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Research Article

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High Modulus Asphalt Concrete: a Long Life Asphalt Pavement

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Abstract

This study uses a layered elastic analysis and a computational model to evaluate the fatigue life of the base layer stabilized with conventional bitumen 60/70 compared with a base layer stabilized with high modulus bitumen 13/22 for a lifetime of 20 years. This study makes a comparative between conventional bitumen and high modulus asphalt concrete in terms of fatigue or cycles to failure of both asphalts at 15°C. The result of this study shows that HMAC 13/22 has much longer fatigue life compared with conventional bitumen 60/70, in some cases even four times longer; the lifetime of the pavement increases considerably with the use of HMAC in the base layer of pavement according to mechanical calculations. HMAC raise elastic modulus of middle layer. HMAC can also improve stress state of pavement structure, reduce shear strain and asphalt pavement rutting.

Keywords: Airports; Fatigue; High modulus asphalt concrete; Lifetime

Introduction

High Modulus Asphalt Concrete (HMAC) originated in France in the early 1980s. HMAC is a mixture of asphalt concrete fabricated for its use in the base course of asphalt pavements. HMAC has closed structure with comparatively large content of bitumen. It has been shown [1] that hard bitumen increases the mixtures resistance to rutting. However large content of bitumen assure workability, fatigue durability and water resistance.

One study [2] showed that HMAC has higher rutting resistance and higher complex modulus compared with styrene–butadiene–styrene (SBS) modified binders (2.7–3.0 times higher) and even higher than conventional bitumen. It has also proved that [3] rutting resistance of HMAC is higher than that of the SBS modified asphalt mixtures or conventional mixtures. The thickness of the base course stabilized with HMAC is 1/4–1/3 times lower than the traditional base course resulting significant saving of asphalt binder and aggregates [4].

With these mentioned properties, the concept of a long life pavement came up initially from the HMAC [5] and is this concept the main idea of this study. The definition of the long life pavement is a pavement that can last at least more than 40 years without major structural strengthening. The basic idea of a long life pavement is to increase the layer moduli and/or thickness of asphalt base layer, and then reduce the potential of structural distresses by minimizing the tensile strain at the bottom of the AC layer and the compressive strain on top of the subgrade. In this way, one can confine all the major pavement distresses within the surface layer. Only periodical rehabilitation for the surface layer might be needed for the entire design life.

Laboratory Test

Materials and sample fabrication

In this study two types of asphalt binders were under investigation, the conventional bitumen 60/70 and the HMAC 13/22 (Table 1). The bitumen content of the mixture in the conventional bitumen sample was 5, 5% and the void air 4, 5%. The optimum asphalt content in the samples of HMAC at the 5, 1% of air void were 4, 5%. The compaction and estimate mixing was done in the test following the Marshall test and the Swedish normative in compaction for bitumen samples. The mixing temperature for conventional bitumen was 165°C and 185°C for HMAC. The test samples used in the laboratory to obtain the dynamic modulus of the mixtures had geometry of 150 mm of diameter and a height of 50 mm for both conventional bitumen and HMAC. The

	B13/22		B60/70	
	Min	Max	Min	Max
Penetration at 25°C, 0.1 mm	13	22	150	200
Softening point °C	60	72	40	47
Ductility at 25°C	10	-	180	-
Fraas temperature, °C	-	+1	-	-16

Table 1: Main properties of the binders used in this research.

Sieve (mm)	25	20	12,5	8	4	2	0,5	0,125	0,25	0,063
% Passing	100-100	75-95	55-75	40-60	25-42	18-32	7-18	4-12	3-8	2-5

Table 2: Grading curve for conventional bitumen 60/70.

Sieve (mm)	25	20	12,5	10	5	2,5	0,63	0,32	0,16	0,08
% Passing	100-100	80-95	65-80	60-75	43-58	30-45	15-25	10-18	8-14	7-10

Table 3: Grading curve for high modulus asphalt concrete 13/22.

samples were compacted using a Marshall compactor. The grading curve of the asphalt mixes that were used in this research are the following:

For both, HMAC and conventional bitumen are these grading curves the usual ones that are used in Sweden for the base course in drainage curves. All the mixes has been compacted to the same level leading to close void contents (from 3,8 to 5,0%) for all the test samples (Tables 2 and 3).

Dynamic modulus test

The linear visco-elastic properties of the asphalt mixes samples of this research were measured from the dynamic modulus test in the asphalt lab of a geotechnical company, GEOCISA. All the tests were done at local ambient temperature, about 15°C, for conventional bitumen B60/70 and for the HMAC. Every test was performed at three different

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frequencies (10, 0, 5 and 0, 1 Hz). The master curve was represented by obtaining the dynamic modulus data at different frequencies. The explanation to the much higher dynamic young modulus of HMAC at high temperatures can be due to the high boiling point binder what increases the stiffness of the HMAC and in this way increases the linear visco-elastic properties of the asphalt mixtures.

Test results

The values that were obtained in the lab with the dynamic press can be seen in the Table 4.

Methodology of the Study

Fatigue test with a mechanical-computational model

The aim of this research work is to evaluate the fatigue in the base layer of the pavement depending on the CBR, annual departures and if the base layer is stabilized with conventional bitumen or with high modulus asphalt concrete [6-10]. For fatigue calculation this study uses a mechanical-computational model in order to carry out an iterative process that gives the following steps: calculation of stress at critical points in the pavement during the experimental time, calculation of the number of cycles to failure (Nf) during the experimental time, calculation of the damage factor (n/Nf) during the experimental time, sum of the factors of fatigue damage produced in the pavement, increasing or decreasing the thickness of the layer if D, total damage to the pavement, is not close to 1 and as final step determine the final calculation of the cross section. To perform all these calculations have been used the EVERSTRESS program. The calculations give the number of times (n) that the aircraft design, Airbus 380, can use the runway until the failure of the pavement [11]. The following diagram is a schema of the mechanical-computational model that has been used in this study (Figure 1).

	Conventional Bitumen 60/70		High Modulus Bitumen 13/22	
Tested Dynamic Modulus (MPa) **Test at local ambient temperature**	6021,13	Mean Value: 6.172	13990,5	Mean Value: 13.497
	6324,35		14006,6	
	---		12495,4	

Table 4: Tested Dynamic Modulus at local ambient temperature, at 15°C, for 60/70 and 13/22 bitumen.

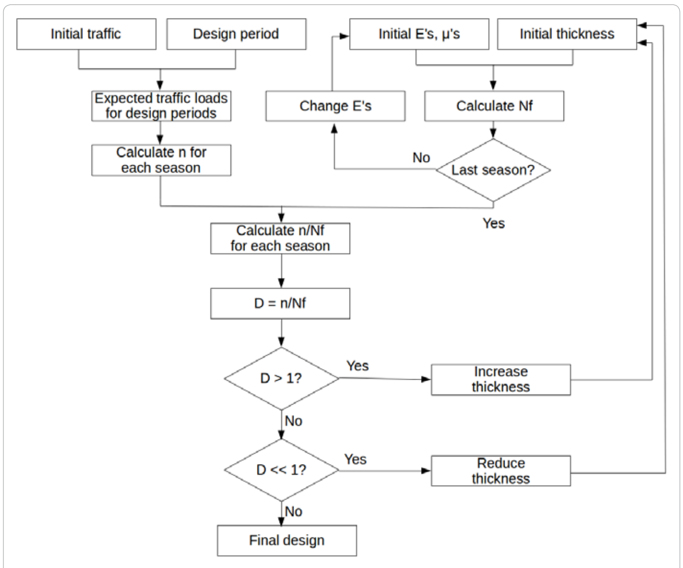

Figure 1: Flow Diagram of the Mechanistic-Empirical design procedure of the test.

Calculation data

In this investigation has been set the thickness of the surface course in 60 mm, and the sub-base course in 250 mm, for calculating later the base course thickness for HMAC and conventional bitumen with the program LEDFAA by considering the dynamic young modulus of the Table 4. Initially the thickness was selected as the minimum thickness allowed according to the type of materials used for the pavement and the operating float. The critical stress in the pavement structure is determined at different positions that can be seen in the above figure and these positions have been used also in the program for the stress analyses. The number of load cycles to fatigue failure (Nf) were computed using failure criteria. In a multilayer model the mechanical characterization of materials is given as a function of the elasticity modulus (E) and Poisson's ratio (υ). Hence the accurate estimation of these parameters is one of the most important data to take into account. The Elasticity Modulus in bituminous mixture is a function of both the temperature (weather conditions) and the total thickness of the mixture. It has been estimated that the temperature gradient affects mainly to the first superior 15 cm pavement. A thermal hypothesis applies to: winter, spring and summer-autumn [12] (Tables 5-7).

Strains and stresses

To calculate the stresses and strains in different parts of the pavement, the EVERSTRESS program has been used. The calculations were performed for different CBR and different number of annual departures. With this data and the fatigue formula 1 it is possible to calculate the number of passes on the pavement until failure. In that way the next step is calculating the life time of the pavement with both high modulus bitumen and conventional bitumen (Figure 2).

With the EVERSTRESS program was calculated the stresses and strains for CBR 5, 10, 15, 20 and 25.

An analysis was done to test the deformations in a base layer stabilized with conventional bitumen compared with high modulus asphalt concrete. From the result obtained in the test for the N values has been calculated the strains with the following fatigue formula 1.

$$\varepsilon_{xx,}\ \varepsilon_{yy} = 6{,}925.10^{-3} N^{-0{,}27243} \qquad (1)$$

With the test the following data for Nf was obtained, and this were the data used for calculating the strains (Formula 1) (Tables 8-13).

Aircraft Operation	Total Aircraft Weight (tons)	Tire Inflation Pressure (MPa)	Speed (km/h)
Take-off	560	1.33	140
Landing	386	1.33	120

Table 5: Design aircraft data for A380.

Layer	Poisson's Ratio	Thickness (cm)	Moduli (MPa)
1	0.33	13	6000
2	0.33	30	5000 (60/70); 12000 (13/22)
3	0.35	25	500
4	0.35	---	100

Table 6: Pavement Layer Data.

	1200 Annual Departures	6000 Annual Departures	15000 Annual Departures	25000 Annual Departures
CBR 5	48,24 cm	56,90 cm	67,19 cm	68,91 cm
CBR 10	20,7 cm	24,59 cm	29,38 cm	28,70 cm
CBR 15	13,62 cm	16,27 cm	20,17 cm	16,97 cm
CBR 20	10,99 cm	11,91 cm	16,61 cm	14,09 cm
CBR 25	---	---	12,42 cm	10,90 cm

Table 7: Calculated base course thickness depending on annual departures and CBR.

Analysis of the mechanical characteristics of the conventional bitumen compare with high modulus asphalt concrete

With the obtained data for the dimensions of the layers for the runway, specially the thickness of the base course that has been calculated with the LEEDFAA and after this, the obtained data from the EVERSTRESS for the number of load cycles to fatigue failure (Nf)

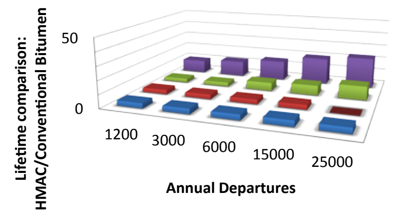

Figure 2: Life time comparison High Modulus/conventional bitumen.

	1200	3000	6000	15000	25000
CBR 5	---	---	---	---	---
CBR 10	390 752	517 811	650 495	1 184 312	1 089 936
CBR 15	184 496	227 208	267 529	---	382 770
CBR 20	---	154 177	177 969	285 459	241 709
CBR 25	---	---	---	215 733	162 157

Table 8: Number of passes in the runway with conventional bitumen until runway failure. (Table: CBR/Annual Departures).

	1200	3000	6000	15000	25000
CBR 5	---	---	---	---	---
CBR 10	1 512 831	2 080 471	2 690 888	5 265 524	4 798 773
CBR 15	628 795	797 138	960 383	1 762 058	1 442 878
CBR 20	---	507 313	597 118	1 076 466	845 713
CBR 25	---	---	---	692 061	137 217

Table 9: Number of passes in the runway with High Modulus Asphalt Concrete until runway failure. (Table: CBR/Annual Departures).

	1200	3000	6000	15000	25000
CBR 5	---	---	---	---	---
CBR 10	3,78	4,02	4,14	4,45	4,40
CBR 15	3,41	3,51	3,59	---	3,77
CBR 20	---	3,29	3,36	3,77	3,50
CBR 25	---	---	---	3,21	0,85

Table 10: Comparison of number of passes in the runway until runway failure. High Modulus Asphalt Concrete vs conventional bitumen. (Table: CBR/Annual Departures).

	1200	3000	6000	15000	25000
CBR 5	---	---	---	---	---
CBR 10	163	86	54	39	22
CBR 15	77	38	22	---	8
CBR 20	---	26	15	10	5
CBR 25	---	---	---	7	3

Table 11: Life time for the pavement with a stabilized base with conventional bitumen. (Table: CBR/Annual Departures).

	1200	3000	6000	15000	25000
CBR 5	---	---	---	---	---
CBR 10	630	347	224	176	96
CBR 15	262	133	80	---	29
CBR 20	---	85	50	36	17
CBR 25	---	---	---	23	10

Table 12: Life time for the pavement with a stabilized base with High Modulus Asphalt Concrete. (Table: CBR/Annual Departures).

	1200	3000	6000	15000	25000
CBR 25	3,86	4,03	4,14	4,51	4,36
CBR 20	3,4	3,5	3,6		3,6
CBR 15	3	3,2	6,33	7,6	10,4
CBR 10	10	12	15	20	23

Table 13: Life time comparison of High Modulus Bitumen vs Conventional Bitumen. (Table: CBR/Annual Departures).

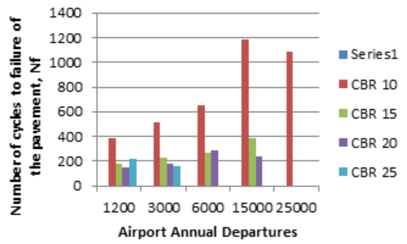

Figure 3: Number of cycles to failure for conventional bitumen.

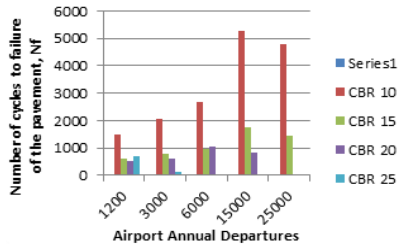

Figure 4: Number of cycles to failure for High Modulus bitumen.

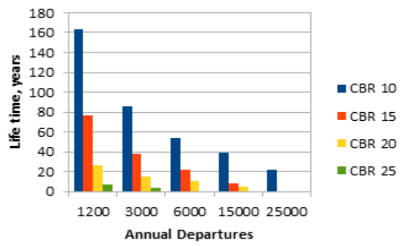

Figure 5: Life Time for a pavement with base stabilized with conventional bitumen.

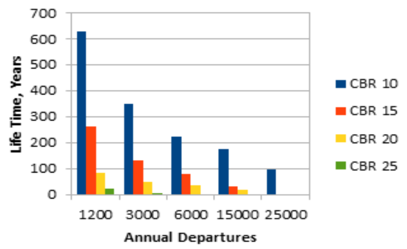

Figure 6: Life Time for a pavement with base stabilized with high modulus bitumen.

for conventional bitumen and high modulus bitumen an analysis and comparison in terms of fatigue and long life of both bitumen [13]. This data has been represented in the following graphs and an analysis of the data has been done (Figures 3-6).

Conclusions

In this research two binders were tested, HMAC 13/22 and conventional bitumen 60/70. The results were compared and the binders were evaluated. The initial data were obtained from laboratory test, the thicknesses of the layers were calculated using LEDFAA, and computational calculations were performed with EVERESTRESS program. The analysis of the results allowed the following statements to be made:

1. This study compares the behaviour of the conventional bitumen 60/70 and the high modulus asphalt concrete 13/22 at a temperature of 15°C on the basis of a computational calculation and two variables: annual departures (1200, 3000, 6000, 15000, 25000) and CBR (10, 15, 20, 25). This study found that the life time of the high modulus asphalt concrete 13/22 is 4 times longer than the conventional bitumen 60/70 for soil CBR =10 and 2 times longer for soil = CBR 25. So there is a clear advantage in terms of life time of using High Modulus Asphalt Concrete specially for soil CBR = 10. The study shows also that the annual departures give the same results for both 60/70 and 13/22 bitumen.

2. In the computational model with EVERSTRESS, the longitudinal strains are generally greater than the transverse strains. This study shows that the calculated strains are systematically greater than the measured values at 15°C.

3. The study has found large differences in the strains between the sections of different thicknesses what indicate the significant effect that the thickness of the asphalt layer has taking into account the annual departures and CBR. This has naturally a high relation also with the number of cycles N at which the structure fails as it is shown in the Figures 3 and 4.

4. From an economical point of view, this study shows a clear advantage of using HMCA for the base course, in the case of CBR =10. Taking into account that the high modulus bitumen is 30% more expensive than the conventional bitumen and with the use of High Modulus Asphalt Concrete for the base layer of the pavement we obtain a reduction of 20% of the thickness of the base course, Figure 5 and 6 show that the use of High Modulus Asphalt Concrete is still very advantageous economically. According to the results obtained in this article the number of cycles to failure (Nf) increase considerably for the high modulus bitumen and increase in the same proportion the number of years that the pavement can be used with minor maintenance.

5. HMAC and conventional bitumen behaved differently in terms of stiffness and elasticity. HMAC in the study had higher complex modulus at all evaluated temperatures and viscosity was also higher than in conventional bitumen 60/70.

6. In this research has been observed that the HMAC´s dynamic young modulus at high temperatures is 50% higher than the conventional bitumen mixture's dynamic young modulus. Rutting resistance of HMAC is twice as high temperature compare to the conventional bitumen mixtures, and the fatigue resistance is 5–10 times higher. Besides it is interesting to add that the research of HMAC at high temperature, made by Jaczewski [14] in Poland, presented similar results that those that are shown in this research and it is that the usage of HMAC in asphalt pavement structure allows reduction in comparative deformations and slower deformation timing, at the same time increasing rutting resistance and durability.

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