International Journal of Engineering & Technology, 7 (4.20) (2018) 386-389

International Journal of Engineering & Technology

Website: www.sciencepubco.com/index.php/IJET

Research paper

Performance Evaluation of Conventional and High Modulus Asphalt Concrete with Novolac Polymer Modifier Using Aashtoware Software

[1]Basim H. Al-Humeidawi*, [2]Abbas F. Jasim, [3]Huda A. Kadhim

[1]Roads and Transport Department, College of Engineering, University of Al-Qadisiyah, Al-Diwaniyah, Iraq.
[2]Highways and Transportation Engineering Department, College of Engineering, Mustansiriyah University, Baghdad, Iraq.
[3]Assistant, Highway and Transportation Engineering Department, College of Engineering, Mustansiriyah University, Baghdad, Iraq.
**Corresponding Author E-mail: Basim.alhumeidawi@qu.edu.iq*

Abstract

In order to changes the original asphalt characteristics, there are many additives have been used to produce or modify the High Modulus Asphalt Binder (HMAB). Even though the hard grade asphalt binder has some disadvantages, such as the aging process due to high mixing and compacting temperature, which can negatively affect the pavement performance, some other advantages include increasing stiffness modulus of asphalt binder and high resistance to permanent deformation. Also, using the hard grade asphalt binder will save construction costs by reducing the asphalt pavement thickness due to its high stiffness modulus. In Iraq, the Novolac modifier and its Cross-linking Agent (Hexamine) was used for the first time as a modifier for asphalt which can significantly improve the rheological properties of asphalt and its role in HMA. This study focuses on estimating the thickness reduction of flexible pavement due to using High Modulus Asphalt Concrete (HMAC). The reduction in permanent deformation and thickness of pavement were estimated for suggested pavement structure sections implemented HMAC mixture compared with the pavement section implemented conventional mixtures using AASHTOWare software version 2.3. The analytical results indicate that adding 4% of Novolac modifier and 15% of Hexamine (form weigth of Novolac) is reduced the permanent deformation and bottom up cracking by 30% and 46 % compared to conventional mix, respectively. However, it can be concluded that adding Novolac polymer modifier enhanced the pavement performance.

Keywords: *AASHTOWare, high modulus asphalt binder, MEPDG, pavement performance, stiffness thickness reduction.*

1. Introduction

The rapid development of most countries of the world leads to substantial grow in traffic volume and axles-load that using roads network. This grow increases the demand for new roads and causes premature structural failure to existing pavement such as rutting and fatigue; consequently, increases the construction and maintenance cost.

During the last decades, several techniques were developed to enhance pavement quality and reduce construction cost. Enrobé à Module Élevé, (EME) is one of these techniques which was developed at the eightieth of last century in France to produce High Modulus Asphalt Concrete Mixture (HMAC) [1]. The main aims were to improve pavement resistance to distress, and reduce construction cost as a result of reducing the required design thickness of pavement. The obtained Mixture (HMAC) usually used in base and binder courses of heavy duty roads to resist heavy axle-loads and reduce pavement thickness (main routes and airports) [1, 2].

The production of HMAC mixture requires High Modulus Asphalt Binder (HMAB). HMAB can be obtained from three methods: HMAB modified by asphaltite, hard grade asphalt produced in a refinery, HMAB modified by polyolefin [3]. The high stiffness of mixtures designed according to EME method can be achieved by using hard grade asphalt binder or use the modifiers (asphaltite, polyolefins) with the conventional asphalt binder [4] and adopting design requirements of EME method. Hard grade asphalt binder with penetration of (10/20, 15/25, and 20/30) was usually applied in HMAC to assure rutting resistance with large content in the mix to assure workability, fatigue and water resistance [1].

Alongside pavement performance enhancement obtained by adopting EME method, a significant thickness reduction in pavement thickness was observed from several studies [3, 5-7]. This reduction is more suitable in areas where there are geometric constraints (Krebs in urban areas, bridge crossings) during rehabilitation [8]. Carbonneauet al. [5] evaluated the mechanical properties of conventional Graded Aggregate Base (GAB) II containing asphalt binder (40-60) compared with high modulus GAB II containing asphalt binder (20-30). Their results showed a significant increase in the modulus of stiffness for high modulus GAB II from 6200 to 12000 MPa, and a significant increase of fatigue resistance. In addition to enhancing of stiffness modulus, this improvement resulted in total thickness reduction of 35 mm in the base course of the pavement structure.

Corté [6] conducted a comparison of the performance of HMAC containing polyolefins modifiers, gilsonite (asphaltite), and hard grade bitumen compared with the conventional mixture. Corte‘s results showed that the pavement section is containing HMAC causes a reduction in total thickness ranging from (25% - 33%) as compared with the conventional mixture, which consequently saves raw materials (asphalt binder and aggregate) and reduces the initial cost of construction. Other study carried out by Espersson [7] showed that the using of HMAC containing bitumen (13/22) resulted in decreasing the base course by about 25 % at 20 ºC compared with the conventional mixture. Also, the results of his study showed that the increase in the performance temperature by one Celsius result in 2% thickness reduction of base course due to increment in the dynamic modulus of HMAC.

Genget al. [3] investigated the effect of using HMAB in the asphaltic mixture on the reduction in thickness of asphalt layer compared with that containing conventional asphalt binder. They concluded that the increase in one grade of continuous high-temperature performance grade could reduce the thickness of the asphalt layer by 1% without an increase in total permanent deformation. According to produced classes of HMAB in the above study, the reduction in thickness value was observed in the range of (9.3 -30.2 %).

Previous studies were conducted by authors to produce hard grade bitumen as a binder for HMAC. The results of these studies showed significant increase in modulus of elasticity for the produced mix and a great improvement in overall performance [9-11].

2. Objectives

The main objective of this study is to evaluate the performance of HMAC in pavement engineering: thickness reduction of asphalt layers and pavement distresses. The reduction in thickness was estimated for suggested pavement structure sections implemented HMAC mixture compared with the pavement section implemented conventional mixtures using AASHTOWare software version 2.3.

3. Material and experimental

3.1 Novolac and its Cross-linking Agent (Hexamine)

Novolac is a thermosetting polymer which is normally produced from the reaction of phenol with formaldehyde in the acidic medium. The Novolac polymer was used as a new technique to produce hard paving grade asphalt binder due to its good thermal stability through unique characteristics of rigidity and its ability to withstand high temperature under mechanical load with minimal deformation or creep [10]. It was obtained from Al- Sawari General Company for Chemical Industries, the characteristics of Novolac are illustrated in Table 1.

Table 1: Characteristics and Composition of Novolac Resin [10]

Properties	**Value**
Phenol-Formaldehyde (w.t%)	100
Density (gm/cm3)	1.25
Melting point (ºC)	95
Thermal conductivity (W/m º C)	0.2
Viscosity (poise)	13-18
Properties medium	Under acidic conditions (HCL)

3.2 Characterization of asphalt binders

Conventional bitumen binder with penetration grade of (40-50) was used to produce hard paving grade bitumen which used for production HMAC. The Novolac was added as a percentage from asphalt binder while the Hexamine was added as a percentage from Novolac to act as a hardener cross-linking for the Novolac. Different percentages of Novolac (1%, 2%, 3%, 4% and 5%) and Hexamine (5%, 10% and 15%) were used. The penetration of the produced asphalt (as shown in Table 2) was used as the main input for the AASHTOWare software to evaluate the effect of Novolac and its Cross-linking Agent (Hexamine) on pavement thickness reduction.

Table 2: Penetration (1/10mm) using different percentages of Novolac and Hexamine

				Penetration (1/10mm)
Natural asphalt (40-50) grade (control)				43
% of Novolac from the weight of asphalt binder	1%	% of Hexamine (HMTA) from the weight of Novolac	5%	43
			10%	30
			15%	28
	2%		5%	39
			10%	27
			15%	22
	3%		5%	29
			10%	20
			15%	14
	4%		5%	23
			10%	17
			15%	12
	5%		5%	13
			10%	11
			15%	8

4. Pavement structure and design criteria

MEPDG software (AASHTOWare version 2.3) was used to evaluate the relation among pavement distress, the thickness of the asphalt layer, and binder continuous performance grade. Four-layer pavement structure was selected for MEPDG calculation, which includes 12cm asphalt concrete, 15cm bitumen base, 20cm subbase and A-7-6 subgrade (semi-infinite) layers which represents the typical pavement structure of Expressway No.1-Iraq (section R4/B) (see Figure 1). Three more additional asphalt layer thickness of 18, 24 and 30 cm were included for MEPDG calculation to evaluate the effect of Novolac modifier and its Cross-linking Agent (Hexamine) variation on pavement distresses. Traffic volume was estimated to 10 $\times 10^6$ ESALs, and level-2 design was selected for calculation. Default values were selected for all the other input values.

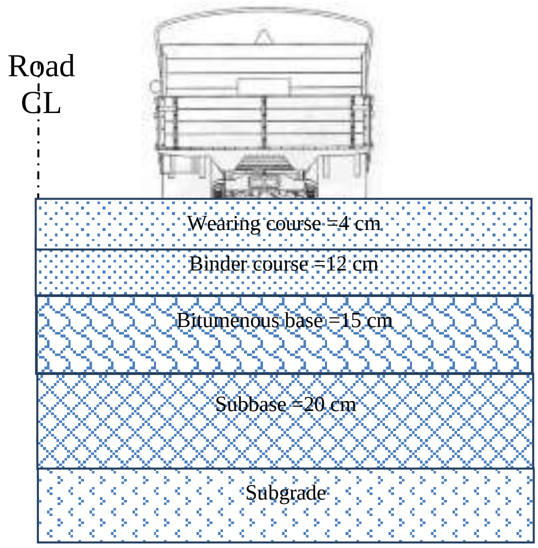

Fig. 1: Typical pavement structures in Expressway No.1-Iraq (section R4/B)

To determine the baseline analysis, an analysis period of thirty years was used to determine the impact of the modifier variation on pavement distresses. The key performance parameters included: rutting in asphalt layer, total pavement rutting, top-down cracking, thermal cracking, alligator (bottom-up) fatigue cracking, top-end smoothness (International Roughness Index). The reflective cracking is not considered in the analysis at the current stage due to the uncertainty of the performance model in the current Pavement ME version. The default roughness, design information and distress limits in MEPDG were utilized for the performance criteria to determine the effect of modifier variation on pavement thickness, as shown in Table 3.

Table 3: M-E Pavement Design Criteria

Design criterion	
Reliability (%)	90
Initial IRI (m/km)	1.0
Terminal IRI (m/km)	2.71
Top-Down fatigue Cracking (m/km)	379
AC bottom-up fatigue cracking (%)	25
Thermal Cracking (m/km)	189
Permanent Deformation (AC Only) (cm)	0.63
Permanent Deformation (Total) (cm)	1.9
Design information	
Base construction	May 2018
Pavement construction	July 2018
Traffic opening	September 2018
Climate data sources	(Taxes, station 133191)*
Assumed total ESAL	10 million
AADTT (veh./day)	3000

*The climate station chosen in the present study was Taxes since this area is close to the Iraq weather.

The elastic modulus obtained from the laboratory indirect tensile stiffness test was defined for each (binder and base course) of conventional and HMAC pavement sections [10]. While other properties for wearing course and underlying layers (subbase and subgrade) were taken with the same properties for each pavement section [12] as shown in Table 4. In this work, all layers were assumed as linear elastic materials and subjected to the same loading conditions (single load).

Table 4: Properties of HMAC and Conventional HMA Used for Estimation Thickness Reduction [10, 12]

Layer	Thickness (cm)	Poisson's ratio	Elastic modulus (MPa)	
			Control	HMAC
Wearing course	4	0.35	1194	1194
Binder and base (stabilizer) courses	8/15	0.35	2609	9260
Subbase course (Granular material)	20	0.4	104	104
Subgrade	-	0.5	40	40

Also, three different traffic scenarios were implemented for designing new pavements shown in Table 5. The analysis focused on the truck traffic classification for expressways (TTC1: bus>2%, multi-trailer<2%, mostly single-trailer trucks) with the default vehicle class distribution and axle load spectra (level 3 input). Furthermore, the load equivalent factor in AASHTO 1993 pavement design guide was used for comparative purposes to convert traffic data over the three-decade period of design into ESALs.

Table 5: Data related to traffic volume

	Traffic Level		
	Low (L)	Medium (M)	High (H)
Assumed total ESAL	5 million	10 million	15 million
AADTT (veh./day)	1000	3000	6000
Design speed (km/h)	80	80	80
Truck in design direction (%)	50	50	50
Truck in design lane (%)	95	95	95
Growth rate	3%	3%	3%

5. Results and discussion

5.1 Thickness reduction based on total pavement permanent Deformation

One of the most advantage of using HMAB is saving the asphalt layer thickness. To evaluate this advantage, The AASHTOware ME software was used to calculate total permanent deformation of typical pavement structures when HMABs are used at different percentage. Since five different percentages of both Novolac and its cross agent was used, sixteen (fifteen plus one control section) permanent deformation values were obtained for each pavement structure. In general, the design criteria for the total permanent deformation acceptance is 1.9 cm by MEPDG as listed in Table 3 [13].

Figure 2 shows the effect of traffic level on the permanent deformation using different modifier percentages. It is noted that high traffic level will increase permanent deformation for conventional and HMABs structure. Also, the Novolac and its cross agent (Hexamine) plays a critical role to reduce permanent deformations. Increasing Novolac percentage reduces the permeant deformation significantly for all traffic levels. For example, using 4 percentage of Novolac modifier and 15 percentage of Hexamine (from the weight of Novolac) reduces the permanent deformation by 30% compared to conventional mix.

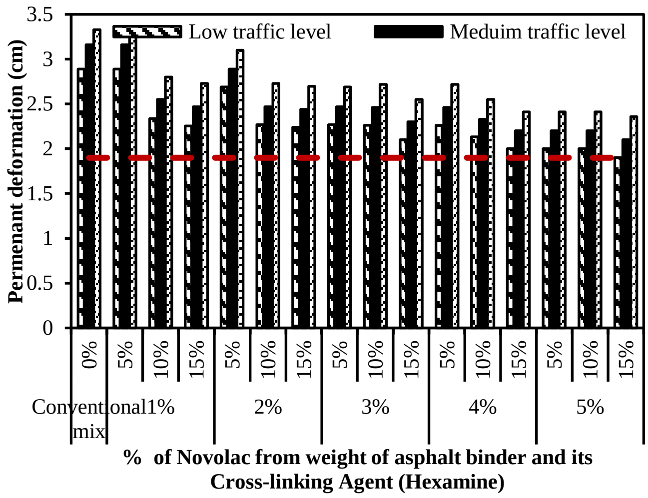

Fig. 2: Effect of Traffic level and modifier amount on permanent deformation

Figure 3 presents the effect of AC layer (HMA) variation on permanent deformation. When the thickness of the asphalt layer constructed by the conventional binder is over 24 cm, the permanent deformation is below 1.9 cm as shown in Figure 2. Again, Using 4 percentage of Novolac modifier and 15 percentage of Hexamine reduces the permanent deformation by 30% compared to conventional mix.

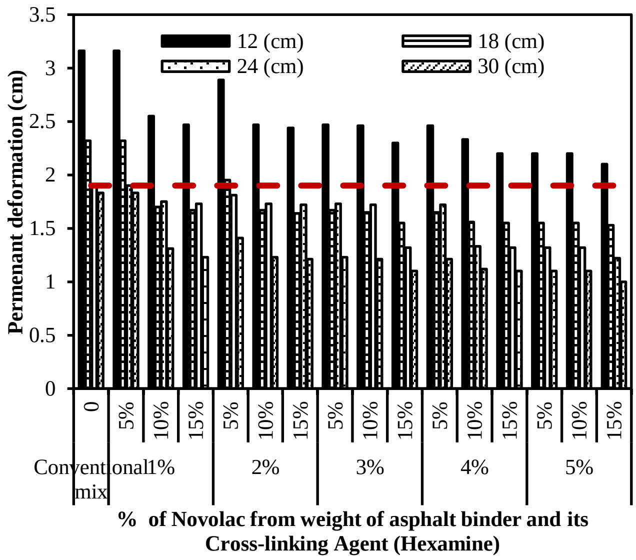

Fig. 3: Effect of asphalt layer thickness and modifier amount on permanent deformation

5.2 Thickness reduction based on bottom-up cracking

Bottom-up cracking values were achieved by MEPDG calculation based on the input of asphalt layer thickness, modulus values and all other default values listed in Table 3, which are shown in 9. The current criteria for bottom-up cracking used by MEPDG is 25% of lane area [13] When the thickness of the asphalt layer constructed by conventional binder is over 18 cm, the bottom-up cracking is below 25% of lane area. At a higher level of traffic, the bottom up cracking increase slightly as compared to low traffic level. In addition, using 4 percentage of Novolac modifier and 15 percentage of Hexamine, reduces the bottom-up cracking by 46% compared to the conventional mix, as shown in Figures 4 and 5. The reduction in the asphalt layer thickness is not as significant as that observed for the total permanent deformation due to the fact that there is no significant difference in the HMABs and conventional asphalt. In general, an increase in the modifier percentage allows a reduction of the thickness of the asphalt layer by at least 2%. However, the software results show that pavements constructed with stiff binders, such as HMABs have slightly less bottom-up cracking than pavements constructed with conventional binders.

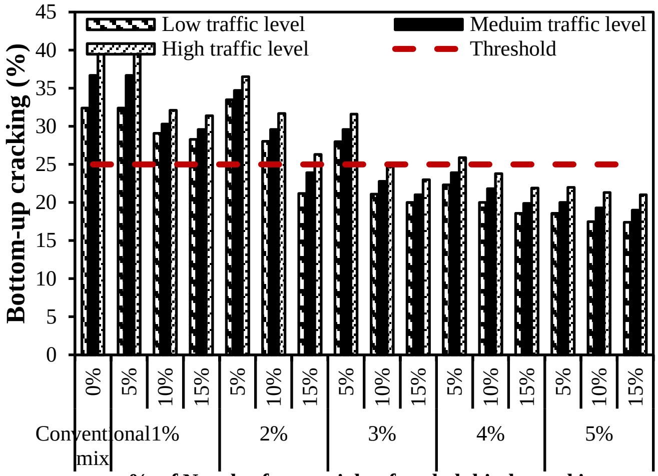

Fig. 4: Effect of Traffic level and modifier amount on Bottom-up cracking

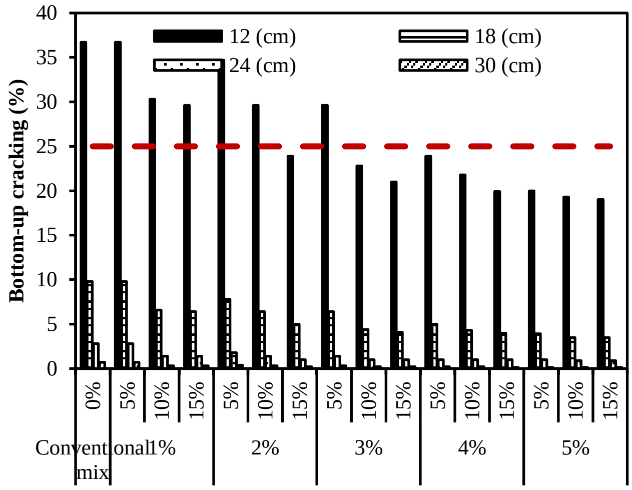

Fig. 5: Effect of asphalt layer thickness and modifier amount on Bottom-up cracking

6. Conclusions and Recommendations

The current research focuses on using AASHTOware to estimate the thickness reduction in binder course of pavement due to using HMAC mixture contained locally produced hard grade asphalt binder. HMABs can be effective in reducing asphalt layer thickness. The following conclusions are drawn based upon the AASHTOWare results:

1. When the thickness of the asphalt layer constructed by the conventional binder is over 24 cm, the permanent deformation is below 1.9 cm
2. High traffic level will increase permanent deformation and bottom-up cracking for conventional and HMABs structure.
3. Using four percentage of Novolac modifier and 15 percentage of Hexamine reduces the permanent deformation and bottom-up cracking by 30% and 46 % compared to conventional mix, respectively.
4. When the thickness of the asphalt layer constructed by the conventional binder is over 18 cm, the bottom-up cracking is below 25%.
5. Increase in the modifier percentage allows a reduction of the thickness of the asphalt layer by at least 2%.

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