QUALITATIVE CHARACTERIZATION OF FOAMED BITUMEN STABILISED MIXES

Aleksander Ljubic, Roman Baselj, Natasa Zavrtanik, Mitja Kozamernik, Damijan Zore
Igmat d.d. Building Materials Institute, Ljubljana, Slovenia

ABSTRACT

In Slovenia the use of reclaimed asphalt in asphalt production is still underdeveloped in comparation to other european states. The goal of our research is to encourage the use of recycled asphalt by the determination of its characteristics in comparison to conventional asphalt mixes with virgin materials using the state-of-the-art testing methods, that is by stiffness modulus testing according to EN 12697-26. Processing can be done in-situ, for example recycling with foamed bitumen or with emulsion or in asphalt plant, using hot or cold feed of reclaimed asphalt. We compared the characteristics of some typical foamed bitumen stabilised mixes for base courses, designed for all classes of traffic loads, with different quantities of RAP and recycled in-situ with foamed bitumen.

Keywords: Recycling, Reclaimed asphalt pavement (RAP), Stiffness, Foam, In-situ Recycling

1. INTRODUCTION

The use of reclaimed asphalt pavement (RAP) gained popularity with the widespread use of specialized milling machines for removing asphalt from the surface of the roadway. Asphalt is now one of the most highly recycled products in the world. Similar case happened with recycling in-situ with foamed bitumen after the industry launched special equipment for producing foamed bitumen almost twenty years ago. RAP is extensively used throughout the world both for re-use in hot mix asphalt and in cold and hot in-place recycling and mixed with road aggregate base.
In Slovenia RAP is mostly being used in production of hot mix asphalt in smaller percentages – tipically approximately 10 % of mass of all aggregates in the mix and predominantly for less trafficked roads. The use of RAP in cold in-place recycling is rapidly growing due to the good experiences with the foamed bitumen stabilisation in rehabilitation of distressed sections of national roads network.
Foamed bitumen stabilisation is a technique whereby a mixture of hot bitumen, water and air is used to bind the existing or imported granular materials to produce a flexible pavement material for use in base and subbase pavement layers.
Foamed bitumen is produced by injecting water into hot bitumen, resulting in spontaneous foaming. The physical properties of bitumen are temporarily altered when the injected water, on contact with the hot bitumen, is explosively transformed into vapour, which is trapped in many tiny bitumen bubbles. The bitumen foam dissipates in less than a minute.
The foaming process occurs in an expansion chamber into which bitumen and water are injected at high pressure and foamed bitumen is incorporated into the aggregate while it is still in its unstable foamed state. The greater the volume of the foam, the better the distribution of the bitumen in the aggregate. During the mixing process, the bitumen bubbles burst, producing tiny bitumen particles that disperse throughout the aggregate by adhering to the finer particles of sand and smaller to form a mastic.
The moisture in the mix prior to the addition of the foamed bitumen plays an important role in dispersing the bitumen during mixing. On compaction, the bitumen particles in the mastic are phisically pressed against the larger aggregate particles resulting in localised non-continuous bonds ("spot welding") [1].

Figure 1: Appearance of the foam bitumen stabilised material specimens – dry (left) and soaked (right)

The behaviour of the foamed bitumen stabilised material is similar to that of unbound granular materials, but with improved cohesive strenght and reduced moisture sensitivity and unlike to hot-mix asphalt, is not black in appearance and does not have a sticky feel, the larger aggregate particles are not coated with bitumen. The bitumen disperses amongst finer particles of aggregate only at temperatures of the aggregate between 15 °C and 25 °C because of low heat energy of foam bubbles to ensure adhesion to finer particles. Small amounts of active filler as cement or hydrated lime

(app. 1 % by mass) are added to the mix to improve the retained strength under saturated conditions and also assisting in dispersing the foamed bitumen particles by increasing the fines content.
Bitumen stabilised materials are used in construction of base and subbase layers and therefore have to be surfaced and protected from direct effects of traffic and environment. Bitumen is protected from UV-radiation and ageing effects of oxidation and high temperature and so retains its elastic properties for longer periods especially in lower portion of thick layers where tensile stresses from loading in the pavement structure develop[2].

2. CHARACTERISATION OF FOAMED BITUMEN STABILISED MATERIALS (BSM-foam)

There are several reasons for a laboratory characterisation ofmaterials such as providing the material parameters for the thickness design method, optimising material performance and meeting the requirements, optimising the use of materials and additives and reducing costs and research and development.
The effective stiffness of a BSM-foam layer is dependent on the constituent materials, the density of the material in the layer, the amount of bitumen added, the dispersion of the bitumen in the mix, active filler, temperature and the moisture content.
The conceptual behaviour of foamed bitumen stabilised material is best described in figure 2

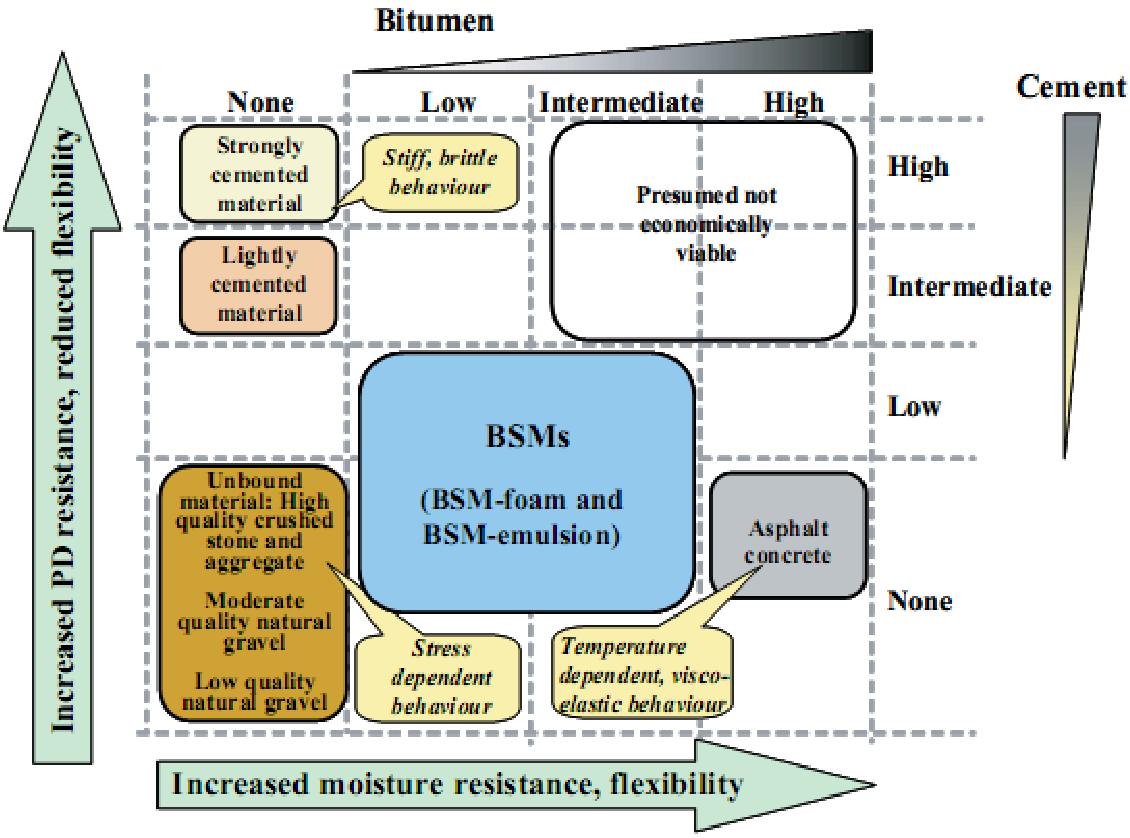

Figure 2: Conceptual behaviour of pavement materials (Asphalt Academy TG2 [1])

2.1 Mix design of foamed bitumen stabilised materials (BSM-foam)

Laboratory mix design for BSM-foam basically incorporates the following steps:

- preliminary tests to determine the grading curve, optimum moisture content, density relationships and plasticity
- initial selection of stabilising agents (suitability of bitumen foaming characteristics - its expansion ratio and half-life) and determining the optimum added foamant water content
- optimisation of the mixture (preparation of specimens with different amounts of foamed bitumen)
- specimen compaction (standard compaction effort by Marshall compaction)
- curing of the specimens to simulate field conditions (curing for 72 hours at the temperature of 40 °C to obtain a dry set of specimens and in parallel a set of wet specimens soaked in water at 25 °C for 24 hours)
- mechanical testing to assess the flexural characteristics and moisture susceptibilty (Indirect Tensile Strength – ITS –testing on both dry and wet specimens, the ratio of ITS_{wet} and ITS_{dry} is the Tensile Strength Retained – TSR)

Mix design results must be integrated with pavement design, for the latter there are various approaches:

- Empirical methods
    - Catalogue design approach (for light traffic loads)
    - Structural Number method (based on AASHTO test)
    - Pavement Number method (South Africa)
- Analytical methods
    - Effective Fatigue Phase – Austroads Asphalt Criteria (Australia)
    - Equivalent granular state – Mechanistic design (New Zealand)

2.2 Mix design of BSM-foam for different road pavement solutions

In Slovenia the empirical Structural Number method is used for pavement design. In order to establish the data and gain experience for future analytical methods of pavement design, we are trying to determine the characteristic design modulus for bituminous stabilised materials such as the foamed bitumen stabilisation.
During the last year we were involved in mix design for five (5) road sections with foamed bitumen stabilisation. Additionally to standard mix design testing in a laboratory we also determined the stiffness modulus for these five pavement rehabilitation projects using the procedure according to European standard EN 12697-26, appendix C.
Testing program comprised the complete mix design for different road sections from the investigation of design traffic, analysis of the available materials in situ, optimisation of recycled and added materials, active filler and bitumen, evaluation of results and in two cases also the quality control of in-situ construction.
The laboratory preparation of foamed bitumen mixes was made with Wirtgen WLB 10 laboratory machine and mixer.

Figure 3: Laboratory equipment for foamed bitumen stabilised material mixing

Road sections ranged from the four-lane city motorway with very heavy traffic (3130 Equivalent Standard Axle Loads - ESAL/day in the first year of opening to traffic and 32 millions ESAL at the end of the 20-year design period) over typical two-lane with heavy traffic loading regional road traffic (403 Equivavalent Standard Axle Loads - ESAL/day in the first year of opening to traffic and 4,1 millions ESAL at the end of the 20-year design period) to two sections of two-lane regional road with medium or light traffic loads (175 & 85 ESAL /day in the first year of opening to traffic and 1,8 & 0,9 millions ESAL at the end of the 20-year design period) representing almost entire range of possible pavement constructions on our national road network. In Slovenia the ESAL is defined as an axle load of 100 kN.

Table 1: Traffic loads and various classifications for test sections

No.	Traffic Loads			Traffic Loads Classification				Road Section
	Average Daily Traffic	Design Traffic 1st year	Design Traffic 20 years	Slovenia Technical Specifications	Austroads[3]	TG2		
						Material class	Mix Design Level	
	Vehicles	ESAL	ESAL x 10^6	Class	Class			
1	61154	3130	32,0	very heavy	high	BSM1	3	H3/ 0090 and 690
2	61154	3130	32,0	very heavy	high	BSM1	3	H3/ 0090 and 690
3	6607	403	4,1	heavy	medium	BSM2	2	R3-646/1196
4	3473	175	1,8	medium	medium	BSM2	1	R1-216/1177
5	6406	85	0,9	medium	light	BSM3	1	R3-642/1360

On the first test section of city motorway H3/0090 and H3/0690 we examined two different recycling solutions as requested by the road owner. The first solution consisting of recycling the existing asphalt pavement together with subbase layer (meaning removing the cracked cement stabilised layer that lies in-between asphalt and subbase layers) and the second solution with recycling the existing cracked cement stabilised layer together with subbase layer (that means removing the two asphalt layers on top of the cement stabilised layer prior to recycling). The condition to comply with was to maintain the same pavement surface vertical alignment because of the road section layout in the city with a lot of junctions.
The first solution represented approximately 30 % RAP and 70 % subbase material mixed with 2,5 % foamed bitumen B 70/100 at 170 °Cand the second one practically 50 % cement stabilisation and 50 % subbase with 3 % foamed bitumen B 70/100 at 170 °C, both times with 1,5 % cement added for assuring the adequate amount of fines for dispersion of the foamed bitumen in the mix and at the same time improving the moisture susceptibility of the mix. We assume that road authorities will select the first solution for the rehabilitation project but so far these two sections of the motorway still haven't been recycled so we can't verify the quality on site of the mix design done in the laboratory.
Next test section (No. 3) on the regional state road R3-646/1196 was designed similar to the first section with approximately 32 % of RAP and remaining 68 % of subbase material recycled with 2,5 % foamed bitumen B 70/100 at 170 °C from the same source as above - requiring 2,5 % of foamant water added for optimum foaming characteristics – expansion ratio of around 24 and half-life of more than 30 seconds.
The recycling with foamed bitumen on the test section No. 4 of the regional road R1-216/1177 was done with 60 % of RAP and remaining 40 % of subbase material recycled with 3 % foamed bitumen B 70/100 from a different source at 170 °C with 3 % of foamant water added for optimum foaming characteristics – expansion ratio of around 28 and half-life of 17 seconds.
Test section No. 5 represented a rehabilitation project of the regional road R3-642/1360 with a high amount of RAP because of frequent resurfacing which was done in the past due to the consolidation. Mix design consisted of 63 % RAP and remaining 37 % of subbase material recycled with 2,5 % foamed bitumen B 70/100 at 170 °C with the same foaming characteristics as above.
On all five test sections the added percentage of cement acting as active filler in the mix design was 1,5 % by mass as it was found as the optimum content by Jian Xu et.al. [6] . The Wirtgen Manual from 2004 [7].also recommended maximum 1,5 % cement content by mass, until lately when Wirtgen Manual 2010 [8] in parallel with Asphalt Academy TG2 [1] limited the cement content to 1,0 % by mass when recycling with foamed bitumen. We decided to for the addition of 1,5 % by mass of cement because of its contribution to provide early strength for immediate trafficking, which is required when rehabilitating narrow two-lane roads to allow the progress of recycling in one lane and simultaneous traffic in the other lane and vice-versa.

Table 2: Foamed Bitumen Stabilised Mix Design

No.	Lab. No.	Type of binder added	Added binder content	Added cement content	Added foamant water	RAP content	Road Section
			% (m/m)	% (m/m)	(%)	% (m/m)	
1	52-A-11	B 70/100	2,5	1,5	2,5	30,0	H3/ 0090 and 690
2	53-A-11	B 70/100	3,0	1,5	2,5	0,0	H3/ 0090 and 690
3	490-A-11	B 70/100	3,0	1,5	3,0	32,0	R3-646/1196
4	464-A-11	B 70/100	3,0	1,5	3,0	60,0	R1-216/1177
5	108-A-11	B 70/100	2,3	1,5	2,5	63,0	R3-642/1360
Average value			2,8	1,5	2,7	37,0	

Table 3: Foamed Bitumen Stabilised Mix Grading

No.	Aggregate grading												Road Section
	Passing through sieve size in mm												
	0,063	0,09	0,25	0,71	2.0	4.0	8.0	11.2	16	22,4	31,5	>31,5	
	% (m/m)												
1	5,8	6,4	10,1	15,4	26,9	38,8	54,8	64,8	76,9	87,9	96,5	100,0	H3/ 0090 and 690
2	5,8	6,4	10,4	16,6	30,4	44,1	62,2	72,5	82,9	92,3	97,9	100,0	H3/ 0090 and 690
3	7,4	8,6	12,3	19,5	34,6	50,4	72,6	84,5	94,2	98,9	100,0	100,0	R3-646/1196
4	6,1	7,0	10,0	17,4	33,0	50,9	75,0	84,2	90,3	93,5	96,1	100,0	R1-216/1177
5	5,1	5,5	9,3	16,4	32,7	50,8	77,9	86,7	93,0	96,9	98,7	100,0	R3-642/1360
Avg.	6,0	6,8	10,4	17,1	31,5	47,0	68,5	78,5	87,5	93,9	97,8	100,0	

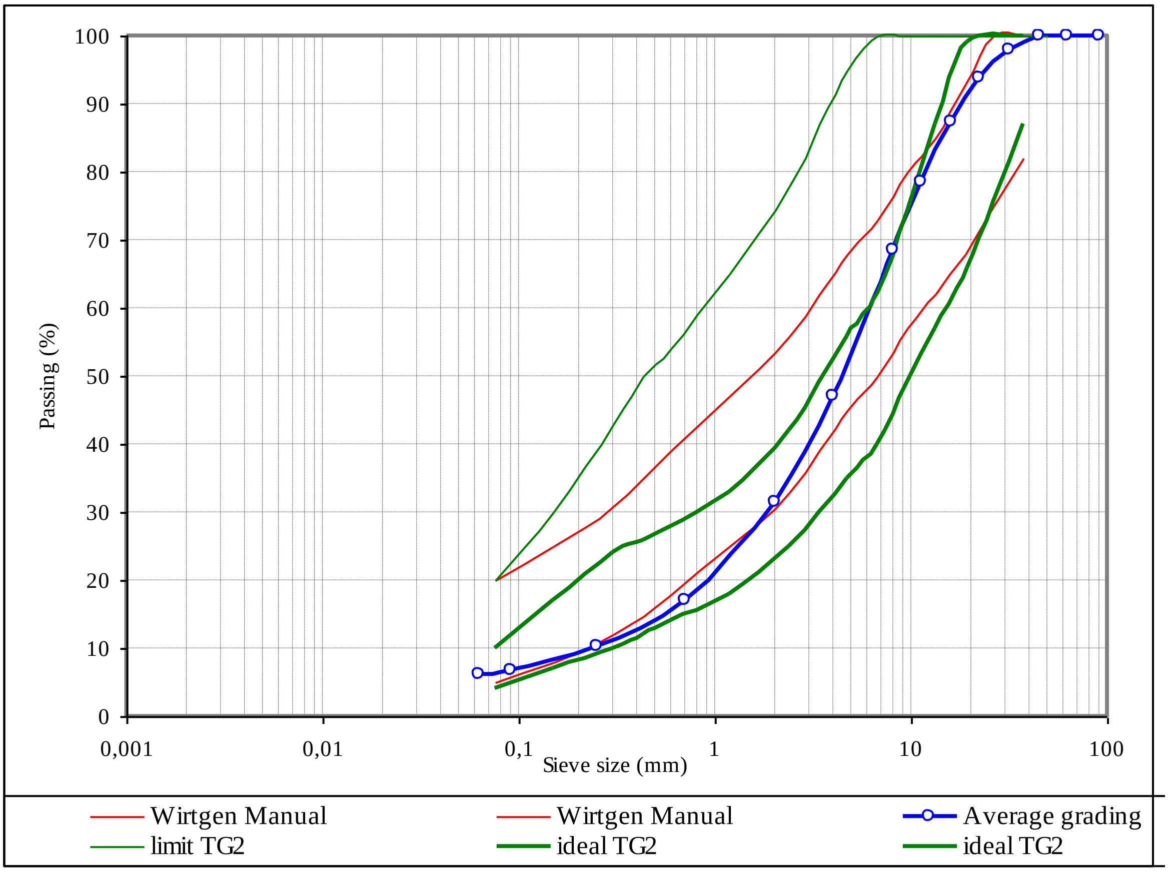

Figure 4: Average grading curve and various proposed limits by Wirtgen and Asphalt Academy

2.3 Laboratory testing of BSM-foam designs

For the mix design procedure in laboratory we followed the Wirtgen Cold Recycling Technology Manual 3rd Edition 2010 [8] Appendix 1 with manufacturing the 100 mm diameter specimens by Marshall compaction with 75 blows for each side and curing the specimens in a forced-draft oven at 40°C for 72 hours. Indirect tensile strenth (ITS) was then determined under dry (ITS_{Dry}) and soaked (ITS_{Wet}) conditions following the procedure in Manual by curing the dry specimens to constant mass and by placing the soaked specimens under water at 25°C for 24 hours before determining ITS_{Wet}. The ratio between ITS_{Dry} and ITS_{Wet} called Tensile Strength Retained (TSR) should always be over 60 % in dry terrain type and drainage and over 70 % in wet terrain type and drainage for assuring good behaviour in terms of moisture susceptibility [8].

All the optimum mix design specimens from the five test sections were also tested for determining the stiffnes according to EN 12697-26 Annex C applying indirect tension to cylindrical specimens (IT-CY) of 100 mm in diameter on both dry and soaked specimens cured by the same procedure as for determining indirect tensile strength. Tests were done at the temperature of 20 °C, the applied sinusoidal loading with a rise time of the load pulse of 124 ms as prescribed by Clause D.8 of European standard for the initial type testing EN 13108-20 of asphalt concrete mixtures and the results were expressed as S'_m – the stiffness modulus, expressed in MPa, adjusted to a load area factor of 0,60.

All laboratory test results on optimum mix designs of BSMs-foam are presented in Table 4.

Table 4: Foamed Bitumen Stabilised Mix Characteristics

No.	Lab. No.	Bitumen Stabilised Mix Characteristics								Road Section
		Mix Bulk Density	Max. Dry Density	ITS Dry	ITS Wet	Ratio ITS W/D	S'm Dry	S'm Wet	Ratio S'm W/D	
		kg/m³	kg/m³	kPa	kPa	%	MPa	MPa	%	
1	52-A-11	2191	2336	418	342	81,8	4526	4370	96,6	H3/ 0090 and 690
2	53-A-11	2150	2247	400	322	80,5	3625	1011	27,9	H3/ 0090 and 690
3	490-A-11	2198	2151	482	431	89,4	4068	3255	80,0	R3-646/1196
4	464-A-11	2267	2216	544	439	80,7	7056	6491	92,0	R1-216/1177
5	108-A-11	2175	2232	374	304	81,3	5234	3556	67,9	R3-642/1360
Average value		2196	2236	444	368	82,7	4902	3737	72,9	

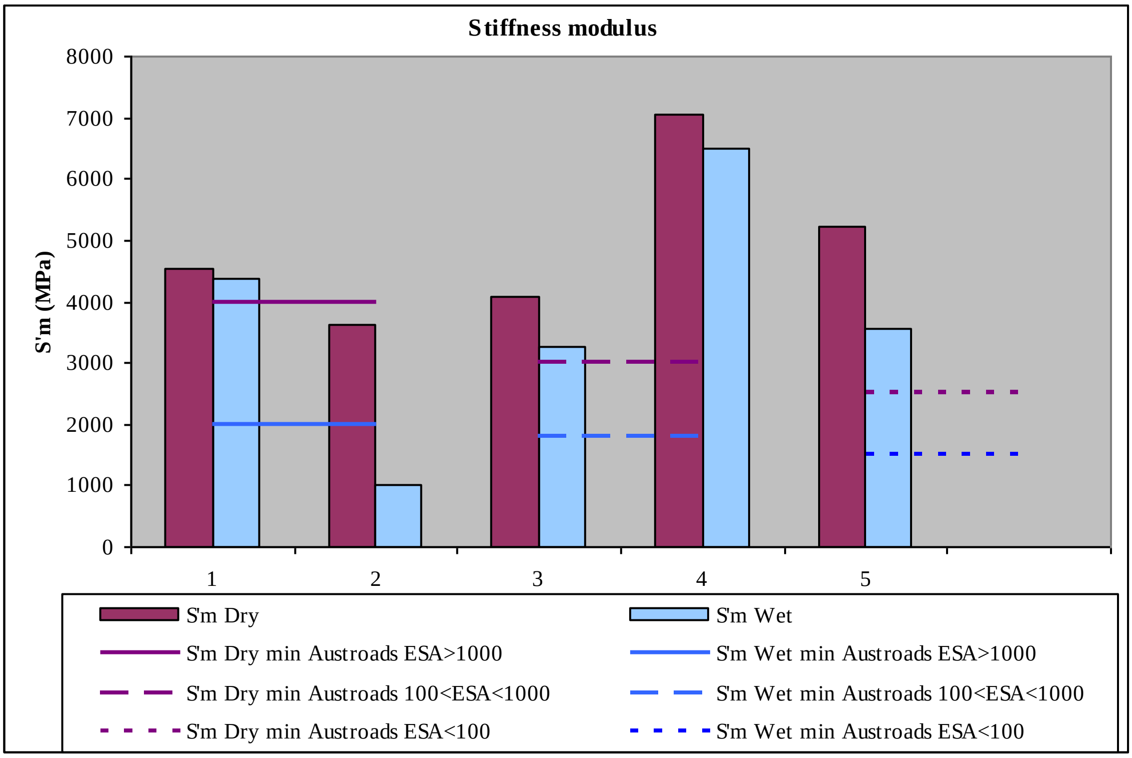

Figure 5: Stiffness modulus results and Austroads specifications

All the ITS values , both dry and soaked, are quite clearly satisfying all the recommended values (even for BSM1 material class by TG2) and also all the stiffness modulus values are satisfying the existing criteria from Austroads [3]. There is a noticeable difference of the achieved ITS values between the mix designs No. 1 and 2 with better results for a RAP solution (No. 1). The difference is even more explicit for stiffness modulus values, where an extreme fall in stiffness is evident for the soaked specimens – that can be partly also attributed to some inhomogeneity of the cracked cement stabilised course used in the No. 2 solution.
It can be observed that in the mix designs with greater amount of RAP used - test sections 4 and 5 with RAP contents of around 60 % by mass of the recycled layer - the stiffness modulus values are the highest. These values appear very high and if they are actually achieved in-situ that would mean there is no need for thick overlay asphalt layers to satisfy the demanded bearing capacity of the road construction. A thin surfacing layer to achieve the acceptable skid resistance would only be needed.

2.4 Construction in-situ and test results of various BSM-foam designs

The first two road sections are still in the pre-tendering phase and we are not able to tell about the performance in practice, but other three road sections have been successfully recycled and are now open to traffic without any defects observed.

On test sections No. 3 and No. 5 we also performed the quality control of the construction works and we can make a comparison of values measured on mix design and measured values on actually recycled layers in-situ. The measurements made on recycled layers in-situ are presented in Table 5 and marked 3a, 5a, 5b and should be compared with mix design measurements marked 3 and 5.

Table 5: Comparison of Foamed Bitumen Stabilised Mix Characteristics – Mix Design and Constructed on site

No.	Lab. No.	Bitumen Stabilised Mix Characteristics								Road Section
		Mix Bulk Density	Max. Dry Density	ITS Dry	ITS Wet	Ratio ITS W/D	S'm Dry	S'm Wet	Ratio S'm W/D	
		kg/m^3	kg/m^3	kPa	kPa	%	MPa	MPa	%	
3	490-A-11	2198	2151	482	431	89,4	4068	3255	80,0	R3-646/1196
3a	541-A-11	2282	2243	401	303	75,6	8634	7964	92,2	R3-646/1196
5	108-A-11	2175	2232	374	304	81,3	5234	3556	67,9	R3-642/1360
5a	219-A-11	2143	2125	306	228	74,5	2827	1989	70,4	R3-642/1360
5b	251-A-11	2087	1939	315	257	81,6	1449	1205	83,2	R3-642/1360
Average value		2177	2138	376	305	80,5	4442	3594	78,7	

Although the values of ITS measured on both dry and wet specimens from the actually recycled layer are distinctly lower than the values on specimens from the mix design in laboratory, they are still satisfying the specifications and recommendations for given levels of the road and load classes. Tensile strength retained or the ratio between ITS of soaked and dry specimens is also good on all the sections and it can probably be attributed to a relatively high amount of cement (1,5 %) acting as active filler in all the mixes.
In general, the above observation is also valid for stiffness modulus results with an exception of test section No. 3a where there was a substantial increase in stiffness values for in-situ recycled material – it can be maybe explained by the failure of bitumen injection that was temporarily observed and resulting in practically only cement stabilisation and consequentially higher stiffness values.

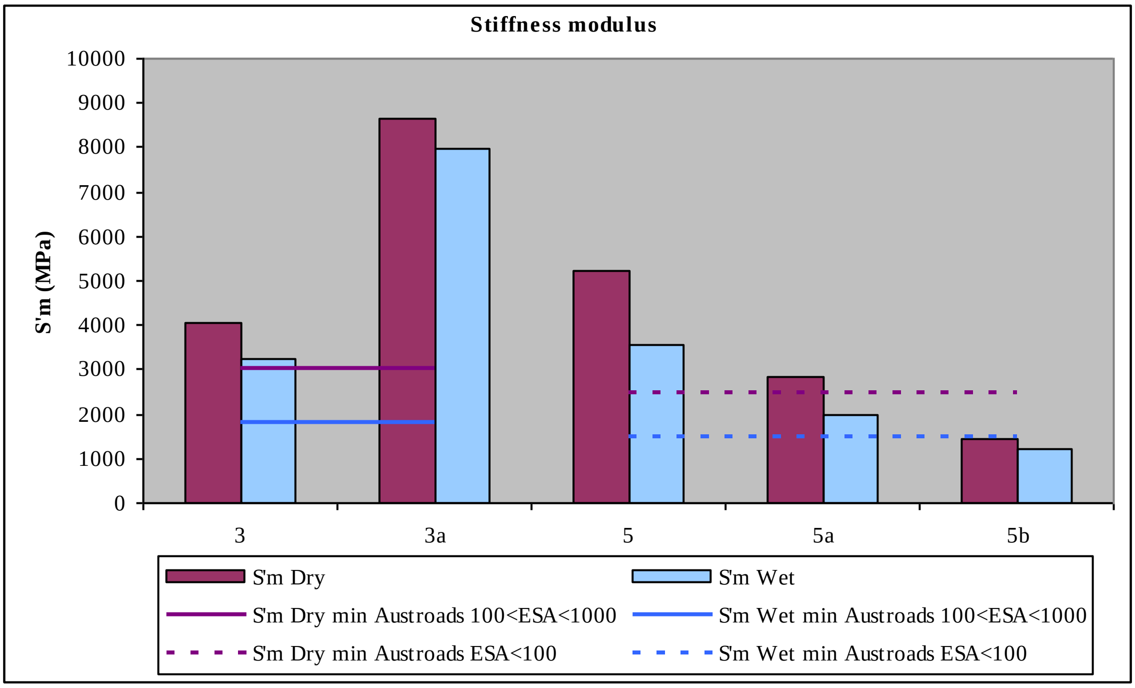

Figure 6: Stiffness modulus comparison between values on mix design in laboratory and in-situ

It is clearly evident that on the construction site there are quite a lot of deviations on the recycled layers from the designed characteristics of the mix. The 'old' materials in pavement construction which are being recycled with some 'new' added materials are in many cases more heterogenous than we are assuming and taking into account when preparing the mix design for recycling solution in a particular case.
The surrounding climatic and traffic conditions on site can also play an important role and have a detrimental or in some cases even beneficial effect on the resulting characteristics of the recycled layer.

There is also the influence of time shift between the actual mixing of the materials on site and compaction of the specimens in laboratory for the following testing, especially because of the 1,5 % of cement added which begins to bond immediately after coming in contact with water in the mixing – recycling process. Some of these bonds are then destroyed by compaction of the samples in the laboratory and reducing the strength that could be achieved if compacted immediately after mixing.

2.5 Discussion of results

In comparison to some of the asphalt concrete base mixes we tested for stiffness in the past, the recycled mixes fared quite well. Typical values of stiffness modulus for AC base varied between 3700 and 9300 MPa so we can assume the structural layer coefficient would be lower than 0,35 which is used for asphalt base layers, but definitely higher than 0,20 which is used for cement stabilised layers. The structural layer coefficient should be calculated according to AASHTO Guide for Design of Pavement Structures. As a guide the indicative values from Figure 7 can be used.

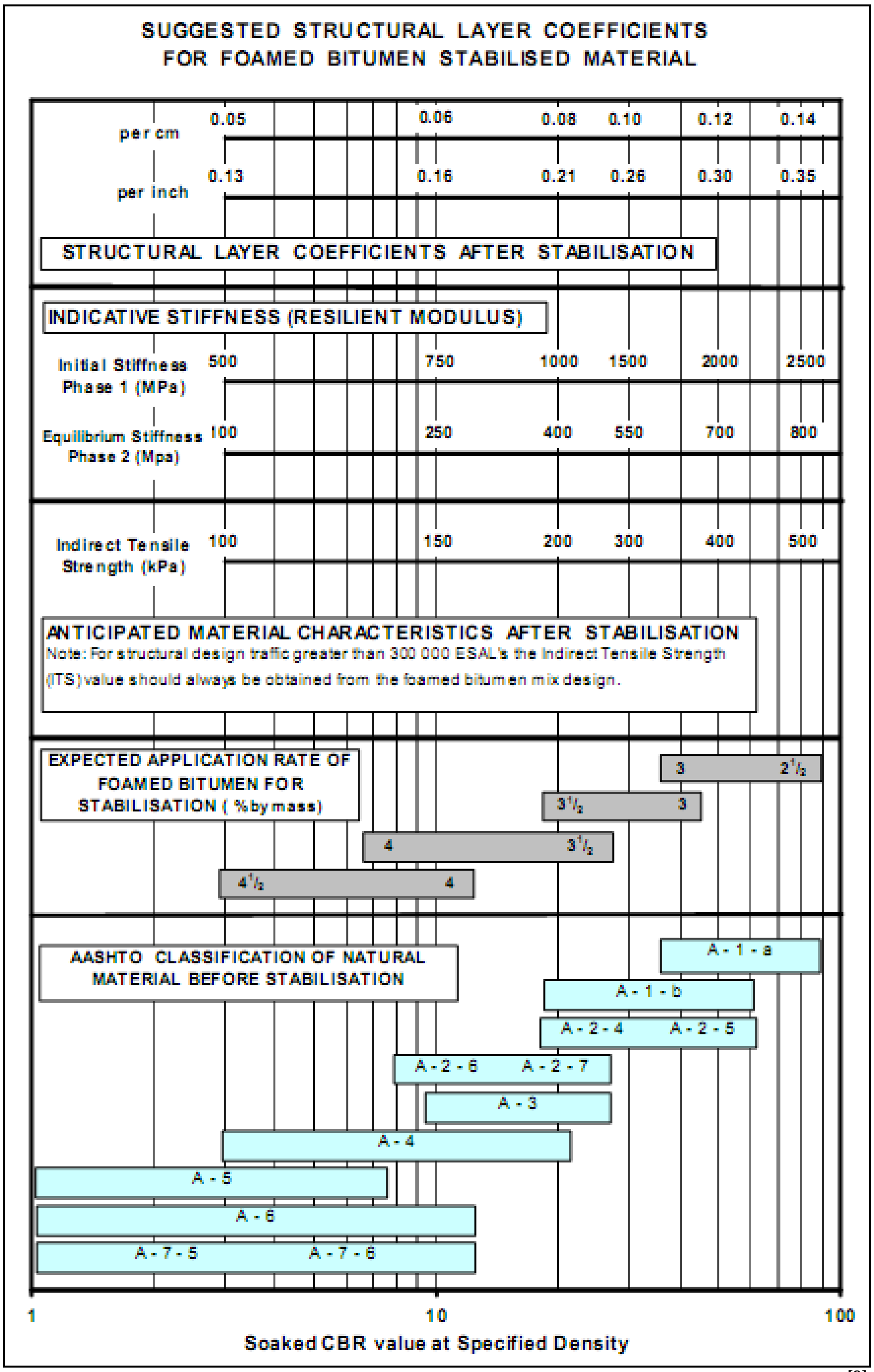

Figure 7: Layer coefficient ranges for foamed bitumen stabilised materials [9]

From the measured ITS values of both mix design and in-situ mixes we can conclude that all five mixes have the suitable characteristics to assume a structural layer coefficient of minimum 0,26 (per inch) that can be a basis for a

pavement design using the structural number method. The suggested structural layer coefficients for BSM from Wirtgen Manual also classify the material with ITS_{Dry} values over 225 kPa in a structural layer coefficient range from 0,26 to 0,35 (per inch), that is near the value for asphalt hot-mix layers.
Due to the differences found between the laboratory mix design values and values from the actual construction of BSM-s on site, care should be taken not to overrate the mix design results and to take into account the seemingly inevitable drop in stiffness moduli to some extent during the construction.
It was also found here that higher amount of reclaimed asphalt pavement (RAP) in the BSM-foam leads to its higher stiffness modulus, so it is beneficial to design the rehabilitation projects with the inclusion of existing asphalt layers as much as possible.

3. CONCLUSIONS

The behaviour of tested BSM-foam mixes and layers that were designed and recycled in-situ according to experiences gained in Slovenia and also considering a lot of expertise and advice in the literature from countries that already have a longer tradition and more knowledge in terms of foamed bitumen stabilisation such as South Africa and Australia, was partially expected and predicted but some findings are also a little surprising and need more evaluation and are still to validate on a larger scale. The existing materials that are to be recycled in-situ are always unpredictable to a certain extent, but with a thorough preliminary testing and with a proper mix design suited to the actual road purpose and with a conscientious construction on site it should be able to achieve the goal of high-quality stabilised layers as demonstrated here.
In general we can assume that foamed bitumen stabilised mixes (BSM-foam) are approaching the characteristics of asphalt mixes in terms of stiffness moduli, they are definitely more close to asphalt layers than they are to unbound granular layers, even if they are conceptually behaving somewhere in between.
If we take into account the cost effectiveness of the recycling in-situ combined with the ecological procedure of re-using the valuable building materials together with the engineering contribution of relatively thick layers with good bearing capacity, we are looking here at a winning solution for road rehabilitation.

REFERENCES

[1].Technical Guideline: Bitumen Stabilised Materials, TG2 Second Edition, Asphalt Academy, Pretoria 2009
[2].Key characteristics of materials stabilised with foamed bitumen, D.C.Collings, K.J.Jenkins, Advanced Testing and Characterization of Bituminous Materials, London 2009
[3].Review of Foamed Bitumen Stabilisation Mix Design Methods, Austroads Publication No. AP-T178/11, Sydney, Australia 2011
[4].Mix design of bitumen stabilised materials: best practice and considerations for classification, L.J.Ebels, K.Jenkins, Proceedings of the 9th Conference on Asphalt Pavements for Southern Africa (CAPSA'07), Gaborone, Botswana 2007
[5].6 years of foamed bitumen stabilisation in New Zealand – a performance review and comparison to overseas practice, A.Browne, 10th Conference on Asphalt Pavements for Southern Africa (CAPSA'11), South Africa 2011
[6].Impacts of cement content on properties of foamed asphalt cold recycling mixtures, Jian Xu, Songchang Huang, Yongchun Qin, Feng Li, 10th Conference on Asphalt Pavements for Southern Africa (CAPSA'11), South Africa 2011
[7].Wirtgen Cold Recycling Technology Manual 2nd Edtion 2004, Wirtgen GmbH, Windhagen, Germany 2004
[8].Wirtgen Cold Recycling Technology Manual 3rd Edition 2010, Wirtgen GmbH, Windhagen, Germany 2010
[9].Recycled Pavements Using Foamed Asphalt in Minnesota, A.Eller, R.Olson, MN/RC 2009/09 Minnesota DOT, St. Paul, Minnesota 2009