preparation of this paper, the author's objective was also to determine the impact of variable grain size distribution on physicomechanical properties of the bituminous mixture intended for installation in thin wearing layers. Bituminous mixtures BBTM are made in accordance with Croatian standards HRN EN 13108-2 [24].

2. Testing program

The testing programs includes formation of five groups of asphalt mixtures labelled BBTM 11B PmB 45/80-65. The BBTM stands for an asphalt mixture of discontinuous grading that is designed for installation in a thin wearing layer 20 - 30mm in thickness. The five series of asphalt samples were made in the lab with the fixed share of polymer bitumen and variable grading with the maximum grain size of 11mm. The designed asphalt mixtures are intended for wearing courses of airport operational areas, and for surfacing layers exposed to a mountain climate. In order to minimize the number of unknowns in the mixture composition design, a fixed proportion of polymer bitumen in the amount of 5.1 % was adopted (B_{min} = 5 %, Table A 16) [25] for all groups of asphalt mixtures. The grading of each group of asphalt mixtures was defined in advance. As the designed asphalt mixtures were intended for use in mountainous climates and airport operational areas, boundary conditions for the content of voids, i.e. 7-10 % v/v, were defined according to technical regulations (Table A 17.) [25].

Physical and mechanical properties of asphalt mix samples were tested in the road construction laboratory for the preparation of the thin wearing layer BBTM 11B PmB 45/80-65 according to the Croatian standard [24]. The layer is made of stone fractions 0/2, 2/4 and 4/8 and 8/11 mm of volcanic origin from the Vetovo quarry, stone dust category KB-I from the Veličanka quarry, and polymer modified bitumen 45/80-65, produced by MOL, Republic of Hungary.

2.1. Asphalt mix constituents

Two types of stone material, fractions from the Vetovo quarry (eruptive material of silicate composition), and stone dust from the Veličanka quarry (sediment of carbonate composition) were chosen for the production of asphalt mixtures. The grain size distribution is shown in Figure 1, and the density of stone fractions, and fillers used in the production of asphalt mixtures, are presented in Table 1 [26, 27].

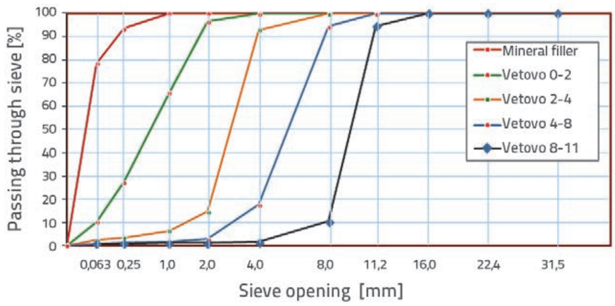


Figure 1. Grain size distribution of stone fractions, and fillers used in asphalt mixtures

The selected binder is a polymer modified bitumen type PmB 45/80-65, produced by MOL, Republic of Hungary. Standard density of polymer bitumen ρ_B = 1.021 g/cm^3, softening point PK = 91 °C and penetration PEN = 57.6 1/10 mm were determined according to to HRN EN 1425:2012 and HRN EN 1426:2008 [28, 29].

Table 1. Densities of tested subfractions of constituent raw materials

Sieve opening [mm]	Stone dust [g/cm^3]	Stone fractions [g/cm^3]
0,000 - 0,063	2,848	2,925
0,063 - 0,25	2,849	2,896
0,25 - 1,00	-	2,852
1,00 - 2,00	-	2,850
2,00 - 4,00	-	2,865
4,00 - 8,00	-	2,860
8,00 - 11,00	-	2,982
11,00 - 16,00	-	2,900

2.2. Asphalt mix design

The following mixtures of variable grain size distribution (see Table 2.), and equal compaction temperature of 163°C, were designed for the purposes of the planned tests. The grain size distribution of mineral mixtures was determined according to the Croatian standard HRN EN 12697-2 [30], while the soluble proportion of the polymer bitumen was defined according to the Croatian standard HRN EN 12697-1 [31].
Proportions of individual fractions, and cumulative grading curves of the designed mineral mixture, are shown in

Table 2. Proportion of constituent components in the designed asphalt mixtures

Materials / Mixture	Stone dust [%]	Polymeric bitumen [%]	0/2 mm [%]	2/4 mm [%]	4/8 mm [%]	8/11 mm [%]
Mixture I.	3,0	5,1	12,0	7,0	35,0	43,0
Mixture II.	3,0	5,1	15,0	7,0	38,0	37,0
Mixture III.	3,0	5,1	12,0	22,0	35,0	28,0
Mixture IV.	2,3	5,1	16,0	21,0	40,0	20,7
Mixture V.	3,0	5,1	10,0	34,0	30,0	23,0

Table 3. Cumulative grading of the stone skeleton and fillers

Sieve opening [mm] / Mixture	0,063	0,25	1,00	2,00	4,00	8,00	11,2	16,0
Mixture I. [%]	4,5	7,2	12,4	17,1	28,3	59,5	97,6	100,0
Mixture II. [%]	4,8	8,0	14,4	20,1	31,7	64,7	97,9	100,0
Mixture III. [%]	4,7	7,6	13,2	19,2	42,0	72,9	98,4	100,0
Mixture IV. [%]	4,5	8,0	15,1	22,3	45,1	79,2	98,8	100,0
Mixture V. [%]	4,4	7,4	12,5	18,9	50,2	77,7	98,7	100,0

Tables 2 and 3. The grading of designed asphalt mixtures, with the limited curves defined in accordance with the Croatian standard HRN EN 13108-2 [24], is shown in Figure 2.

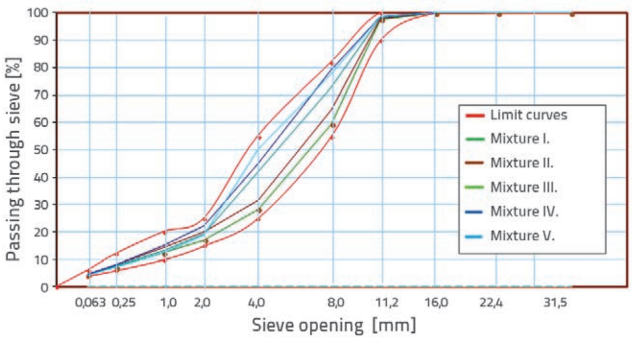


Figure 2. Grading of designed asphalt mixtures

2.3. Preparation of a set of asphalt mixture samples

Three samples were prepared for each group of asphalt mixtures (I - V) based on the standard compaction procedure using the Marshall rammer with the falling hammer. According to the Appendix C of the Croatian standard HRN EN 13108-20 [32], the samples are prepared by two compaction series, each consisting of 50 blows. The initial testing of asphalt samples includes testing with a fixed proportion of polymer bitumen (5.1 %) so that an optimum grading of the asphalt mixture can be obtained. Once an optimum grading is determined, the testing of asphalt samples continues with a variable proportion of polymer bitumen. After cooling of asphalt samples at room temperature, the following physical properties are determined:

- Density of asphalt sample according to HRN EN 12697-6 [33],
- Density of asphalt mixture according to HRN EN 12697-5 [34],
- The proportion of voids according to HRN EN 12697-8 [35],
- Voids content in stone mixture according to HRN EN 12697-8 [35],
- Bitumen filled voids according to HRN EN 12697-8 [35],
- Stability / deformation/ stiffness according to HRN EN 12697-34 [36].

The appearance of asphalt sample after stability testing is shown in Figure 3.

Figure 3. Asphalt samples

3. Results

Requested parameters, i.e. physical and mechanical properties, and defined boundary conditions for voids content ranging from 7.0 to 10.0 % [25], were determined for the tested set of asphalt mixture samples, in which each mixture group contains three samples. Laboratory test results are shown in Table 4.
The obtained results relating to physicomechanical properties of asphalt samples show that the mixture II has an optimum grain size distribution. The proportion of voids amounted to 9 % (threshold values 7-10 % [25]) and the density of asphalt samples was 2.408 kg/m^3.
Table 5 shows the achieved physicomechanical properties of mixture II asphalt samples, if the proportion of polymer bitumen in the mixture is variable, or in the range of 4.5 % to 5.7 %.
It can be seen from Table 5 that the asphalt samples of the mixture II, with the bitumen content ranging from 4.8 to 5.4 %, meet the limit values for voids laid down in [25]. The same conditions are prescribed for the minimum bitumen content (5.0 %) for thin asphalt mixtures BBTM 11B, whereas asphalt

Table 4. Physicomechanical properties of asphalt samples

Properties / Mixture	Stability [kN]	Deformation [mm]	Stiffness [kN/mm]	Density of asphalt sample [kg/m^3] HRN EN 12697-5	Density of asphalt mixture [kg/m^3] HRN EN 12697-6	Proportion of voids [%(v/v)] HRN EN 12697-8	Voids in stone mixture [%(v/v)] HRN EN 12697-8	Bitumen filled voids [%(v/v)] HRN EN 12697-8
Mješavina I.	11,5	3,71	3,1	2.428	2.649	8,3	20,5	59,3
Mješavina II.	11,9	3,84	3,1	2.408	2.646	9,0	21,0	57,2
Mješavina III.	10,7	4,12	2,6	2.367	2.648	10,6	22,45	52,7
Mješavina IV.	10,8	3,48	3,1	2.406	2.644	9,0	21,0	57,3
Mješavina V.	10,5	2,92	3,6	2.393	2.646	9,6	21,5	55,6

Table 5. Physicomechanical properties of asphalt samples from mixture II

Properties / Bitumen content	Stability [kN]	Deformation [mm]	Stiffness [kN/mm]	Density of asphalt sample [kg/m³] HRN EN 12697-5	Density of asphalt mixture [kg/m³] HRN EN 12697-6	Proportion of voids [%(v/v)] HRN EN 12697-8	Voids in stone mixture [%(v/v)] HRN EN 12697-8	Bitumen filled voids [%(v/v)] HRN EN 12697-8
4,5 %	12,2	2,4	5,1	2.396	2.675	10,4	21,0	50,4
4,8 %	11,1	2,3	4,8	2.402	2.663	9,8	21,0	53,3
5,1 %	11,9	3,8	3,1	2.408	2.646	9,0	21,0	57,2
5,4 %	12,4	2,8	4,4	2.426	2.637	8,0	20,7	61,5
5,7 %	11,2	2,6	4,3	2.432	2.621	7,2	20,8	65,4

samples with 4.5 % and 4.8 % of binder do not meet the criteria. The obtained laboratory test results clearly show that an increase in the proportion of bitumen in asphalt samples causes an increase of the density of asphalt samples, reduction of the density of the asphalt mixture, reduction of voids content in asphalt samples, smaller proportion of voids in the stone mixture, and better filling of voids with bitumen.

3.1. Comment of the results

A graphical representation shown in Figures 4 to 6 can be used to analyse the dependence between the grading of asphalt mixtures and physical and mechanical properties of asphalt samples. The analysis of test results enables establishment of correlations of individual properties, and determination of the shape and strength of these connections.
The relation between the stability and deformation for the observed group of asphalt samples is shown in Figure 4.

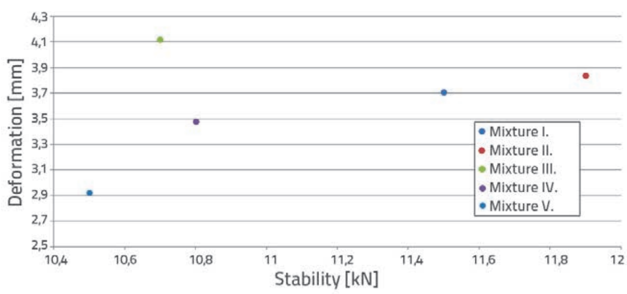


Figure 4. Relationship between stability and deformation

It can be seen from Figure 4 that the asphalt samples of mixtures with larger grain size distribution (mixtures I and II) exhibit greater stability compared to other mixtures. These mixtures are able to withstand greater forces because of the higher content in 8/11 mm stone fractions. Thus, asphalt samples from the mixture I contain 43 % of the 8/11 mm fraction. Mixture II contains 37 % of the 8/11 mm stone fraction.
The densities of the tested asphalt samples and mixtures are shown in Figure 5. The density of an asphalt sample is defined as the ratio of mass and volume of the asphalt sample prepared in asphalt compactor.
A linear interpolation of results was made by the first degree polynomial to determine functional dependences of densities obtained during the testing.

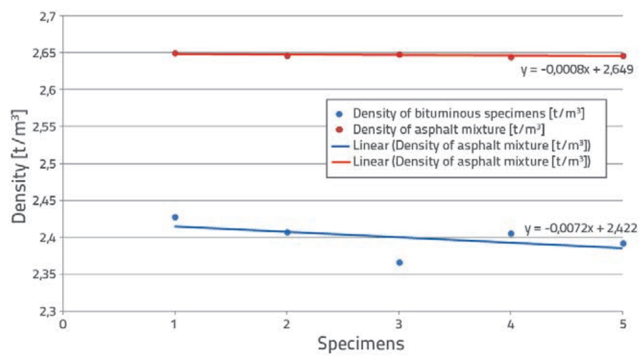


Figure 5. Density of asphalt samples and mixtures

Results obtained are shown in Figure 5. They are expressed by the following mathematical functions:
$y = -0,0008x + 2,649$ (variable y is the expected density of asphalt mixture on the vertical axis, while the variable x of the abscissa represents the grading of asphalt mixtures I – V);
$y = -0,0072x + 2,422$ (variable y is the expected density of the asphalt sample on the vertical axis, while the variable x of the abscissa represents the grading of asphalt mixtures I – V)

The obtained functions (Figure 5) show that a change in grading of asphalt mixtures has a much greater impact on the density of asphalt samples than on the density of mixtures. The grading of finer granularity (mixtures III - V) enables realization of lower densities of compacted asphalt samples and mixtures.
Figure 6. shows the voids content in asphalt samples and mineral mixture and their filling with polymer bitumen. The content of voids in asphalt samples is defined as the ratio of the densities of asphalt samples and asphalt mixture.
Results obtained are shown in Figure 6. They are expressed by the following mathematical functions:

y = - 0,0072x + 2,422 (variable y is the expected voids content in asphalt samples on the vertical axis, while the variable x of the abscissa represents the grading of asphalt mixtures I – V)
y = - 0,0008x + 2,649 (variable y is the expected voids content in the mineral mixture, while the variable x of the abscissa represents the grading of asphalt mixtures I - V);
y = - 0,73x + 58,61 (variable y is the expected filling of mineral mixture voids with bitumen, while the variable x of the abscissa is the grading of asphalt mixtures I. - V).

It can be seen from the presented mathematical functions that the use of smaller grading (mixtures III - V) leads to an increase in the content of voids in asphalt samples and mineral mixture. It is evident that the final result is the reduced filling of voids with bitumen. The analysis of grain size distribution in mixtures I and II shows that they generate greater discontinuity in grading compared to mixtures III - V. This discontinuity is achieved by using a larger share of the 8/11 mm stone fraction, and a reduced share of middle fractions (stone fractions 2/4 and 4/8 mm).

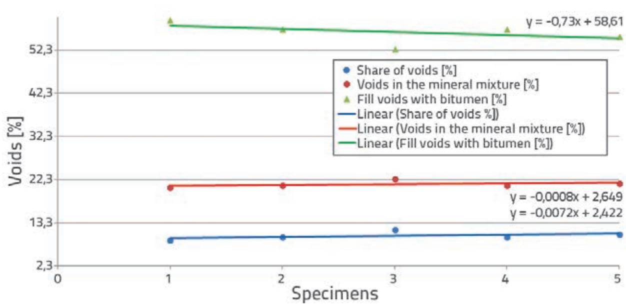


Figure 6. Voids in asphalt samples

It can be concluded from laboratory test results that the effect of grading on physicomechanical properties of samples is quite evident.

4. Conclusion

Because of small thickness of the embedded layer and discontinuity in grain size distribution, thin-layer asphalt mixtures BBTM exhibit greater sensitivity to the variability of constituent components in the mixture. The variability of constituent components directly affects achievement of required physical and mechanical properties of the derived layer.

In this study, laboratory tests were conducted so as to determine the influence of grading on the properties of thin-layer asphalt mixtures. For this purpose, tests were carried out in five groups of asphalt mixtures of variable grain size distribution. The differences in grain size distribution of asphalt mixtures were achieved by oscillating the proportion of middle stone fractions (2/4 mm and 4/8 mm) and larger stone fractions (8/11 mm). Laboratory asphalt mixtures were designed and fabricated with a fixed proportion of polymer bitumen. Physicomechanical properties of asphalt samples presenting a larger grain size distribution point to an increase in stability, higher density of asphalt samples and asphalt mixes, and a smaller proportion of voids in the mineral mixture. Consequently, as the final result, there is a better filling of voids with bitumen.

In further research, it would be recommended to conduct laboratory testing of designed asphalt mixtures with different grain size distributions, and to determine functional dependence with generated properties.

REFERENCES

[1] Nicholls, C., Carswell, I., Gibb, M., Williams, J.: Service Lives of Thin Surfacing Systems in the UK. Paper at the conference Transport Research Arena Europe 2006, Gothenburg, Sweden, 12-15 June 2006.

[2] AFNOR STANDARD NF P 98-137, 1992.

[3] Gilbert, T.M., Olivier, P.A., Gale, N.E.: Ultra Thin Friction Course: Five years on in South America. Proceedings of the 8th Conference on Asphalt Pavements for Southern Africa (CAPSA'04), Sun City, South Africa, 12 - 16 September 2004.

[4] Cooley (Jr), L.A., James, R.S., Buchanan, M.S.: Develpoment of mix design criteria for 4,75 mm mixes. NCAT Report 02-04 National Center for Asphalt Technology, Auburn University, Alabama, 2002.

[5] Rasmussen, R.O., Rozycki, D.K.: Thin and ultra thin whitetopping. NCHRP Synthesis of Highway Practice 338, National Cooperative Highway Research Program, National Research Council, Washington, D.C., 2004.

[6] Silfwerbrand, J., Petersson, O.: Thin concrete inlays on old concrete roads. Proceedings Fifth International Conference on Concrete Pavement Design and Rehabilitation, Vol.2., Purdue University, West Lafayette, Indiana, USA, pp. 255-260, 20-22 April 1993.

[7] Cho, Y.H., Koo, H.M.: A behavior analysis of concrete overlay based on the characteristics of asphalt pavements. 82nd Annual Meeting of the Transportation Research Board, Washington, DC, 12-16 January 2003.

[8] Nishizawa, T., Murata, Y., Kokubo, K.: Mechanical behaviour of ultra-thin whitetopping structure under stationary and moving loads. Transportation Research Board, National Research Council, Washington, D.C., pp. 102-109., 12 January 2003

[9] Rosenberg, J.: Thin pavements with syntetic binder used in Denmark. Nordic Road and Transport Research Journal, No. 2, 2000.

[10] Nicholls, J.C., Carswell, I., Williams, J.T.: Typical properties of proprietary thin asphalt surfacing systems. Proceedings of the Institution of Civil Engineers, Transport, Vol. 3, pp. 183-190, 2002.

[11] Watters, J.C.: PAVEtex TH – Ultra thin asphalt a coast effective treatment with texture – some case studies. NZIHT 2006 Conference Recycled asphalt and porous pavements – Enviromental, Social and Cost Advantages. Auckland, New Zealand, 5-7 March 2006.

[12] Yeo, R.: Bituminous and concrete surfacing trial: Report on Performance Monitoring. Proceedings of 10th AAPA International Flexible Pavements Conference, Vol. 1, Paper 25, Perth, 1997.

[13] Roesler, J., Bordelon, A., Ioannides, A., Beyer, M., Wang, D.: Design and concrete material requirements for ultra-thin whitetopping. Research Report FHWA-ICT-08-016, Ilinois Center for Transportation, 2008.

[14] Sandberg, U., Kragh, J., Goubert, L., Bendtsen, H., Bergiers, A., Biligiri, K.P., Karlsson, R., Nielsen, E., Olesen, E., Vansteenkiste, S.: Optimization of thin asphalt layers. ERA-NET ROAD Project, Swedish National Road and Transport Research Institute (VTI), Danish Road Institute (DRI) and Belgian Road Research Centre (BRRC), 30 April 2011.

[15] Brown, E.R., McRae, J.L., Crawley, A.B.: Effect of aggregate on performance of bituminous concrete. ASTM STP 1016, Philadelphia, pp. 34-63, 1989.

[16] Kandhal, P.S., Khatri, M.A., Motter, J.B.: Evaluation of particle shape and texture of mineral aggregates and their blends. Journal of Association of Asphalt Paving Technologists, 61, pp. 217-240., 1992.

[17] Kim, Y.R., Yim, N., Khosla, N.P.: Effect of aggregate type and gradation on fatigue and permanent deformation of asphalt concrete. ASTM STP 1147, Philadelphia, pp. 310- 328., 1992.

[18] Krutz, N.C., Sebaaly, P.E.: Effect of aggregate gradation on permanent deformation of asphaltic concrete. Proceedings of Association of Asphalt Paving Technologists, 62, pp. 450-473, 1993.

[19] Oduroh, P.K., Mahboub, K.C., Anderson, R.M.: Flat and elongated aggregates in Superpave regime. Journal of Materials in Civil Engineering, 12, pp. 124-130., 2000.

[29] Cooley (Jr), L.A., Brown, E.R.: Potetntial of using stone matrix asphalt (SMA) for thin overlays. NCAT Report 03-01, Alabama, 2003.

[21] Guide specification for HMA ultra-thin, MDOT – Michigan Department of Transportation, 2005.

[22] Pretorius, F.J., Wise, J.C., Henderson, M.: Development of application differentiated ultra-thin asphalt friction courses for southern African application. Conference on Asphalt Pavements for Southern Africa (CAPSA'04), Sun City, South Africa, 12 - 16 September 2004

[23] Xie, H., Cooley (Jr), L.A., Huner, M.H.: 4.75 mm NMAS stone matrix asphalt (SMA) mixtures, NCAT Report 03-05, Alabama, 2005.

[24] HRN EN 13108-2:2007/Ispr.1:2008 Bitumenske mješavine - Specifikacije materijala - 2. dio: Asfaltbeton za vrlo tanke slojeve (EN 13108-2:2006/AC:2008)

[25] Razrada tehničkih svojstava i zahtjeva za građevne proizvode za proizvodnju asfaltnih mješavina i za asfaltne slojeve kolnika, Hrvatske Ceste d.o.o., Zagreb, ožujak 2012.

[26] HRN EN 1097-7:1999 Ispitivanje mehaničkih i fizičkih svojstava agregata - 7.dio: Određivanje gustoće punila - piknometarska metoda (EN 1097-7:1999)

[27] HRN EN 1097-6:2000 Ispitivanje mehaničkih i fizičkih svojstava agregata - 7.dio: Određivanje gustoće i upijanje vode (EN 1097-6:2000+AC:2002)

[28] HRN EN 1425:2012 Bitumen i bitumenska veziva - Karakterizacija vidljivih svojstava (EN 1425:2012)

[29] HRN EN 1426:2008 Bitumen i bitumenska veziva - Određivanje penetracije iglom (EN 1426:2007)

[30] HRN EN 12697-2:2003 Bitumenske mješavine - Ispitne metode za asfalt proizveden vrućim postupkom - 2. dio: Određivanje granulometrijskog sastava

[31] HRN EN 12697-1:2003 Bitumenske mješavine - Ispitne metode za asfalt proizveden vrućim postupkom - 1. dio: Topljivi udio veziva

[32] HRN EN 13108-20:2007/Ispr.1 Bituminous mixtures - Material specifications - Part 20: Type Testing (EN 13108-20:2006/AC:2008)

[33] HRN EN 12697-6:2003 Bitumenske mješavine - Ispitne metode za asfalt proizveden vrućim postupkom - 6. dio: Određivanje gustoće asfaltnih uzoraka

[34] HRN EN 12697-5:2003 Bitumenske mješavine - Ispitne metode za asfalt proizveden vrućim postupkom - 5. dio: Određivanje gustoće asfaltnih mješavina

[35] HRN EN 12697-8:2003 Bitumenske mješavine - Ispitne metode za asfalt proizveden vrućim postupkom - 8. dio: Određivanje šupljina u asfaltnim uzorcima

[36] HRN EN 12697-34:2004 Bitumenske mješavine - Ispitne metode za asfalt proizveden vrućim postupkom - 34 - Marshallovo ispitivanje