Effect in the high modulus asphalt concrete with the temperature

Maria Inmaculada García Hernández[1, a], Abbas Shahri[1, b]

[1] *Construction Engineering, Uppsala Universitet, SE-751 21 Uppsala, Sweden*

[a] mighaero@yahoo.es
[b] shahri.abbas@gmail.com

Digital Object Identifier (DOI): dx.doi.org/10.14311/EE.2016.046

ABSTRACT

SYNOPSIS

The use of the High Modulus Asphalt Concrete in the base course of airport pavements is not of recent utilization, but at present there is a considerable gap in the regulation for the use of this bitumen. The main objective of this paper is to present the results of the research that has been done using the experimental dynamic modulus of different mixtures of conventional bitumen with different penetration index B40/50, B60/70, B100/150, B150/200 and the high modulus bitumen B13/22 to calculate the percentage of reduction in thickness of the base course in airport pavements when is used High Modulus Asphalt Concrete (HMAC) compare with conventional bitumen mixtures and is also taken into account the temperature. In order to obtain the reduction in thickness depending on the temperature and the use of HMAC, the tests have been performed at the different temperatures -20°C, -10°C, 0°C, 10°C, 20°C and all the results in this paper are presented for these temperatures.

To perform the calculations of this research the Airbus A380 has been taken as Aircraft Design.

Keywords: Runways, Airports, High Modulus Asphalt Concrete.

Keywords: Design of pavement, Low-Temperature, Mechanical Properties, Modified Binders, Social and economic cost-benefit analysis

1. INTRODUCTION

The design of roads is made taking into account the number and types of heavy vehicles circulating. The design of airport runways is made basically depending on four factors: Operational Capacity, Runway Length, Airport Classification/Design Standards and Wind Coverage. For the design of both runways and roads, it is very important the material selection. And this material selection depends on several factors, for example soil properties, water condition or traffic type.

In the eighties, a French company started to develop what today is known as High Modulus Bitumen. Nowadays, HMAC has made an important contribution to the structural design of pavements due mainly to its good anti-rutting properties of the HMAC.

HMAC allow the construction of base layers of very resistant pavements to be more rigid (higher modulus) and more resistance to fatigue. HMAC allows the building of base layers of pavements which are longer-lasting, or to decrease the thickness of pavements manufactured with conventional bitumen, with the resulting savings. For instance, the use of HMAC in pavement reinforcement has the advantage of avoiding the complete removal of old bituminous layers, as HMAC make possible to reduce the thickness of the pavement [1].

At present despite all the advantages of the High Modulus Asphalt Concrete there is a considerable gap for the use of HMAC and the real reduction in thickness for the base layer depending on the temperature with the use of HMAC compare with conventional binders. This paper shows the results of the experimental research that has been done to calculate the reduction in thickness of the base layer with HMAC compare to a base layer with conventional bitumen for runway pavements at the different temperatures -20°C, -10°C, 0°C, 10°C, 20°C. The program used in this research to calculate the thickness of the layers for a runway pavement has been LEDFAA 1.3. LEDFAA is a Federal Aviation Administration program and uses Layered Elastic Design (LED) methods for airport pavements design.

Apart that the thickness of the layer can vary depending on the temperature, viscous elastic properties of asphalt materials are significantly influenced by temperature. The temperature is a key factor for selecting the binder type for the asphalt mixture. The binder which is sufficiently stiff at high temperature often is not elastic enough at low temperatures [2].

2. HIGH MODULE MIXTURES

HMAC began to be used in France in the 1980´s. Those mixtures were stiffer than traditional ones and had better mechanical behaviour relative to the fatigue cracking and permanent deformations. Since 1980´s, HMAC have been used to reinforce old pavements or in the base layer to obtain economical benefits by reducing thickness. The main objective of this research is to calculate the real reduction in thickness of the base layer with HMAC compare with conventional binder.

In the 1990´s the use of the HMAC for the base layer of roads and runways had increased. HMAC has made an important contribution to the mechanical performance of the pavements, mainly because of the good anti-rutting properties of the binders [3].

HMAC is designed for its use in base pavements. It has closed structure with comparatively large content of bitumen. Hard road bitumen grades are applied, mainly 10/20, 15/25, 20/30 and polymer modified bitumen. Hard bitumen assures the mixtures resistance to rutting. However large content of bitumen assure workability, fatigue durability and water resistance [4].

HMAC is a type of bituminous mixture that incorporates continuously graded aggregates, typically having 32 to 35 % of material less than 2 mm and 7 to 8 % less than 0,075 mm. The maximum aggregate size is 10, 14 or 20 mm for layers whose thickness' varies from 6 to 10 cm, 7 to 12 cm and 10 to 15 cm.

The binder that has been used for the HMAC is B13/22, and its main characteristics compare with a conventional bitumen can be seen in the table 1.

3. METHODOLOGY OF THE STUDY

3.1 Bituminous Binder Test

This research is completely based on experimental results obtained in lab-test for about 164 samples of bituminous mixtures that were tested in a servo-hydraulic and dynamic press with a climatic chamber which allowed us to obtain the dynamic modulus of the asphalt mixture to different temperatures. The test for every sample and every temperature has been performed 6 times to get a better value and avoid errors [5].

The test was done with different conventional binders (B40/50, B60/70, B100/150 and B150/200) and HMAC (B13/22) with different temperatures (-20°C, -10°C, 0°C, 10°C, 20°C). The goal of these tests was to evaluate the performance of the conventional binder mixtures and compare them with the performance at the same temperature of the HMAC.

The results of these test are presented in the figure 1.. We could see that the dynamic modulus of the HMAC is three times larger than those mixtures of the conventional binders. However, the HMAC shows a slightly decreasing smaller dynamic modulus in the comparison with those conventional binders mixtures that have a higher penetration index. The penetration value of the HMAC is lower than 30 mm at 25°C. The fraas temperature of the HMAC is +1°C, whereas B60/70 (PG 64-22) binder is -8°C indicating that the resistance to low temperature cracking decreases as the binder stiffness increases.

Table 1. Main properties of the bitumen used in this research.

	B13/22		B40/50		B60/70		B100/150		B150/200	
	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
Penetration at 25°C, 0,1 mm	13	22	40	50	60	70	100	150	150	200
Softening point °C	60	72	52	61	48	57	44	51	40	47
Ductility at 25°C	10	-	70	-	90	-	130	-	180	-
Fraas temperature °C	-	+1	-	-4	-	-8	-	-12	-	-16

3.2 Materials and sample fabrication

In the research five types of binders were used to produce the specimens that were tested, the conventional bitumen mixtures and the HMAC.

The penetration index of conventional binders were (B40/50, B60/70, B100/150 and B150/200) at different temperatures and with a mixture of high modulus to the same temperatures (-20°C, -10°C, 0°C, 10°C, 20°C). The conventional bitumen content in the samples were 5,5% and the void air 4,5 %.

The high modulus bitumen that was used in this research had a penetration of index B13/22. The optimum asphalt content in the samples of HMAC was 5,1 % and 4,5 % void air.

The test samples used in the laboratory for obtain the dynamic modulus of the mixtures had geometry of 100 mm of diameter and a height of 150 mm for both conventional binder and high modulus binder. The samples were compacted using a Marshall compactor.

The grading curves of the mixtures that are used in this research are the following:

Table 2. Grading curve for conventional asphalt mixture with 40/50, 60/70 and 150/100 binders.

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 3. Grading curve for high modulus asphalt concrete with 13/22 binder.

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

For both, HMAC and conventional mixtures 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.

3.3 Dynamic modulus test

The linear viscoelastic properties of the mixtures 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 during one year and the goal of all these tests were to obtain the values of the dynamic young modulus at five different temperatures (-20 °C, -10°C, 0°C, 10°C, 20°C) for different conventional binder mixtures (B40/50, B60/70, B100/150 and B150/200) and for the HMAC to calculate the reduction in thickness of the base layer depending on the temperature (-20°C, -10°C, 0°C, 10°C, 20°C) when the pavement is constructed with HMAC instead of conventional binder mixtures (B40/50, B60/70, B100/150 and B150/200).

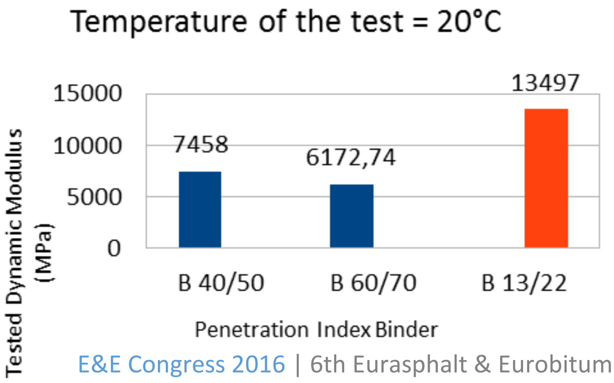
At each temperature, the tests were performed at three different frequencies (10, 0.5 and 0.1 Hz). The master curve was represented by obtaining the dynamic modulus data at different temperatures and different frequencies.

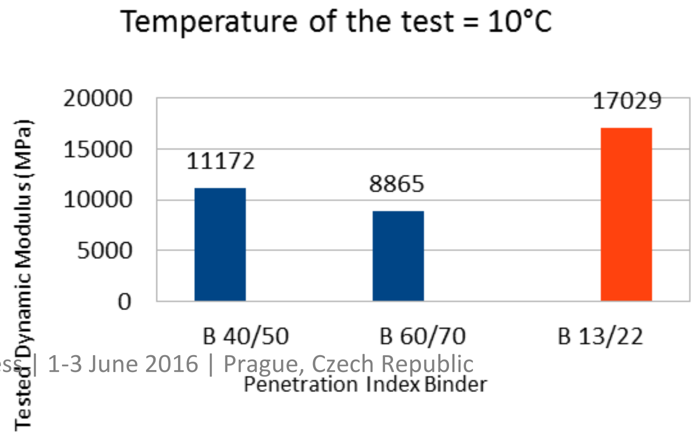
The explanation to the much higher dynamic young modulus of HMAC at high temperatures can be due to the high softening point binder what increases the stiffness of the HMAC and in this way increases the linear visco-elastic properties of the mixtures.

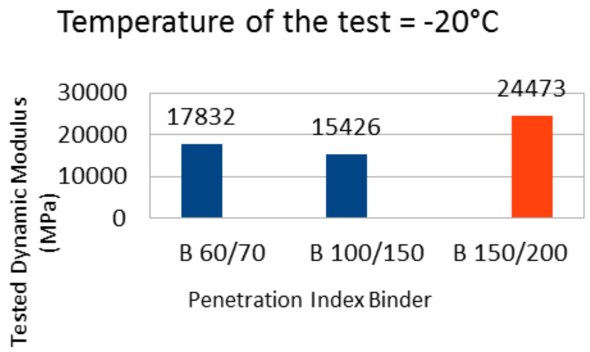
3.4 Test Results

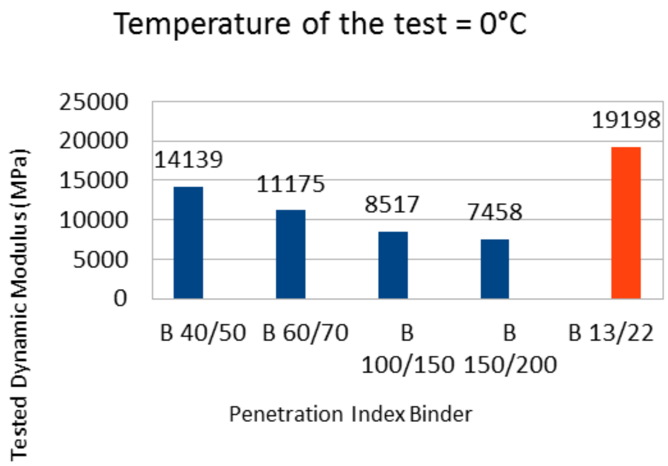
The values that were obtained in the lab with the dynamic press with a climatic chamber can be seen in the following diagrams, figure 1. The elastic modulus of the HMAC can be always seen in all the diagrams with a different colour. It has been done a diagram with the results obtained in the lab of the dynamic young modulus for every temperature.

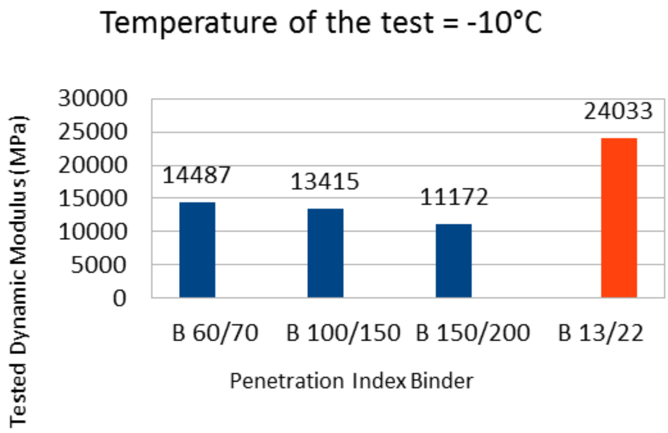
Figure 1. Tested Dynamic Modulus at different temperatures for different asphalt mixtures.











The results show that at higher temperature, the elastic modulus of the mixtures is higher and consequently the thickness of the base course will be thinner.

3.5 Calculated data

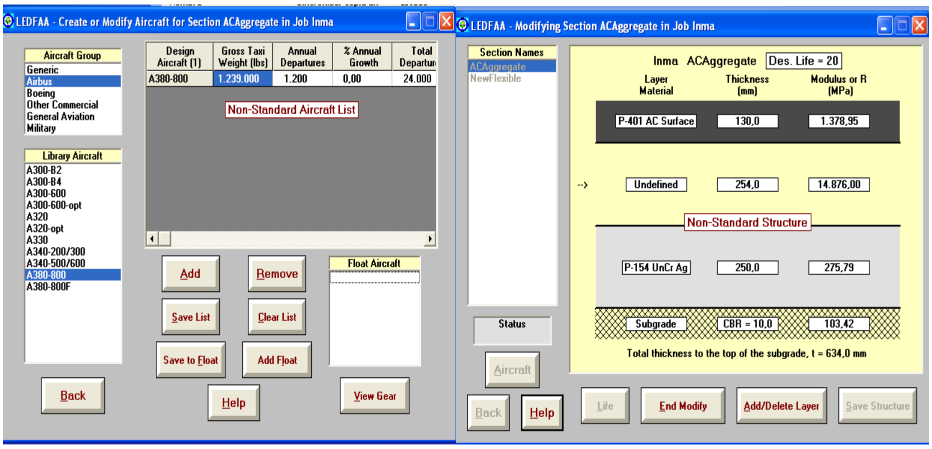
With the results obtained in the tests has the thickness of the base course of a pavement runway with an Airbus A380 as aircraft design been calculated. LEDFAA was the simulation program that was used in this research for calculating the thickness of the base course of the pavement.

The procedure for the calculations in this investigation has been set the thickness of the surface course in 60 mm, and set the sub-base course in 250 mm, for calculating later the base course thickness for HMAC and conventional bitumen mixtures with the program LEDFAA by considering the dynamic young modulus obtained in the tests. The goal was compare the thickness of the base course with HMAC and the thickness of the base course with conventional bitumen.

The materials that have been taken from the FAA material specifications to use them in the LEDFAA program where the P-401 that is an asphalt mixture and consists of mineral aggregate and bituminous material mixed in a plant according to specifications and the P-154 that is a sub-base course composed of granular materials.

The calculations were made for different conventional bitumen mixture and high modulus asphalt concrete, to experimentally obtain the percentage of thickness reduction of the base layer stabilized with high modulus asphalt concrete with respect to those stabilized with conventional bitumen. The calculations were carried out as reflected in the tables 4-18 that can be seen for different number of annual departures and different CBR of the ground.

Figure 2. LEDFAA Program



3.5.1 Average Temperature = 20°C

The dependence of the elastic modulus of the mixture and the composition ratio of the mixture (aggregates, bitumen, voids in mix) has been already proved in different researches [6]. If the bituminous mixture has a low dynamic elastic modulus, below 10 MPa, or the mixture is subjected to high temperatures and/or long periods of application of load, young module does not depend only on the parameters listed but also the nature and size of aggregates. Other factors such as the method of mixing and compaction can also affect the results [7].

Taking into account all these circumstances the tests have been performed for the same samples at different temperatures for only introduce the variable of the temperature in the mixtures.

With the results obtained in the lab for dynamic young modulus at different temperatures has been calculated with the LEDFAA program the thickness of the base layer for different operative conditions. The calculated data with the obtained dynamic young modulus from the test at the temperature of 20°C are the following:

Table 4. Thickness of the base course for Airports with 1.200 annual departures and an average temperature of T = 20°C for different types of mixtures.

CBR	5	10	15	20	25	30	35
B40/50	364 cm	176 cm	126 cm	96 cm	71 cm	X	X
B60/70	378 cm	171 cm	115 cm	81 cm	53 cm	51 cm	X
HMAC	287 cm	137 cm	96 cm	84 cm	65 cm	X	X

Table 5. Thickness of the base course for Airports with 6.000 annual departures and an average temperature of T = 20°C for different types of mixtures.

CBR	5	10	15	20	25	30	35
B40/50	433,2 cm	204 cm	145,8 cm	113,5 cm	89,4 cm	68,8 cm	X
B60/70	454,5 cm	201,8 cm	137,1 cm	101 cm	73,8 cm	71,1 cm	X
HMAC	341,9 cm	159,2 cm	112,4 cm	85,6 cm	64,6 cm	62,5 cm	X

Table 6. Thickness of the base course for Airports with 25.000 annual departures and an average temperature of T = 20°C for different types of mixtures.

CBR	**5**	**10**	**15**	**20**	**25**	**30**	**35**
B40/50	503 cm	233 cm	170 cm	130 cm	106 cm	85 cm	73 cm
B60/70	531 cm	234 cm	158 cm	120 cm	92 cm	69 cm	55 cm
HMAC	397 cm	182 cm	128 cm	100 cm	79 cm	61 cm	66 cm

Table 7. Thickness of the base course for Airports with 50.000 annual departures and an average temperature of T = 20°C for different types of mixtures.

CBR	5	10	15	20	25	30	35
B40/50	540 cm	249 cm	175 cm	139 cm	114 cm	93 cm	81 cm
B60/70	572 cm	251 cm	170 cm	129 cm	101 cm	78 cm	X
HMAC	426 cm	195 cm	136 cm	107 cm	86 cm	68 cm	57 cm

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3.5.2 Average Temperature = 10°C

With lower temperatures, according to the result obtained in the test, the possibility of reducing the thickness of the base course with the use of HMAC is reduced significantly.

The most immediate conclusion of the research is that the use of HMAC is very recommendable for countries with high temperatures, especially in terms of savings.

In addition to the factors mentioned for areas with very low annual temperatures if complete protection of ground foundation is needed, the thickness of the pavement should correspond to the depth of frost penetration. The Corps of Engineers has determined the allowable amount of frost penetration in the pavement.

Table 8. Thickness of the base course for Airports with 1.200 annual departures and an average temperature of T = 10°C for different types of mixtures.

CBR	**5**	**10**	**15**	**20**	**25**	**30**	**35**
B40/50	376 cm	181 cm	131 cm	130 cm	106 cm	85 cm	73 cm
B60/70	401 cm	182 cm	126 cm	94 cm	70 cm	68 cm	X
HMAC	316 cm	149 cm	106 cm	100 cm	62 cm	60 cm	X

Table 9. Thickness of the base course for Airports with 6.000 annual departures and an average temperature of T = 10°C for different types of mixtures.

CBR	**5**	**10**	**15**	**20**	**25**	**30**	**35**
B40/50	376 cm	181 cm	131 cm	130 cm	106 cm	85 cm	73 cm
B60/70	401 cm	182 cm	126 cm	94 cm	70 cm	68 cm	X
HMAC	316 cm	149 cm	106 cm	100 cm	62 cm	60 cm	X

Table 10. Thickness of the base course for Airports with 25.000 annual departures and an average temperature of T = 10°C for different types of mixtures.

CBR	**5**	**10**	**15**	**20**	**25**	**30**	**35**
B40/50	436 cm	205 cm	149 cm	118 cm	97 cm	79 cm	69 cm
B60/70	468 cm	210 cm	145 cm	111 cm	86 cm	66 cm	53 cm
HMAC	366 cm	170 cm	121 cm	95 cm	75 cm	59 cm	63 cm

Table 11. Thickness of the base course for Airports with 50.000 annual departures and an average temperature of T = 10°C for different types of mixtures.

CBR	**5**	**10**	**15**	**20**	**25**	**30**	**35**
B40/50	467 cm	219 cm	157 cm	126 cm	104 cm	86 cm	76 cm
B60/70	503 cm	225 cm	154 cm	119 cm	94 cm	74 cm	X
HMAC	393 cm	182 cm	128 cm	101 cm	82 cm	66 cm	55 cm

3.5.3 Average Temperature = 0°C

Low temperatures and the possible presence of frost on the pavement make the runway surface slippery. Therefore would it be good to include materials in the surface layer to increase the rolling friction coefficient [8] in addition to use the antifreeze glycol.

For an airport with different annual operations, different CBR (5, 10, 15, 20, 25, 30, 35) and different binders (B40/50, B60/70, B110/150, B13/22) has been calculated the thickness of the base course according to the dynamic young modulus of the asphalt mixture that was obtained in the lab.

Table 12. Thickness of the base course for Airports with 1.200 annual departures and an average temperature of T = 0°C for different types of mixtures.

CBR	5	10	15	20	25	30	35
B40/50	285 cm	144 cm	106 cm	82 cm	63 cm	X	X
B60/70	297 cm	141 cm	98 cm	71 cm	66 cm	X	X
B100/150	302 cm	143 cm	99 cm	72 cm	66 cm	X	X
High Modulus	255 cm	126 cm	88 cm	65 cm	61 cm	X	X

Table 13. Thickness of the base course for Airports with 6.000 annual departures and an average temperature of T = 0°C for different types of mixtures.

CBR	**5**	**10**	**15**	**20**	**25**	**30**	**35**
B40/50	337 cm	165 cm	121 cm	97 cm	78 cm	61 cm	51 cm
B60/70	354 cm	164 cm	115 cm	87 cm	66 cm	64 cm	X
B100/150	360 cm	166 cm	88 cm	66 cm	64 cm	X	X
High Modulus	303 cm	144 cm	103 cm	79 cm	61 cm	59 cm	X

Table 14. Thickness of the base course for Airports with 25.000 annual departures and an average temperature of T = 0°C for different types of mixtures.

CBR	**5**	**10**	**15**	**20**	**25**	**30**	**35**
B40/50	389 cm	186 cm	136 cm	110 cm	91 cm	75 cm	65 cm
B60/70	411 cm	188 cm	132 cm	102 cm	81 cm	62 cm	67 am
B100/150	418 cm	191 cm	133 cm	103 cm	81 cm	63 cm	51 cm
HMAC	345 cm	157 cm	112 cm	88 cm	71 cm	56 cm	X

Table 15. Thickness of the base course for Airports with 50.000 annual departures and an average temperature of T = 0°C for different types of mixtures.

CBR	5	10	15	20	25	30	35
B40/50	417 cm	199 cm	144 cm	116 cm	97 cm	81 cm	71 cm
B60/70	442 cm	201 cm	140 cm	110 cm	88 cm	69 cm	58 cm
B100/150	540 cm	249 cm	175 cm	139 cm	114 cm	93 cm	81 cm
HMAC	376 cm	175 cm	124 cm	98 cm	80 cm	64 cm	54 cm

3.5.4 Average Temperature = -10°C

The elastic modulus is a characteristic of materials with elastic behaviour. However, asphalt mixtures have a visco-elastic-plastic behaviour. That is, the recovery of the primitive form has a certain delay with respect to the application of the load. When working at low temperatures the elastic component of the module has preponderance and is often like a mix asphalt elastic body. A good surface drainage is very important in areas with low temperatures to try to eliminate water and consequently ice, which is very destructive for the pavement [9].

The Corps of Engineers makes a classification of soils according to their degree of susceptibility to frost.

For an airport with different annual operations, different CBR (5, 10, 15, 20, 25, 30, 35) and different binders (B60/70, B110/150 and HMAC B13/22) has been calculated the thickness of the base course according to the dynamic young modulus that was obtained in the lab for the mentioned asphalt mixtures to -10°C.

Table 16. Thickness of the base course for Airports with 1.200 annual departures and an average temperature of T = -10°C for different types of mixtures.

CBR	5	10	15	20	25	30	35
B60/70	260 cm	126 cm	90 cm	66 cm	61 cm	X	X
B100/150	263 cm	128 cm	90 cm	66 cm	62 cm	X	X
HMAC	237 cm	117 cm	84 cm	62 cm	58 cm	X	X

Table 17. Thickness of the base course for Airports with 25.000 annual departures and an average temperature of T = -10°C for different types of mixtures.

CBR	**5**	**10**	**15**	**20**	**25**	**30**	**35**
B60/70	358 cm	167 cm	119 cm	93 cm	74 cm	58 cm	63 cm
B100/150	362 cm	169 cm	120 cm	94 cm	75 cm	59 cm	63 cm
HMAC	324 cm	157 cm	110 cm	87 cm	70 cm	55 cm	X

Table 18. Thickness of the base course for Airports with 50.000 annual departures and an average temperature of T = -10°C for different types of mixtures.

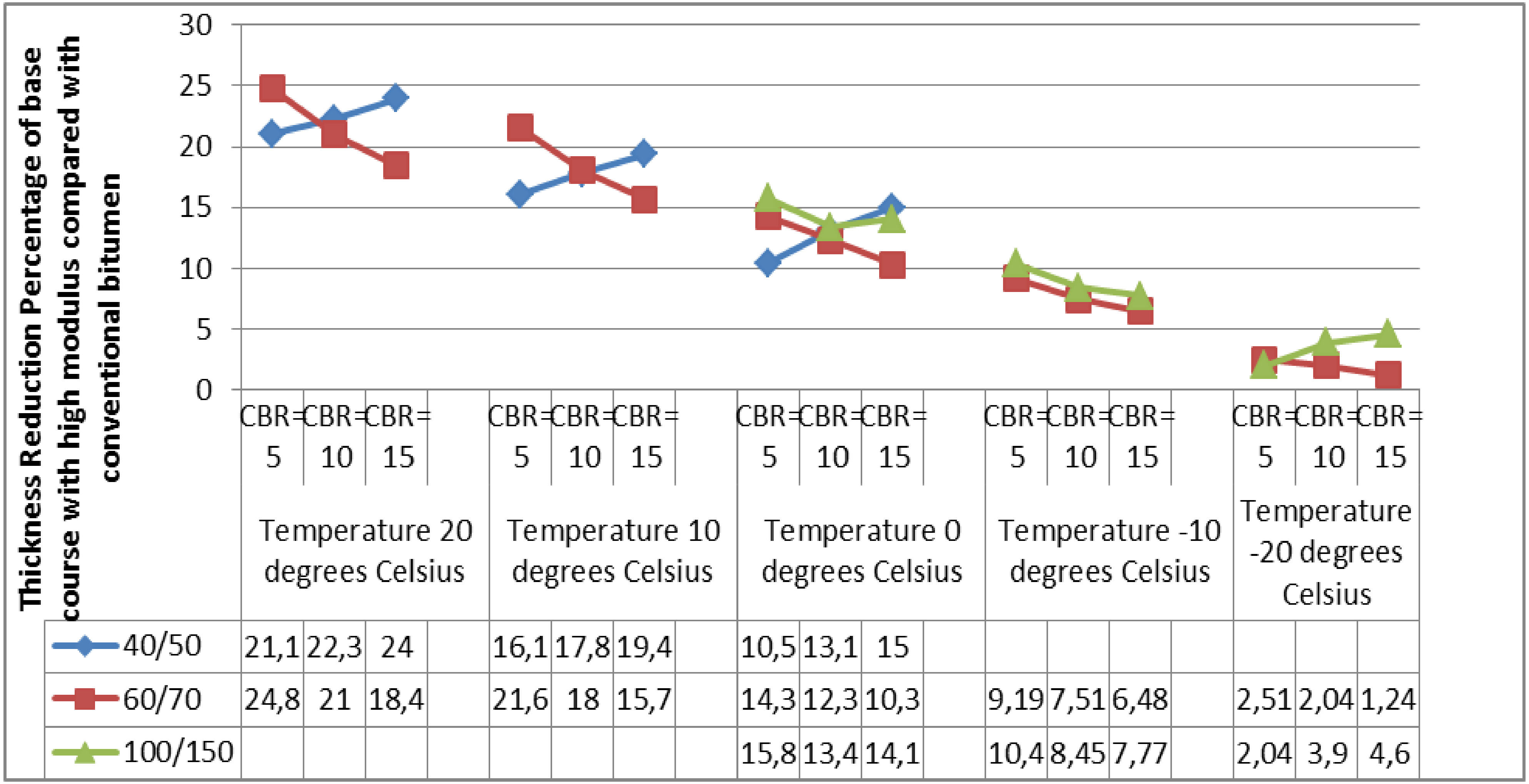
CBR	**5**	**10**	**15**	**20**	**25**	**30**	**35**
B60/70	384 cm	178 cm	126 cm	100 cm	81 cm	65 cm	X
B100/150	389 cm	180 cm	127 cm	101 cm	81 cm	65 cm	55 cm
HMAC	347 cm	163 cm	117 cm	93 cm	76 cm	61 cm	52 cm

3.6 Data Analysis

The following graph shows the percentage of thickness reduction of a runway pavement with a base course stabilized with high modulus bitumen compared with a base course stabilized with conventional bitumen, and all this taking into account the temperature.

In the graph is easy to see that with a medium temperature of 20°C it is possible to reduce the thickness of the base layer if stabilized with high modulus bitumen in about 25% for CBR =5 compared with the thickness that the layer would have if stabilized with conventional bitumen.

On the other hand with a medium temperature of -20°C the percentage of reduction in the base layer stabilized with high modulus compared with conventional bitumen mixtures is almost 0%, so we can conclude that from different point of views, but for instance from an economic point of view it is not convenient to use high modulus asphalt concrete in cold weathers.



	Temperature 20 degrees Celsius			Temperature 10 degrees Celsius			Temperature 0 degrees Celsius			Temperature -10 degrees Celsius			Temperature -20 degrees Celsius		
	CBR= 5	CBR= 10	CBR= 15	CBR= 5	CBR= 10	CBR= 15	CBR= 5	CBR= 10	CBR= 15	CBR= 5	CBR= 10	CBR= 15	CBR= 5	CBR= 10	CBR= 15
40/50	21,1	22,3	24	16,1	17,8	19,4	10,5	13,1	15						
60/70	24,8	21	18,4	21,6	18	15,7	14,3	12,3	10,3	9,19	7,51	6,48	2,51	2,04	1,24
100/150							15,8	13,4	14,1	10,4	8,45	7,77	2,04	3,9	4,6

4. Conclusions

In this research 5 binders were tested, one of them was high modulus binder and the other four were conventional binders. The results were compared and the binders were evaluated for effect on the penetration index. Layer thickness was calculated using the LEDFAA. The analysis of the results allowed the following statements to be made:

1. HMAC and conventional bitumen mixtures behaved differently in terms of stiffness and elasticity. HMAC in the study had higher complex modulus at all the evaluated temperatures and viscosity was also higher.

2. HMAC can be effective in reducing asphalt layer thickness. The increment in one Celsius grade the performance temperature of the HMAC let a reduction of the asphalt base layer thickness by 2% due to an increment of the dynamic young modulus of the HMAC. The research shows also that the base layer thickness could be reduced by 24,77 % at 20°C and about 1,24 % reduction at -10°C. However the results obtained in the tests show that the percentages of reduction in the base layer stabilized with high modulus binder respect to a base layer stabilized with conventional binder at different temperatures show that the percentage of reduction is not variable with the number of annual departures therefore the calculations did not take into account this parameter.

3. The increase in the continuous tested temperature performance did not appear to affect the fatigue performance negatively. Samples done with stiff bitumen, such as high modulus bitumen had slightly less bottom-up cracking than samples stabilized with conventional bitumen.

4. The compaction and estimate mixing was done in the test following the Marshall test and the Swedish normative in compaction for asphalt mixtures samples. The mixing temperature for conventional bitumen mixture was 165°C and 185°C for HMAC.

5. The low temperature for the HMAC was not good in terms of thickness reduction and performance of the mixture as compared to conventional bitumen mixtures. The use of HMAC in areas with an average temperature of -10°C should be done with caution and more research is needed in terms of using HMAC in low temperatures. However, test results show that with an annual average temperatures of 20°C or above is clearly advantageous to use HMAC as the reduction in the thickness layer, and related savings, with respect to conventional bitumen mixtures (40/50, 60/70, 100/150) is 20-25 % or higher with increasing temperature; so taking into account that the price of the high modulus bitumen is 30 % higher than conventional bitumen, the use of HMAC would be an advantage because of the reduction in thickness of the layer specially in warm climates.

6. In this research has been observed that the HMAC´s dynamic young modulus at high temperatures is 50 % higher than the conventional bitumen mixtures´s dynamic young modulus. Besides it is interesting adding that the research of HMAC at high temperature, made by Jaczewski [10] in Poland, showed 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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