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PREDICTED DESIGN THICKNESS OF MODIFIED HMA LAYER FOR FLEXIBLE HIGHWAY PAVEMENT

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ABSTRACT

The major reason for using asphalt mixture modifiers is to improve the performance of asphalt pavement to meet the requirement under prevailing stresses from traffic loading and environment effects and to reduce the pavement thickness.

Structural design of thickness for asphalt pavement layers is a function of many variables; one of the most important of them is the elastic modulus (E) of the asphalt mix.

E values may be estimated directly in a laboratory by test, or indirectly by correlation with other tests like Marshall Stability. Additionally, E of hot mixture asphalt is used to predict the relative strength coefficient (a) of the layer which is used to estimate the Structural Number parameter (SN), that leads to determine the required layer thickness.

The major objective of this research is to predate a statically model to estimate the effect of asphalt modification on the layer thickness. 75 specimens of control and modified HMA for surface are designed and tested according to Marshall Method with optimum asphalt cement content (4.8%) and different types and contents of available modifiers.

In order to establish a relationship between the thickness of the surface layer (D) for a flexible pavement and modifier type (MT) with modifier content (MR) in the mix design. The structural model displayed a nonlinear relationship between the parameters of the mix design having R^2 = 0.7 as shown below:

$$\mathbf{D = a*e^{(b*MT)} + c*e^{(g*MR)}} \text{ (a, b, e, g are constants)}$$

KEYWORDS: Marshal stability; Static modulus; Strength coefficient layer; Structural number; Prediction model

السمك التصميمي المتنبأ به لطبقة الخلطة الاسفلتية الحارة المحسنة ضمن تبليط طرق المرن

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الخلاصة

ان السبب الرئيسي لاستخدام مضافات الخلطة الاسفلتية هو تحسين اداء التبليط الاسفلتي لتحقيق المتطلبات تحت الاجهادات السائدة من حمل مروري وظروف محيطة وكذلك لتقليل سمك التبليط.

ان السمك التصميمي لطبقة التبليط الاسفلتي يعتمد على عدة عوامل، اكثر تلك العوامل اهمية هو مرونة الخلطة الاسفلتية (E).

ان قيم المرنة (E) يمكن ان تخمن مباشرة من الفحص المختبري او بشكل غير مباشر عبر علاقة مع فحوض مختبرية مثل فحض الثبات بطريقة تصميم مارشال، بالاضافة كون المرونة تستخدم لتخمين معامل المقاومة النسبية (A) والذي يستخدم بدوره في حساب الرقم الانشائي للطبقة (SN) الذي يسمح لايجاد سمك الطبقة المطلوب.

ان الهدف الرئيسي من هذا البحث هو لتقديم موديل احصائي لتخمين اثر تحسين الاسفلت على سمك الطبقة التصميمية. 75 نموذج من الخلطة الاسفلتية الحارة القياسية والمحسنة لطبقة سطحية تم تصميمها وفحصها باستخدام طريقة مارشال ولنسبة اسفلت مثلى هي 4.8% لجميع انواع ونسب المضافات المتوفرة.

من اجل تثبيت علاقة بين سمك الطبقة السطحية (D) للتبليط المرن مع نوع المضاف (MT) ونسبة المضاف (MR) في تصميم الخلطة، فان موديل احصائي بيّن علاقة لا خطية مع معاملات تصميم الخلطة وقيمة R^2 مساوية 0.7 كما هو في ادناه:

$\mathbf{D = A*E^{(B*MT)} + C*E^{(G*MR)}}$ كثوابت (A, B, E, G) على اساس

1. INTRODUCTION

1.1. HMA Modification by Polymers

In Iraq, in the recent years, the increasing number of vehicles and trucks with their heavy traffic loading and with the effects of other exterior factors, such as air temperatures effects, and moisture, the accumulation of these factors on the road surfaces with an insufficient maintenance have caused distresses or deteriorations on pavement. Numerous distresses effect on the flexible pavements performance in Iraq and cause in early failure. In the flexible pavements, the main distress types are rutting, moisture damage, thermal cracking, and fatigue cracking. These distresses appear most of the time because of improper design, poor maintenance and/or construction material quality.

Decreases of pavement distresses or improving the performance of flexible pavement required many improvements on the pavement surfaces, such as improving design, structure of paving, and performance of the mix by controlling the properties that affect it. In order to improve HMA performance, the practice of modifying the asphalt binder became common polymers in particular have received widespread attention as the performance improvers of the asphalt hinder.

Asphalt modifiers are defined as materials, which would usually be added to binder or mixtures to improve their properties. The main reason for using modifiers on the asphalt mixtures as asphalt-modification is to enhance the performance of paving mixture to comply with the requirements under prevailing circumstances from loading and environmental effects.

The technical aims for incorporating modifiers in asphalt mixtures are to produce stiffer mixes at high service temperature to improve rutting resistance as well as to produce softer mixtures at law temperature to decrease thermal cracking and enhance fatigue resistance of asphalt pavement.

Almost, the main reasons to improve the bituminous materials with different types of substances might be summarized as follow:

- To develop softer blends at law service temperature, so decrease cracking
- To develop stiffer blends at high temperature, so decrease rutting
- To increase Marshall stability and the strength of asphalt mixtures
- To enhance fatigue resistance of the produced mixtures
- To reduce structure thickness of pavement (King et al., 1986).

Better asphalt pavement performance by using Polymer-Modified Asphalt (PMA) has been studied for a long time. Several fundamental functional properties have been improved such as rutting, fatigue, stripping, low temperature cracking, and aging.

Many efforts are directed towards modifying the asphalt or enhancing paving properties to get superior performance and serviceability under conditions and to economize the construction of pavement.

Most of the literatures showed that the properties of PMA are dependent on the blending process, the polymer characteristics, bitumen nature and polymer amount. There are relatively little types of polymeric products among the large number of them that are appropriate as bitumen modifiers. Selected polymers should be compatible with bitumen, capable of being processed by conventional mixing and laying equipment, able to sustain their premium properties throughout storage, mixing and application in service. Also, using of a modifier should be not costly (Crossley, 1998).

Generally, there are two categories of polymers: elastomers and Plastomers. The first group increase slightly the strength of the binder at the early low strain level, while at a higher strain they may be stretched out and get stronger, then recover when the practical load is released. While the latter produces a rigid three-dimensional networks and increase the tensile strength under heavy load but it tends to be cracked at higher strains.

An elastomer is a polymer, Styrene Butadiene Styrene (SBS) as an example, which has a flexible “rubber” and large side- chains in its structure. Generally, they are added to enhance the resiliently of the flexible pavement. They tend to enhance the elasticity of asphalt binder, and as such they might increase the failure strain of asphalt concrete at low temperatures. The elasticity and strength of the thermoplastic elastomers can be attributed to the physical cross-linking of the molecules into a three dimensional networks.

For SBS, the strength gain to the polymer can be attributed to the polystyrene end-blocks, while the exceptional elasticity of the material due to the existence of the mid-block butadiene. Therefore, the ability of asphalt modified by SBS to resist rutting at high temperatures and decrease low temperature and fatigue cracking at low temperatures were attributed to this combination of elasticity and strength (Airey, 2004).

Other common elastomers include SB, which is a diblock copolymer of styrene-butadiene, PBD, which is polybutadiene, and Ground tire rubber (GTR) or crumb rubber (CR), which is produced from recycled tires (Airey, 2004).

On the other hand, a plastomer is a polymer that deforms in a viscous or plastic method at the melt temperatures and becomes hard and stiff at the low temperatures. This behavior can be attributed to that the structure is reversibly broken down with the application of heat. Whereas elastomers can improve the resistance to permanent deformation and low temperature and fatigue cracking, plastomers will generally only improve the resistance to rutting. While, plastomers produce mixes with a higher stuffiness and stability. Generally, these substances increase the stiffness of the binder, therefore improve the resistance to plastic deformation at high temperatures.

Ethylene vinyl acetate (EVA) is the most common plastomer used in asphalt and acts by making the PMA stiffer than conventional asphalt. EVA polymers are simply blended into asphalt using a simple low shear mixing. As with most PMA systems, to achieve optimum properties of the produced binders the EVA polymer must be compatible with the base asphalt. The most commonly investigated plastics that are used to modify the asphalt binders include low and high density polyethylene (LDPE and HDPE), polypropylene (PP), and polyvinyl chloride (PVC) (Crossley, 1998).

Two processes are used to incorporate polymer into the asphalt-aggregate mix which are dry and wet process:

1.1.1. The Dry Process

This process includes mixing the polymer particles with aggregates substances before adding of asphalt to them. In this process firstly the aggregate is heated then polymer is incorporated and mixed thoroughly for approximately 15 seconds to produce a homogeneous mixture. Thereafter, a straight binder is added in a conventional mixing plant. In this process, modified binders are created, since there is no absorption of the rubber by the conventional binder. The time of interaction between the binder and the rubber in this process is relatively not sufficient to produce all necessary reactions between the two ingredients (Al-Bana'a, 2002).

1.1.2. The Wet Process

This method of mixing includes the blending of the polymer with the asphalt cement at an elevated temperature. Special equipment is needed for blending. It is the common method which consists of the adding of the polymer to the asphalt cement. The straight asphalt is primarily preheated to about 190 °C in a suitable tank under restricted circumstances and then conveyed to a blending tank, where the modifier is added. A mechanical agitation created by a horizontal shaft is used to facilitate the blending process (Al-Bana'a, 2009).

Two primary solutions can be adopted to construct a more durable pavement. Applying a thicker asphalt pavement layer is the first solution that will rise the total construction cost. While the second one is produce an asphalt mixture with modified properties. Modified binder (such as polymer modified binder) was also suggested to enhance the resistance of the asphalt mixtures against permanent deformation and thermal cracking of asphalt pavement i.e. fracture of the pavement due to the lack of flexibility at low temperatures (Al-Harbi, 2012).

The addition of polymer increases the stiffness and flexibility of the modified binder at the high and intermediate temperatures, therefore the permanent deformation resistance and fatigue properties of the produced mix will be enhanced. Also, low temperature cracking resistance can be improved when using softer asphalt base and polymer presence. Furthermore, the higher stiffness of polymer modified asphalts at the high temperatures generate thicker films on the aggregate particles, producing less "drain down" in open graded mixes and providing better long term durability in comparison with the control mixtures (Al-Harbi, 2012).

1.2. HMA Modification by Building Materials

Hydrated lime is an accepted modifier of a mix. The general practice is adding 1–1.5 percent lime by a total mass of aggregate to the hot mix. If there is more fines in the aggregate, it may be required to add more lime because of the increment of the aggregate surface area. There are three main types of lime which are: dolomitic limes, hydrated lime ($Ca\ (OH)_2$) and quick lime (CaO) (Terrel and Epps, 1989).

Numerous techniques can be adopted for adding lime to the hot mixes. Adding of dry hydrated to the aggregate before adding of the binder is the first option. In this method, it is important to ensure that there is no problem in keeping the coverage until the binder is incorporated. Adding of the hydrated lime slurry is the second option which will increase the quantity of water and the production costs due to more fuel consuming. Thirdly, dry hydrated lime can be added to the wet aggregate, which has the same results of the second option.

By means of cost, hot slurry i.e. quicklime is comparable to hydrated lime, but when slaked, a 25% higher hydrated lime will be yielded. Also, some of the added moisture will be evaporated because of the elevated temperature during slaking. Hydrated lime generates a very strong bond between the binder and the particles of the aggregate, preventing stripping at all pH levels. It was reported that the hydrated lime reacted with alumina and silica aggregates in a pozzolanic means which will add a substantial strength to the produced mixture (Terrel and Epps, 1989).

2. HMA MODIFICATION BY LOCALLY AVAILABLE POLYMERS AND HYDRATED LIME OF SURFACE ASPHALTIC LAYER

The materials were widely used in HMA works in the middle and south of Iraq. One asphalt cement grade (40-50) from Durah refinery and eight different types of locally available polymers (Crumb Rubber (CR), Reclaimed Rubber (RR), Polypropylene (PP), High Density Polyethylene (HDPE), Low Density Polyethylene (LDPE), Styrene Butadiene Styrene (SBS), and Solid Styrene Butadiene Styrene (S.SBS)). Solid Styrene Butadiene Rubber S.SBR & liquid

Styrene Butadiene Rubber L.SBR have been used with their percentages for each type. These percentages were (12, 15, and 18) % for CR, (9, 12, and 15) % for RR , (2, 4, and 6) % for LDPE & (1, 3, and 6) % for HDPE, (1,2, and 3) % for P.P, (1,3, and 6) % for S.SBR, and (1,3, and 5) % for L. SBR. Hydrated Lime was used as an additive with three percentages (1, 2, and 3) % according to the main conclusion in (Al-Bana'a, 2009; Al-Harbi, 2012).

Each kind of these modifiers has been mixed with asphalt cement by means of wet process at various mixing times and suitable temperature for polymers.

One type of aggregate with nominal maximum size12.5 mm (for the surface layer type A) was used; the coarse aggregate used was crashed aggregate from Al-Najaf quarry while the fine aggregate from Karbala quarry. One type of mineral filler is used. Ordinary Portland cement (Taslujal). All the mentioned materials are agreed with SCRB – Iraqis specification).

Table 1. Blending time and temperature of mixing polymers with asphalt

No.	Polymers type	Blending time (min)*	Temp. of mixing (^{0}C)*
1	CR	60	190
2	RR	60	190
3	LDPE	90	170
4	HDPE	90	180
5	PP	60	160
6	SBS	60	180
7	S. SBR	60	200
8	L.SBR	30	170

* According to limitation in (Al-Bana'a, 2009; Al-Harbi, 2012)

Crumb Rubber (CR)

Crumb rubber has the name (40 mesh Crumb); it was taken from An- Najaf tires factory. It is recycled from used tiers, comprise black granules with 1.13 specific gravity and several practical sizes. Three sizes are attained in accordance to the sieving analysis using No. 50 (0.3mm), No.8 (2.36mm), and No.4 (4.75 mm) sieves.

Furthermore, it is the recycled rubber found from grinding of tires into small coarse crumb rubber. It is worthy to note that tires are comprised of numerous different kinds of rubber compounds (Company for Tire Industry, 2009).

The major CR compounds effect on the physical properties of the produced asphalt rubber (AR) as the total rubber hydrocarbon content with further effects from the natural rubber content. Also, the rubber of tires is often composed only of about one-half of actual rubber polymer which well swells in the asphalt. (Coomarasamy and Hesp, 1998; Hordecka et al., 2000) listed the properties of CR as shown in Table (2).

Reclaimed Rubber (RR)

It was brought from tires factory in AL-Najaf governorate. It is a black, solid, large size pieces, with specific gravity (1.16), and this type is recycled from used tires (Company for Tire industry, 2009; Morrison, 1995). Table (3) shows the properties of RR.

Low Density Polyethylene (LDPE)

Polyethylene is collected from An-Najaf tires factory, which is a white particles and normally used to manufacture the plastic belts in several private factories in addition to the tires factory in Iraq. Low Density Polyethylene (LDPE) is a plastomers polymer, in which the four carbons long represents the most common branch length. The properties are included in Table (4).

High Density Polyethylene (HDPE)

Polyethylene is brought from a locally market in Iraq and provided from State Company for Petrochemical Industry (SCPI) in Basra City, Iraq. It is a white granule and used to produce plastic belts in several private factories in addition to the tires factory in Iraq. High-Density Polyethylene (HDPE) is a plastomers thermoplastic polymer material with approximately 0.95 density and composed of carbon and hydrogen atoms joined together forming high molecular weight products. The properties are included in Table (5).

Polypropylene (PP)

It was collected from the locally markets in Baghdad– bab Almuadham. This product represents a white fiber. Polypropylene (PP) is normally used to produce a modified binder which in turn used to produce asphalt concrete to satisfy the required mechanical properties and durability of the asphalt pavement. The properties are included in Table (6).

Styrene Butadiene Styrene (SBS)

Styrene Butadiene Styrene (SBS) is collected from the locally markets in Iraq. It is tri-block particles with white color and small sizes. Which is the most traditional polymer modifier to the asphalt cement. SBS is elastomer tri-block copolymer combining a central butadiene section linked to styrene sections. Also, the molecules of polymer may have different forms lengths. Accordingly, the modification degree by SBS, blending process and the storage stability strongly affected by these differences. The polymer polystyrene is made up of numerous styrene molecules linked together one after the other (GIC, 2009). The properties are included in Table (7).

Solid Styrene Butadiene Rubber (S.SBR)

The solid Styrene Butadiene Rubber (SBR) is collected from An-Najaf tires factory. It is color is similer to the block rubber i.e. dark yellow. It has been cut in the lab to little pieces to make the blending process with asphalt cement easy (Company for Tire industry, 2009).

It is thermoplastic elastomers polymer that its elasticity and strength developed from a physical cross-linking of the molecules into a three dimensional networks. It can characterized as a block copolymer that contains two kinds of repeating molecular unites which are in turn polymerized in an unsystematic arrangement. The properties are included in Table (8).

In order to evaluate the effect of the physical properties of SBR polymer should be compared a state and texture as a main category from polymer physics of SBR according to available states and types from it in locally commercials materials, therefore Two states of SBR (solid and liquid) will be taken in this research (SCPI, 2008).

Liquid Styrene Butadiene Rubber (L.SBR)

A liquid Latex Styrene Butadiene Rubber (SBR) is gotten from the locally markets in Iraq. It is an emulsion product with a white apparent. SBR has been widely used as a commercial binder modifier material usually as a dissolve in water (latex). When styrene and butadiene are polymerized in a random arrangement, the polymer is called Styrene Butadiene Rubber or SBR (GIC, 2009). The properties are included in Table (9).

SBR latex is a random elastomeric copolymer of styrene and butadiene in a water based system. SBR is often used in asphalt emulsions for chip sealing or slurry seals. It increases the ductility of asphalt cements. The advantages of using SBR modified asphalt is enhancing the mechanical properties and durability of asphalt concrete pavement and seal coats. These benefits can be summarized by improving the low-temperature ductility, increasing the viscosity and the elastic recovery and enhancing the adhesive and cohesive properties of the pavement (SCPI, 2008).

Hydrated Lime (H.L.)

Hydrated lime is a dry powder obtained by hydrating quicklime with enough water to satisfy its chemical affinity, forming hydroxide due to its chemically combined water. According to National Lime Association, normal grades of hydrated lime that is suitable for most chemical purposes have 85% or more passing through sieve No. 200 while for special applications it may be obtained as fine as 99.5% passing sieve No. 325. The Hydrated lime used in this research brought from Alnoora plant in Karbala Province.

Table 2. Physical properties and materials specification of 40 mesh CR (Company for Tire Industry in AL- Najaf City - Engineering Office -Technology Department, 2009)

Property	Unit	Value
Density	gm/m^3	1.320
Specific gravity	------	1.130
Melting Point	°C	200
Tensile strength (σt)	MPa	40 - 70
Young's Modulus (E)	MPa	2600 - 2900
Elongation at Break	%	25 - 50
Acetone Extract	%	10 - 20
Rubber Hydrocarbon	%	48 min
Carbon Black	%	25 - 35
Metal Content	%	0.030 max
Ash at 550	%	8.000 min

Table 3. Characteristic of RR (SCTI, 2009)

Characteristic	Requirement
all hydrocarbon rubber	% 41-74
Iso prenic rubber, content (NR and BR)	% 40 min
Carbon black	%18-28
Acetone extract	%10-30
Chloroform extract	%10 max
Asphalt 550	%12 max
Metal content	30 max mm^2/kg
Mooney viscosity ML (1+4) 100 ^0C	30-80

Table 4. Physical properties of LDPE

(State Company for Petrochemical Industry, SCPI, 2008)

Property	**ASTM – standard**	**Unit**	**Value**
Density	D-1505	gm/cm^3	0.922
Melt index	D-1238	g/10min	0.33
Tensile strength at break	D-882, MD	MPa	21
	D-882, TD		19
Tensile strength at yield	D-882,MD	MPa	9
	D-882,TD		
(1% Secant Modulus)	D-882,MD	MPa	175
	D-882,TD		210
Elongation at break	D-882,MD	%	310
	D-882,TD		550
Kinetic coefficient	D-1894	----	0.6
Melting point	-----	^0C	170

Table 5 Physical properties of HDPE

(State company for Petrochemical Industry, SCPI, 2008)

Property	**ASTM – Standard**	**Unit**	**Value**
Density	D-1505	gm/cm^3	0.949
Melt index	D-1238	g/10min	0.15 - 0.33
Tensile yield strength	D-882	MPa	18 - 32
Tensile strength at break	D-882	MPa	10 - 60
Hardness	------	Shore D	45 - 70
Flexural modulus (Ef)	D-790	MPa	758 - 1103
Melting point	------	^0C	180

Tab1e 6. PP Properties (SCPI, 2008)

From	**polypropylene Fiber**
Specific gravity	0.91
Fiber length	(6-12) mm
Fiber thickness	(18-30) microns
Tensile strength	350 MPa
Young modulus	(5500-7000) MPa
Chloride content	Nil
Alkali content	Nil
Sulfate content	Nil
Melting point	(150-160) ^{0}C

Table 7. Physical and mechanical properties for SBS

(Company of Gulf International Chemicals, GIC, 2009)

Property or Characteristic	**Unit**	**Requirement or Value**
Density	gm/cm^3	1.242
Specific gravity	----	0.94
Modulus 300%	MPa	2.8
Tensile Strength (σt)	MPa	32
Elongation	%	880
Apparent	-----	White Kraton particles
Melting point	^{0}C	180

Table 8. Typical properties of SBR latex (Company of Gulf International Chemicals, GIC, 2009)

Property or Characteristic	**Unit**	**Requirement or Value**
Density	gm/cm^3	0.93
Specific gravity	-----	1.02$\pm$0.02 @ 25 **^{0}C**
Compressive strength	MPa	35
Tensile Strength (σt)	MPa	5.5
Flexural Strength	MPa	11.5
Elongation at break	%	450 - 600
Apparent	------	White emulsion
PH Value	------	7 - 9
Active Solids Content	%	45

Table 9. Physical properties and materials specification of SBR1502

(Company for Tire Industry in AL-Najaf City -Engineering Office - Technology Department, 2009)

Property or Characteristic	Unit	Requirement or Value
Specific gravity	-----	0.95
Modulus at 300 % ext	MPa	11-23
Tensile Strength (σt)	MPa	23 min
Elongation at break	%	340 min
Hardness	IRDH	-
Volatile matter	%	0.75 max
ETA extract	%	4.75-7.75 + stabilizer
Ash	%	1.00 max
Soap	%	0.50 max
Bound Styrene	%	23.5+1.0 max
Organic acid	%	4.7-7.2
Stabilizer	%	Advised by Supplier
Viscosity ML (1+4) 100 ^{0}C	M.U.	52$\pm$3
Melting point	^{0}C	200 $\pm$10

3. REQUIREMENTS OF DESIGN THICKNESS OF ASPHALTIC LAYER

In order to complete the requirement of the experiment program, HMA specimens are designed and tested by Marshall apparatus test with the optimum asphalt cement content (4.8%) for the surface layer – type A (nominal maximum size of used aggregate = 12.5mm) (ASTM D-1559, 2002; SCRB/ R9, 2004).

Resilient (Elastic) Modulus (Er) is an important parameter to determine the performance of the pavement and analysis or design the pavement reopens to move traffic loading. E values might be expected directly from lab test results or/and indirectly by relationship with other lab tests like Marshall Stability. Additionally, the layer relative strength coefficient (a) can be indicated in accordance to E of HMA which is in turn used in the determining the layer thickness and the calculations of Structural Number (SN).

Developed models relate resident (elastic) modulus E to Marshall Stability as below (Al-Bayati et al., 2014):

$$E = 1442\ e^{0.094\ M.S} \qquad (1)$$

Where: E = Mpa

M.S = kN & (E_{psi} = $E_{\ Mpa}$ $\times$145)

$$a = 0.35\left(\frac{E}{275\times10^3}\right)^{1/3} \qquad \text{Or chart in [AASHTO, 1993, pp.II-18]} \qquad (2)$$

E = psi, which is used to predict (a), the structural layer coefficient, of HMA (control and modified for the surface layer in the flexible pavement depending on E values (ASHTO, 1993). The result are included in Table (10).

In accordance to the adopted design procedure, several kinds of materials characterization and types testing have been used to assess the strength of the pavement structural substances; therefore, in any study one of them can be used. In addition, the designer should has a better considerate of the "layer coefficients" which have conventionally been adopted in the AASHT pavement design method. Therefore, the elastic modulus of the selected materials is not essential in this procedure. Generally, layer coefficients determined from test roads or satellite sections are favorite (Roberts et al., 1991).The results are included in Table (10).

Table 10. Results of Marshall Stability and resilient elastic modulus with corresponding layer coefficient for control mix (HMA) & modified HMA

Type of HMA	% of modifier	Marshall Stability (kN)	Resilient (Elastic) Modulus (Psi)× 10^3	Layer coefficient (a)
Control HMA	0%	9.30	501	0.427
modified with CR	12	10.0	535	0.436
	15	9.70	520	0.433
	18	8.60	469	0.418
modified with RR	9	9.20	498	0.427
	12	8.70	474	0.419
	15	7.80	435	0.408
modified with LDPE	2	12.5	678	0.473
	4	14.3	802	0.50
	6	11.7	628	0.461
Modified with HDPE	1	13.2	723	0.483
	3	15.0	856	0.511
	6	13.6	751	0.489
Modified with PP	1	12.8	696	0.477
	2	11.9	640	0.464
	3	9.60	516	0.432
Modified with SBS	1	14.2	794	0.498
	3	16.2	959	0.531
	6	16.5	986	0.535
Modified with S.SBR	1	9.90	530	0.435
	3	12.8	690	0.477
	6	10.3	551	0.441
Modified with L.SBR	1	8.50	465	0.417
	3	10.8	577	0.448
	5	8.70	474	0.420

It is well known that the engineering property of any paving or roadbed materials can be characterized by indicating the elastic modulus. However, for those material kinds that are exposed to a substantial rutting under load, this property i.e. elastic modulus might be not reveal the material's performance under load. Hence, resilient modulus states the substance's stress-strain behavior under common pavement loading circumstances (AASHTO, 1993). Material's strength is essential in addition to the stiffness. Moreover, future mechanistic-based methods may reflect strength as well as stiffness in the ingredients characterization methods.

A value coefficient is given to each layer material in the pavement structure in order to indicate the layer thicknesses in accordance to the structural number. This layer coefficient states the empirical correlation between SN and thickness of the layer and is a measure of the comparative ability of the material function as a structural element of the pavement.

The common equation below for the structural number reveals the relative influence of the thickness (D) and the layer coefficients (a) (AASHTO, 1993).

$$SN = \sum_{1=1} a_1 D_1$$

Identifying the corresponding layer coefficients despite the resilient modulus was adopted, as a standard substances quality measure is necessary due to their treatment in the structural number design method.

Elastic modulus is an essential design factor in the flexible pavement design. Therefore, it is incorporated into the design procedure which is adopted in the 1986 AASHTO guide. In addition, the stiffness modulus is an important parameter in appraising the pavements.

Furthermore, it (the 1986 AASHTO guide) assumed the typical value of the resilient modulus of asphalt concrete mixes to determine the required pavement layer thickness.

An equation might be used to predict the structural layer coefficient of a dense-graded AC surface course in accordance to its resilient modulus (E_{AC}) at 68°F. While stiffer mixtures i.e. has higher modulus asphalt concretes are more resistant to bending, they may are more exposed to the fatigue and thermal cracking.

Many factors affect the structural design of asphalt concrete pavement layers. The asphalt mix stiffness can be named as the most important factor. However, the assumed stiffness value are used in the structural design of pavements instead of the actual values. It is well known that the stiffness modulus test needs skilled labour and special equipment in addition to that it is time and effort consuming. Hence, it is not implemented to check the stiffness of the asphalt concrete mixes. This investigation was implemented to found a relationship between the stiffness and modifier type (MT) with modifier content (MR).

$$SN_1 = a_1 \times D_1 \quad (3)$$

$$D_1 = \frac{SN1}{a1}$$

Where: D_1: The thickness of HMA layer (surface layer) in flexible pavement

a_1: Layer coefficients

SN_1: Structural Number

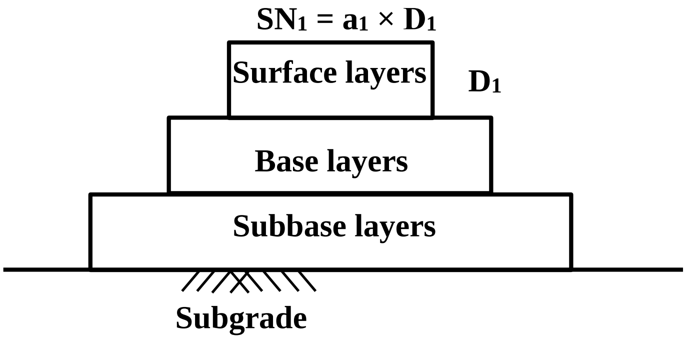


Fig. 1. Layers of adopted flexible pavement.

From a chart in AASHTO-93 depending on the following data:

- R = 95% (Reliability)
- S_o = 0.35 (combined street error of performance prediction) from experience
- $Wt_{18} = 15 \times 10^6$ (for main highway)
- E for base = 30×10^3 psi
- ΔPSI = 1.9 [4.6 (for the flexible pavement) – 2.5 (for main highway) – 0.2 (for swelling effect]
- SN_1 = 3.3 (from chart) (ASHTO, 1993, pp. II-32)

4. PREDICTION MODEL FOR THE EFFECT OF HMA MODIFICATION ON LAYER THICKNESS

- **Model Prediction**

In general, two approaches are used to investigate the appropriateness of the recommended regression models. The former is based on observing the goodness of fit measures, while the later is based on the graphical analysis of the residuals that are named as diagnostic plots.

- **Goodness of Fit Measures**

The main aim of the measures of goodness of fit is to compute the quantity of how well the suggested regression model fits the input data. The value that is commonly presented is coefficient of multiple determinations (R^2).

Its value i.e. the R^2 is the percent difference of the criterion variable explained by the proposed model and calculated in accordance to the following equation:

$$R^2 = 1 - (SSE / SST)$$

Where SSE is the error sum of squares = sum (y_i-y'_i), where y_i is the actual value of criterion variable for i^{th} case, y_i' is the actual value of criterion variable for the i^{th} case, and y'_i is the regression predicted value of the variable i^{th} case. SST is the total sum of squares = sum (y_i-y'_i)^2, where y'_i is the mean observed y. it is worthy to state that the correlation between the observed and calculated value of the dependent variable is R^2 and $0 \le R^2 \le 1$ (Al-Hadidi et al., 2015).

- **Diagnostic Plots**

On the other hand, computing the predicted criterion values, y'_i, and the residuals, $e_{i\ to}$ assess the model adequacy represent another effective approach. Residuals are the variance between an observed value of the criterion**.**

Variable y_i and the value predicted by the model, ($e_i=y_i-y'_i$). the next step represent plotting several functions of the computed quantities. The plot may used either to confirm our choice of model or to indicate that the model is not appropriate (Al-Hadidi et al., 2015).

Following includes the regression method and its term for thickness of the surface layers (asphaltic layers) including (base, binder, and wearing if needed as shown in Fig. 2).

The dependent variables: D

The independent variables: MT, MR

Where: D = Thickness of Surface Layers.

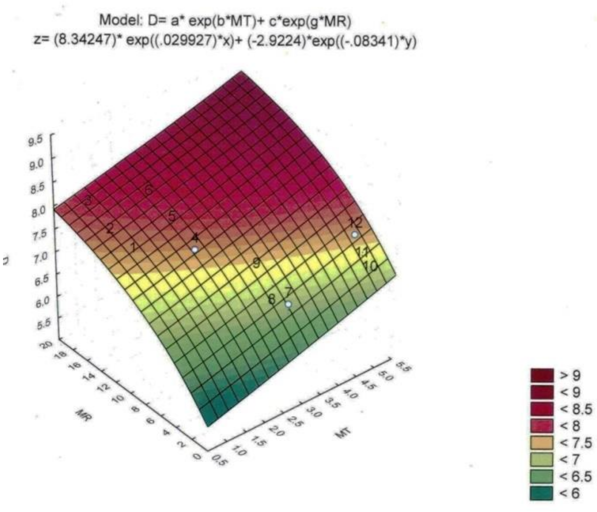
MT = Modifier Type.

MR = Modifier Content.

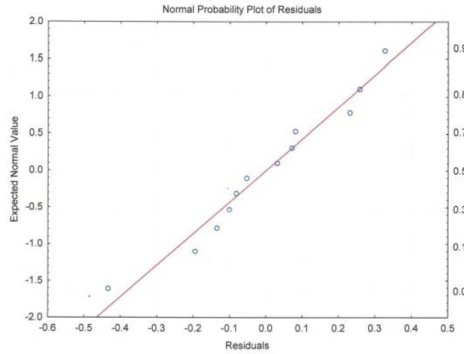
The model that can be used for this purpose:

$$D = a*e^{(b*MT)} + c*e^{(g*MR)}$$

A = 8.34247 , b = 0.029927
C = -2.92240 , g = -0.083410
R^2 = 0.69600 , R = 0.880000

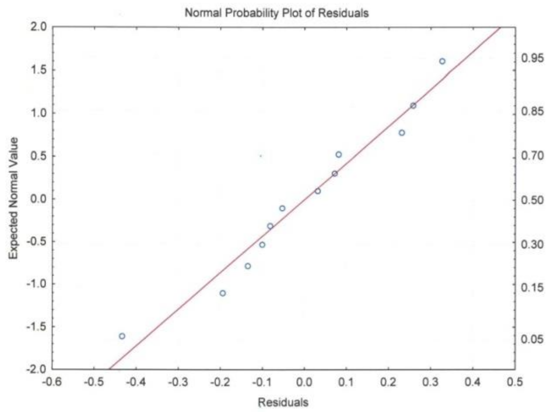


a- Surface representation of thickness variation with modifier type and modifier content.

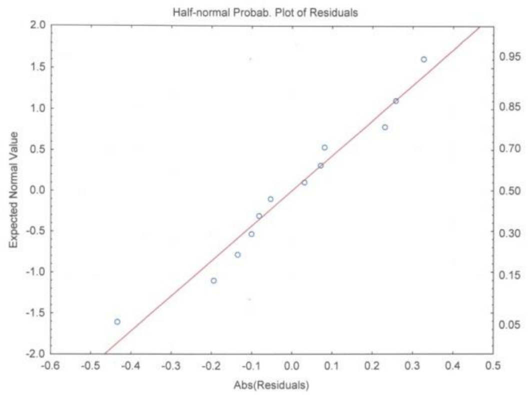


8.34247	1.005738	8.29488	0.000034	6.02323	10.66170
0.02993	0.012056	2.48228	0.037976	0.00213	0.05773
-2.92242	0.943493	-3.09745	0.014723	-5.09812	-0.74672
-0.08341	0.058610	-1.42311	0.192510	-0.21856	0.05175

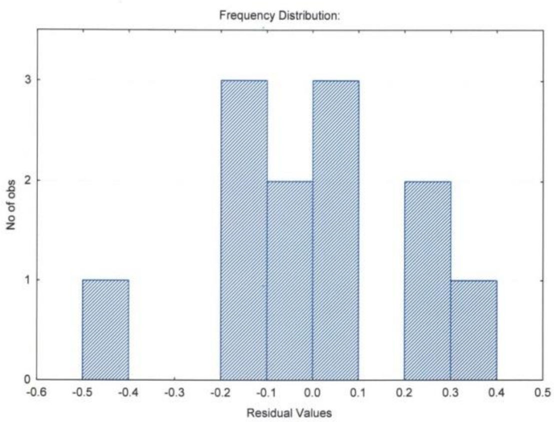
b- Normal probability plot of residuals.



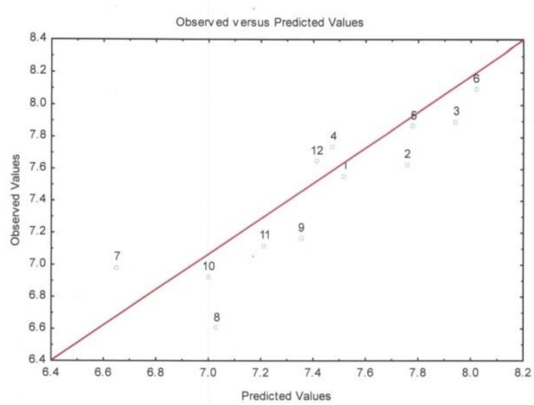
c- Normal probability plot of residuals.



d- Half - normal probability plot of residuals.



e- Frequency distribution plot.



f- Observed versus predicted values.

Fig. 2. Diagnostic plots of the model.

5. CONCLUSION

Within the limitation of the collected date used in this search, the following conclusions can be introduced:

1. Investigations of Marshal tests on modified surface HMA layer imposed mostly a significant increase in stability values for different modifier types content that can be reflected on finding modulus values for the same mixes and then on estimating layer relative strength coefficient which allows for determining layer thickness.
2. A model is predicted to estimate the HMA layer thickness within the flexible pavement. It is clear that the thickness can be predicted in terms of the main selected variables with ($R^2 = 0.696$).
3. Modifier type and content play a significant role in the layer coefficient (a) and then (D) thickness of asphaltic layer.
4. All most modified HMA is the best solution for development of local pavement with available materials by decreasing design thickness. And we can say that cost estimation of pavement with modifiers is similar to the cost of the pavement without modifiers when taking into consideration the cost of maintenance.

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