A NEW TYPE ASPHALT SURFACE LAYER FOR STEEL BRIDGE DECKS

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ABSTRACT

The usual type of asphalt layers for steel bridge decks in the Netherlands is Mastic Asphalt. The properties of this type of asphalt mixture are according the necessary flexibility and fatigue behaviour due to the large deflections of an orthotropic steel bridge deck.
However, with the growing intensity and axle-loads of the traffic, the problems of rutting and cracking are rising more and more. Especially the rutting problems are related to the "overfilled" character of the bituminous-rich Mastic Asphalt.
To solve this problem of non-corresponding requirements, an asphalt mix was developed according the way of function-separation. In this mix the high stability in vertical direction for carrying the traffic load is combined with the required horizontal flexibility to follow the high deflections of the bridge deck.
The result is an asphalt mixture that can produced en laid like normal hot asphalt. This solves also the problem of the lack of special equipment for producing and laying Mastic Asphalt in the Netherlands.
In this paper the developments, mechanical characteristics and experiences with the new developed asphalt-mix are reported and evaluated.

Keywords: Steel bridge deck, Mastic Asphalt, Stone Mastic Asphalt (SMA), Flexibility, Fatigue, Rutting

1. INTRODUCTION

The Netherlands is a densely populated country with 16.5 million inhabitants. In order to transport people and goods, the Netherlands are equipped with an extensive network of roads, waterways and railways. The crossing of roads and waterways is usually formed by steel and concrete bridges, but sometimes by tunnels and aquaducts.
Traffic loads (traffic intensity and the use of super single tyres) are increasing more and more. And the end to this increase is not yet in sight. Higher axle-loads have far stretching consequences regarding requirements for durable, low-maintenance surface layers on steel bridge decks.
The smaller and harder tyres lead to higher contact stresses and demand higher requirements to the stability of the mixture. The passage of heavy trucks will lead to high deflections on the bridge. Steel bridge decks are relatively light and differences in rigidity in the construction lead to wide varieties in the bending of the bridge decks. This can cause cracking in the surface layer.
The paving on the steel bridge decks usually consists of one or two layers of Mastic Asphalt, sometimes with an added top layer of porous asphalt, if noise reduction is required. The last few years experience has been gained with High Strength Concrete (HSC) with the aim to make bridge decks more rigid and thus reduce deformations. But there have been developments as well to improve the classic Mastic Asphalt mixture, because Mastic Asphalt and also HSC have their limitations.

2. THE PROBLEM

At the moment a traditional Mastic Asphalt surface layer on a steel bridge has already achieved a critical stage. The end of lifetime can be marked by too much rutting as well as by cracking. Mastic Asphalt can be made sufficiently flexible to balance out the movements. However, during periods with high temperatures this increases the chance of rutting in the top layers. This problem of stability in relation to the desired flexibility could be solved by applying a more stable binder. However, this increases the chances of cracking. In other words, the requirements on flexibility (for the bending of the bridge deck) and on the stability (for the traffic) are, with the increasing traffic load, incompatible. Due to this, steel bridges need more and more maintenance. The lifespan of Mastic Asphalt was rather good in the past, but because of the increase in traffic load and/or hotter summers (increasing by climate change), damages like cracking and rutting appear sooner and sooner.

Figure 1: Orthotropic steel bridge deck

Figure 2: Cracks in Mastic Asphalt layer

Besides that a practical problem occurs. In only a few places in the Netherlands Mastic Asphalt for steel bridges can be produced the last few years. This often results in unwanted too long transport distances between the asphalt plant and the work site. Therefore Mastic Asphalt is often obtained from German contractors.
Mastic Asphalt is not laid by a standard paver, but with a special machine. Because laying Mastic Asphalt is not common, it is an extra investment for Dutch contractors to keep a special machine for Mastic Asphalt in operation including the crew or, otherwise, to purchase this expertise.
Summarising, the disadvantages of Mastic Asphalt are: the increasing damages by traffic loads and climatological influences in combination with the limited laying, the deviating production and other laying process compared to hot asphalt.

3. A NEW APPROACH

A solution for the problems sketched above is the development of a more robust mixture for bridge decks, with a high resistance to fatigue and permanent deformation (i.c. sufficient rigidness) and which can be produced and processed with conventional asphalt plants and pavers.

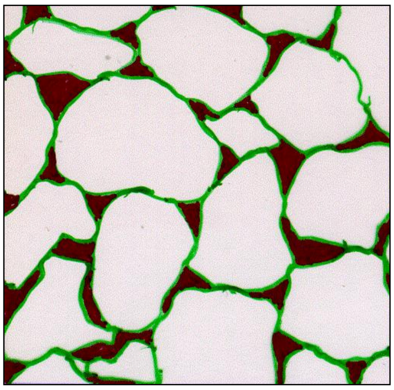

Figure 3: Stone skeleton structure

A modified Stone Mastic Asphalt (SMA) is seen as the most promising solution for the problems sketched. The resistance to permanent deformation in vertical direction is obtained by the grain-to-grain contact of the stone skeleton. Sufficient voids in the compacted layer prevent the mixture from becoming over-filled with mortar.
Due to traffic loads, deformations occur in the bridge deck system. These repeated deformations have to be followed by the asphalt layer and are not supposed to lead to fatigue cracking, because being impermeable is a major requirement of the construction. By modifying the mortar of the SMA mixture in such a way that a very flexible mortar is obtained, no cracking will occur and a robust and stable bridge deck mixture will be created, which can be produced and laid with conventional means.

4. TEST SET-UP

Within the described SMA-concept a mixture is developed with different characteristics in dual directions. In order to achieve a good transfer for the required vertical stresses the stone skeleton in the SMA-mixture is used. In order to absorb the bending and the horizontal movements (strain and stress) as a result of the movement in the steel deck, a very flexible modified bituminous mortar has been applied.
In this approach use has been made of the latest insights in the area of volumetric mix design according to the national CROW IVO SMA working group, (report is expected in 2008) and the test methods of asphalt mixtures. For the mechanical tests the University of Aachen, Germany, has been called in, a specialist in the field of Mastic Asphalt in the German market .

In the Laboratory of Heijmans Infrastructure in Rosmalen (the Netherlands) the study is started with looking to the required binder characteristics. To take care of the needed flexibility a PMB was chosen with a high SBS content. Then a mortar composition has been developed from which it was to be expected that it would meet the high requirements regarding flexibility. Result of this work was a mortar with a high content of high modified binder with addition of fibres. The fibres has to be added to prevent dripping of the binder.
Subsequently, by means of volumetric optimisation, an asphalt mixture has been designed with this mortar, in which, even after heavy compacting a relatively high percentage of voids remains (design level 5,2 %). This is a guarantee that the stone-to-stone contact will remain and with that, the stability.
Next, the mixture has been thoroughly tested mechanically. The testing has been executed by the Technical University of Aachen and the laboratory of the former Road and Hydraulic Engineering Institute (Since 1 October 2007 Centre for Traffic and Navigation) of the Rijskwaterstaat (Department of Public Works) in Delft, the Netherlands.
In table 1 an overview is given of the used materials and their most relevant properties.

Stones	Sandstone	grading 8/11 mm	Density 2730 kg/m^3	PSV (Polished Stone Value) 54
Sand	Natural Sand	grading: fraction 180 – 500 µm: ca. 50%		Density 2655 kg/m^3
Filler	Limestone Filler	grading: < 63µm: 88 %	Density 2580 kg/m^3	Hydrated Lime: 30%, BN=61
Bitumen	SBS modified	Pen 25^{o}C: 50 –70 $T_{r\&b}$: > 90 ^{o}C	Density 1050 kg/m^3	Elastic recovery at 25^{o}C: > 75% Fraass Breaking Point < -15^{o}C Ductility at 5^{o}C: > 50 cm
Fibres	Cellulose		Density 1700 kg/m^3	

Table 1. Materials and properties

In table 2 the mix composition of the Bridge deck mixture is given.

Passing sieve	%
C16	100
C11,2	96
C8	27
C5,6	16,5
2mm	14
0,063mm	5,3
Bitumen (at 100%)	12,0
Fibres (in)	0,50

Table 2. Mix composition of the Bridge deck mixture

In table 3 a overview is given of the test carried out and the used test conditions.

Test	Norm
Resistance to deformation: Triaxial test	EN 12697-25
Resistance to crack propagation: Semi Circular Bending Test	prEN 12697-44
Resistance to fatigue: Four point bending test	EN 12697-24
Stiffness: Four point bending test	EN 12697-26

Table 3 Test program and norms

The results of this research and the testing to the specifications are presented in chapter 5.

5. MECHANICAL RESULTS

In the research the resistance to deformations as well as the sensitivity to cracking have been determined and compared to the requirements.

Property	Test method	Test conditions	Requirement
Resistance to deformation	Triaxial test	25ºC	min. 1.8µm/ms
Cracking sensitivity	Semi-Circular Bending test (SCB)	0ºC 15ºC	min. 18.8 kJ/m³ min. 17.2 kJ/m³

Table 4: Requirements for Mastic Asphalt on steel Bridge decks

The requirements are based on Mastic Asphalt surface paving used on steel bridges for motorways by the Department of Public Works in the Netherlands.
The new developed mixture met all the requirements with plenty of margin to spare.
In addition, stability, fatigue sensitivity and the stiffness of the new type of asphalt have been tested.
The results have been compared to the Mastic Asphalt normally used for these applications. The results are presented below.

Test method	Test specs	MA 8 [1]	MA 11[2]	MA 11[3]	Bridge deck mix Heijmans
Resistance to deformation (Triaxial test)	fc [µm/m] 40°C	0.78	-	0.80	0.58
Fatigue sensitivity (4-point bending test)	ε4 [µm/m], 5°C, 10Hz, $N=10^4$	900	550	350 [5]	1050
	ε6 [µm/m], 5°C, 10Hz, $N=10^6$	450	200	150 [5]	500
Stiffness (4-point bending test)	E* [MPa], 5°C 8Hz [4]	8300	16200	21000[5]	5700
	E* [MPa], 20°C 8Hz [4]	2100	4800	8200 [5]	1700
Resistance to crack propagation (SCB test)	W_t [kJ/m³], 0°C				40,9
	W_t [kJ/m³], 15°C				23,7

Table 5: Mechanical properties of the new mix, compared to several types Mastic Asphalt

[1]: SBS modified Mastic Asphalt applied at the Moerdijkbrug, a high loaded steel bridge in the Netherlands lit.[2]
[2]: SBS modified Mastic Asphalt as applied in Germany Lit.[1].
[3]: Mastic Asphalt at hard bitumen base (6.5% Bitumen 20/30) corresp. the German regulations ZTV-Asphalt-StB
[4]: At little strains
[5]: From literature and nomograms Lit. [2], [3], [4], [5].

The above showed results make clear that the new developed mixture has an exceptionally high fatigue resistance at high strain levels. It is a known fact that high strain levels occur especially above the cross girders on steel bridge decks. These are also the areas in which the Mastic Asphalt cracks first (see pictures). Due to the very flexible binder and high binder content, the new asphalt mixture will have a considerably longer lifespan with regard to cracking.
From the results it can be deduced that regarding stiffness the new asphalt mixture is less rigid than Mastic Asphalt. This means the contribution of the asphalt layer to the rigidity of the bridge deck is less. This would give higher deflections in the Bridge deck. However, because of the longer life span of the new Asphalt layer the support of the Asphalt layer to the steel deck will exist longer. So, over the total lifespan, the contribution of the new top layer to the steel deck wil have a positive effect.
The gained result cleared the way for the first application.

6. FIRST APPLICATION IN PRACTICE

The new type of asphalt surface layer was proposed to be applied on the steel bridge crossing the Juliana canal near Roosteren (Province of Limburg) in the south of the Netherlands. The span of the Bridge is approx. 100 m, the width of the Deck is 13 m. The thickness of the steel deck is 10 mm.
The Bridge forms an important element in the route of industrial traffic from Belgium, passing The Netherlands to Germany.

6.1 Construction build-up.

With the new asphalt mixture a construction build-up has been designed comparable to a Mastic Asphalt bridge deck construction.
After removal of the existing asphalt, the bridge deck first has to be blasted and then a primer coating will be applied. Some strips are connected at the top of the steel deck, which give a rather big discontinuity in the asphalt layer thickness.

Figure 4: Levelling the steel strips

Figure 5: Melting the membrane

Therefore the corners next to these strips have to be filled out / levelled with a flexible two-component mortar which adheres to the bituminous primer. Next a bridge deck isolation membrane will be applied over it all. This will protect the steel deck to (salt) water.
Directly on this membrane the asphalt surface layer can be laid and compacted.
At some places, mostly under the bow of the bridge, vertical columns are connected to the bridge deck. Around these places it is impossible to lay and compact asphalt. Therefore these places, where no traffic loads will occur, have to be filled with Mastic Asphalt afterwards.

6.2 Test sections

The abovementioned method of working was tested and optimized beforehand by means of the realisation of several test sections, partly on steel test plates. On these plates, the complete construction and the method of working were tested: blasting, applying primer, filling-out strips, melting the membrane and laying and compacting the asphalt. Especially the optimum compacting method of the asphalt has been determined in this way; type and weight of the rollers and the number of roller runs.
Drilled cores out of the test construction taken afterwards showed a good bonding and melting of the membrane, to the steel deck, as well as to the applied asphalt top layer.

6.3 Realisation

The results of the mechanical research and the results of the test sections gave the road administration enough bases for authorising the application of the new material. In the course of September 2005, the old surface layer was removed and the steel surface was cleaned completely and primed. Next the filling out and the isolation membrane were applied. On 19th September the new asphalt surface top layer was applied. Just before rolling fine material was spread on the new asphalt surface to take care for a good skid resistance. Both the main driving lane as well as the bicycle lanes next to it were laid with the new asphalt. Laying the new asphalt took approximately half a day. After finalizing with markings and Mastic Asphalt the edges, the bridge was opened for traffic after only a few days.

Figure 6: Paving the asphalt at the membrane

Figure 7: Compacting like normal asphalt

Figure 8: Texture like SMA

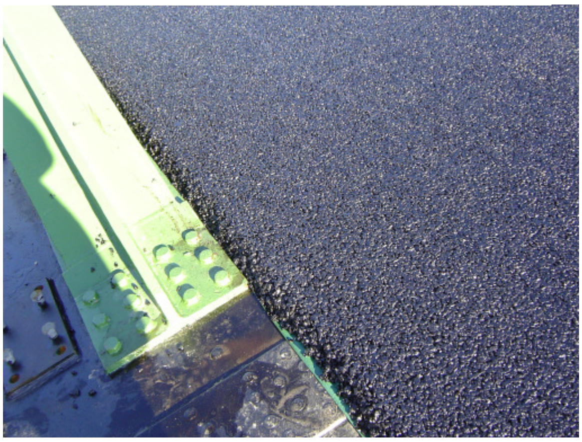

Figure 9: The new paved steel bridge

In the meantime also the skid resistance of the surface has been measured; it resulted in a value of about 0.50 (measured with test 150 conform the national Standard RAW 2005), measured after two weeks. An excellent value for a mixture so rich in binder. The skid resistance during lifetime must be above the value of 0.38.

7. CONCLUSIONS

Within this research project a new type asphalt mixture is developed for application on steel bridge decks. It concerned a type of asphalt with very specific characteristics; very flexible in horizontal direction and less sensible to fatigue, yet stable especially in vertical direction. The new type of asphalt is an alternative for the Mastic Asphalt used so far.

The first application has taken place in September 2005. Nowadays, after more then two years, the bridge deck is in excellent condition. Even, where the connecting roads to the bridge show already rutting because of the heavy traffic, the bridge deck itself shows no deformation at all.

The researchers as well as the Centre for Traffic and Navigation are very satisfied about the result achieved. The laboratory tests herewith and the practice prove that an exceptional flexible and stable asphalt mixture can be produced and laid with the speed of normal asphalt. This reduction of construction time gives an extra advantage in relation to Mastic Asphalt.

The result clears the way for wider applications.

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