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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 thickness design of asphalt pavement layers is a function of many factors; 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 estimate the layer relative strength coefficient (a) that is used to estimate the Structural Number parameter (SN), which allows for determining 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 showed 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. Several distresses hamper the performance of the flexible pavements in Iraq and cause in premature failure. In the flexible pavements, the primary forms of distress are fatigue cracking, rutting, moisture damage, and thermal cracking. These distresses appear themselves most of the time due to construction material quality, poor maintenance, and improper design.

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 normally 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 improve the performance of paving mixture to meet the requirements under prevailing conditions from loading and environmental effects.

The technical reasons for using modifiers in asphalt concrete mixtures are to produce stiffer mixes at high service temperature to resist rutting as well as to obtain softer mixtures at law temperature to minimize thermal cracking and improve fatigue resistance of asphalt pavement.

Almost, the main reasons to modify bituminous materials with different types of additives could be summarized as follow:

- To obtain softer blends at law service temperature and reduce cracking
- To reach stiffer blends at high temperature and reduce rutting
- To increase the stability and the strength of mixtures
- To improve fatigue resistance of blends
- To reduce structure thickness of pavement (King et al., 1986).

The use of polymer-modified asphalt (PMA) to achieve better asphalt pavement performance has been investigated for a long time. The improved functional properties include permanent deformation, fatigue, low temperature cracking, stripping, 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 polymer characteristics, polymer content, and bitumen nature as well as the blending process. Despite the large number of polymeric products, there are relatively few types that are suitable as bitumen modifiers. Selected polymers should be compatible with bitumen, capable of being processed by conventional mixing and laying equipment, able to maintain their premium properties during mixing, storage and application in service. Also, useing of a modifier should be cost effective (Crossley, 1998).

Polymers can be classified into two categories: elastomers and Plastomers. Easterners add only a little strength to the binder at the initial low strain level, but they can be stretched out and get stronger at a higher strain, level and recover when the applied load is removed. Plastomers form a rigid three dimensional networks and provide tensile strength under heavy load but crack at higher strains.

An elastomer is a polymer that has a flexible "rubber" and large side- chains in its structure. Styrene butadiene styrene (SBS) is an example of this type. Thermoplastic elastomers derive their strength and elasticity from a physical cross-linking of the molecules into a three dimensional networks. Elastomers are chosen to give a more resilient flexible pavement, as their name suggests, tend to improve the elasticity of asphalt binder, and as such they may increase the failure strain of asphalt concrete at low temperatures.

For SBS, it is the polystyrene end-blocks that imparts strength to the polymer and the mid-block butadiene that gives the material its exceptional elasticity. This combination of strength and elasticity gives SBS modified asphalts the ability to resist permanent deformation and to minimize fatigue and low temperature cracking (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).

A plastomers is a polymer that will deform in a plastic or viscous manner at the melt temperatures and becomes hard and stiff at the low temperatures, i.e. the structure is reversibly broken down with the application of heat. Whereas elastomers can improve the resistance to rutting as well as low temperature and fatigue cracking, plastomers will generally only improve the resistance to rutting. Plastomers result in mixes with a higher stability and stuffiness, which are the materials that increase the stiffness of the binder and therefore its 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 easily blended into asphalt by simple low shear mixing. As with most PMA systems, there must be compatibility between the base asphalt and the EVA polymer to ensure that the optimum properties are achieved. 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).

The processes have been used to add polymer into the asphalt-aggregate mix are the dry and wet process:

1.1.1. The Dry Process

This process includes mixing the polymer particles with aggregates prior to addition to asphalt, where aggregate are heated, then polymer is added and mixed for about (15) seconds until a homogeneous mixture is obtained. Straight binder is then added in a conventional mixing plant. It provides a way to blend the polymer with the asphalt and aggregate without the use of the special equipment needed in the wet process. In the dry process, modified binders are produced, since there is no digestion of the rubber by the conventional binder. The time of contact between the rubber and the binder in the dry process is relatively short and not enough to produce all necessary reactions between the two materials (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. The more common method, referred to as the wet process, consists of the addition of the polymer to the asphalt binder. The straight binder is initially preheated to around 190°C in a tank under hermetic conditions and then transported to a blending tank, where rubber is added. The process is facilitated by a mechanical agitation produced by a horizontal shaft (Al-Bana'a, 2009).

There are two principal solutions to construct a more durable pavement; firstly, applying a thicker asphalt pavement that will increase the construction cost and, secondly, making an asphalt mixture with modified characteristics. Modified binder (for example, polymer modified binder) was also recommended to improve the resistance of the asphalt binder against rutting and thermal cracking (fracture of the pavement due to the lack of flexibility at low temperatures) of asphalt pavement (Al-Harbi, 2012).

The polymer addition increases the viscosity (stiffness) and flexibility of the blend at the high and intermediate temperatures, thus improving the rut resistance and fatigue characteristics of the mix while the softer asphalt base and polymer presence provide an improved low temperature cracking resistance. The higher viscosity of polymer modified asphalts at the high temperatures also results in thicker films on the aggregate particles, causing less "drain down" in open graded mixes and providing better long term durability for all mix types (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 to 1.5 percent lime by a dry weight of aggregate to the mix. If an aggregate has more fines present, it may be necessary to use more lime additive due to the increase of the surface area of aggregate. Three forms of lime are used: hydrated lime ($Ca\ (OH)_2$), quick lime (CaO), and Dolomitic limes (Terrel and Epps, 1989).

Several methods exist for adding lime to mixtures. Dry hydrated lime is added prior to the asphalt cement. However, there is a problem in maintaining the coverage until the asphalt cement is added. Using hydrated lime slurry will increase the amount of water needed and the fuel costs of production. Adding dry hydrated lime to the wet aggregate has the same results as hydrated lime slurry.

Hot (quicklime) slurry is equivalent in cost to hydrated lime, but when slaked, there is a 25 percent higher hydrated lime yield. Also, the elevated temperature during slaking helps to evaporate some of the added moisture. Hydrated lime creates a very strong bond between the bitumen and the aggregate, preventing stripping at all pH levels. It was found that the hydrated lime reacted with silica and alumina aggregates in a pozzolanic manner added a considerable strength to the 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, Low density polyethylene LDPE, high density polyethylene, HDPE, Polypropylene PP, 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 type of these modifiers was blended with asphalt cement by wet process at various blending 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 is brought from tires factory in AL- Najaf governorate. It is black granules and recycled from used tiers (specific gravity is 1.13) with various practical sizes. Three sizes are obtained from sieving analysis at sieves (No 50 (0.3mm), No.8 (2.36mm), and No.4 (4.75 mm).

Crumb rubber (CR) is the recycled rubber obtained by mechanical shearing or grinding of tires into small coarse crumb rubber. Tires are composed of several different types of rubber compounds (Company for Tire Industry, 2009).

The major CR compositional effect on asphalt rubber (AR) physical properties is the total rubber hydrocarbon content with additional effects from the natural rubber content. When using CR, it is important to comprehend that tire rubber is typically composed only of about one-half of actual rubber polymer that 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). The properties are included in Table (3).

Low Density Polyethylene (LDPE)

Polyethylene is brought from tires factory in AL-Najaf governorate, which is a white granules and used to produce plastic belts in the tires factory and another private factories in Iraq. LDPE is a plastomers polymer, in which the most common branch length is four carbons long. 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, which is a white granule and used to produce plastic belts in the tires factory and another private factories in Iraq. High-Density Polyethylene (HDPE) (0.941 < density < 0.965) is a plastomers thermoplastic polymer material composed of carbon and hydrogen atoms joined together forming high molecular weight products. The properties are included in Table (5).

Polypropylene (PP)

It was brought from the locally markets in Baghdad– bab Almuadham; it is a white fiber apparent product. Polypropylene is used as a modifier in asphalt concrete to satisfy the desire mechanical properties of the asphalt pavement. The properties are included in Table (6).

Styrene Butadiene Styrene (SBS)

A Styrene Butadiene Styrene is brought from the locally markets in Iraq. It is white tri-block particles with small size. It is the most common asphalt polymer used in the asphalt modification. SBS is elastomer tri-block copolymer incorporating styrene sections attached to a central butadiene section. The polymer molecules can be in different lengths and can have different arrangements of the molecules. These differences can affect the degree of modification provided by the polymer as well as the ease of blending and the storage stability. The polymer polystyrene is made up of many 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 rubber styrene butadiene (SBR) is obtained locally from tires factory in AL-Najaf governorate. It is dark yellow color as block rubber, which is cut into small pieces in the laboratory to simplify the process of mixing with asphalt (Company for Tire industry, 2009).

SBR is thermoplastic elastomers polymer which derives its strength and elasticity from a physical cross-linking of the molecules into a three dimensional networks. It is a block copolymer having two different sorts of repeating molecular units that are polymerized in a random 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 brought from the locally markets in Iraq. It is a white emulsion apparent product. 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 benefits of SBR modified asphalt is improving the properties of bituminous concrete pavement and seal coats. Low-temperature ductility is improved, viscosity is increased, elastic recovery, adhesive and cohesive properties of the pavement are improved (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 or characteristic	Unit	Requirement or Value
Specific gravity	------	1.130
Density	gm/m^3	1.320
Young's Modulus (E)	MPa	2600 - 2900
Tensile strength (σt)	MPa	40 - 70
Elongation at Break	%	25 - 50
Melting Point	^{0}C	200
Rubber Hydrocarbon	%	48 min
Carbon Black	%	25 - 35
Acetone Extract	%	10 - 20
Ash at 550	%	8.000 min
Metal Content	%	0.030 max

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 ^{0}C	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. Characteristic of PP (SCPI, 2008)

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

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 $^{\mathbf{0}}$**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 may be estimated directly from laboratory testing and indirectly by correlation with other laboratory tests like Marshall Stability. Additionally, E of HMA is used to estimate the layer relative strength coefficient (a) that is used for the calculation of Structural Number (SN), which allows for determining the layer thickness.

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

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

Where: E = Mpa

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

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

E = psi, is used to estimate the structural layer coefficient (a) 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).

Although there are many types of material proper types and laboratory test procedures for assessing the strength of pavement structural materials, one has been adopted as a basis for design in this guide. However, the user should have a better understanding of the “layer coefficients” that have traditionally been used in the original AASHT flexible pavement design procedure; it is not essential that the elastic modulus of these materials be characterized. In general, layer coefficients derived from test roads or satellite sections are preferred (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)$\times 10^3$	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

Elastic modulus is a fundamental engineering property of any paving or roadbed material. For those material types which are subjected to a significant permanent deformation under load, this property may not reflect the material's behavior under load. Thus, resilient modulus refers to the material's stress-strain behavior under normal pavement loading conditions (ASHTO, 1993). The strength of the material is important in addition to stiffness, and future mechanistic-based procedures may reflect strength as well as stiffness in the materials characterization procedures.

A value coefficient is assigned to each layer material in the pavement structure in order to convert actual layer thicknesses into the Structural Number (SN). This layer coefficient expresses the empirical relationship between SN and thickness and is a measure of the relative ability of the material function as a structural component of the pavement.

The following general equation for structural number reflects the relative impact of the layer coefficients (a) and thickness (D) (ASHTO, 1993).

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

A though the elastic (resilient) modulus has been adopted as a standard material quality measure, it is still necessary to identify (corresponding) layer coefficients because of their treatment in the structural number design approach.

Resilient modulus is an important design parameter in the flexible pavement design. The 1986 AASHTO guide for the design of pavement structures incorporated the resilient modulus into design procedures. Apart from design the stiffness modulus is also a key parameter in evaluating the pavements.

The resilient modulus of asphalt concrete mixes is an important input in the structural design process of AC pavements, assumed (typical) values for this modulus are used to determine the required pavement layer thicknesses.

An equation may be used to estimate the structural layer coefficient of a dense-graded asphalt concrete surface course based on its elastic (resilient) modulus (E_{AC}) at 68°F. Although higher modulus asphalt concretes are stiffer and more resistant to bending, they are also more susceptible to the thermal and fatigue cracking.

The structural (thickness) design of asphalt pavement layers is a function of many factors; one of the most important factors is the stiffness of the asphalt mix. The structural design of pavements is performed using assumed values for stiffness that may not represent the actual stiffness of the used material. Stiffness modulus testing is time and effort consuming and requires skilled labour and special equipment. Therefore, it is not performed on a routine basis to check the stiffness of the asphalt-concrete mixes. This study was performed to establish a relationship between the stiffness and modifier type (MT) with modifier content (MR).

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

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

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

a_1: Layer coefficients

SN_1: Structural Number

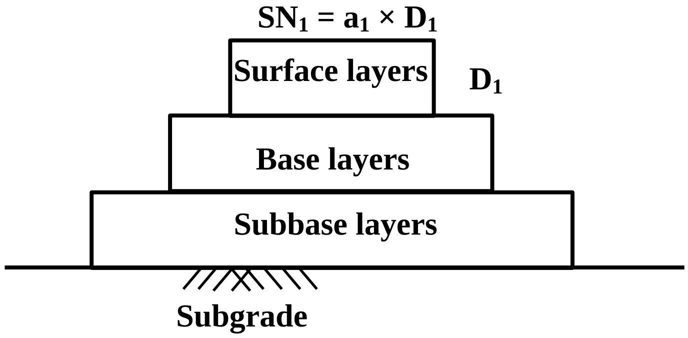


Fig. 1. Layers of adopted flexible pavement.

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**

There are two approaches generally used to assess the adequacy of the proposed regression models. The first one is based on examining the goodness of fit measures, while the second approach is based on the graphical analysis of the residuals, also called diagnostic plots as shown in the articles below:

- **Goodness of Fit Measures**

The measures of goodness of fit aimed to quantify how well the proposed regression model obtained fits the data. The measure that is usually presented is coefficient of multiple determinations (R^2).

The R^2 value is the percent variation of the criterion variable explained by the suggested model and calculated according 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. R^2 is the square of the correlation between the observed and calculated value of the dependent variable and $0 \leq R^2 \leq 1$ (Al-Hadidi et al., 2015).

- **Diagnostic Plots**

Another effective approach to the assessment of model adequacy is to compute the predicted criterion values, y'_i, and the residuals, e_i. Residuals are the difference between an observed value of the criterion residuals are the difference between an observed value of the criterion**.**

Variable y_i and the value predicted by the model, ($e_i=y_i-y'_i$). Then plot various functions of these computed quantities where the plot are examine either to confirm our choice of model or for indications 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.

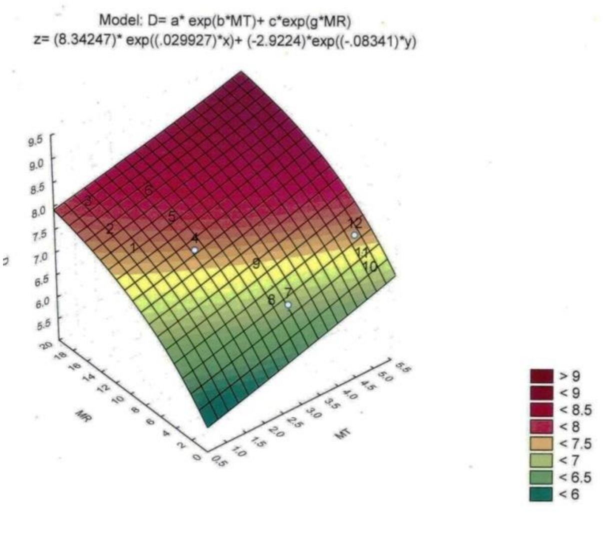
MT = Modifier Type.

MR = Modifier Content.

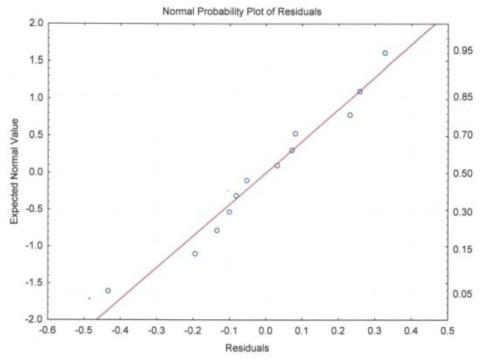
The model that can be used for this purpose:

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

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

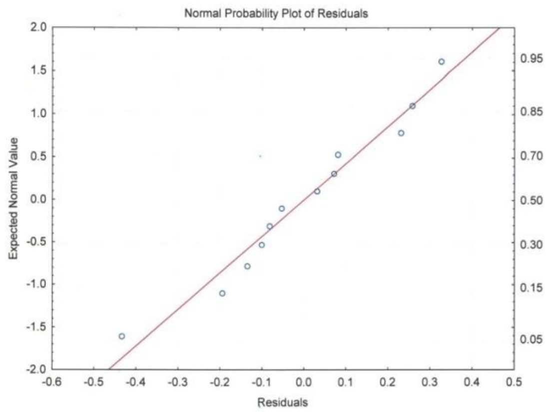


a- Surface representation of thickness variation with modifier type and modifier content.

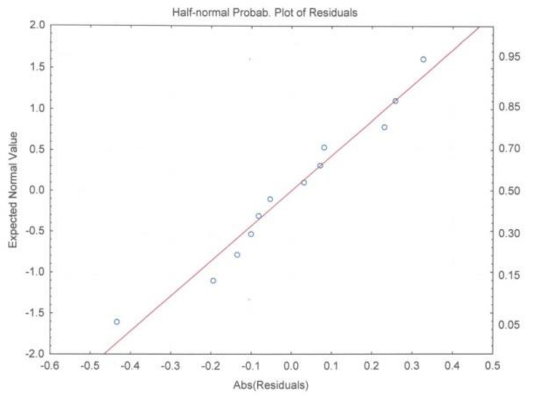


8.34247	1.005738	8.29488	0.000034	6.02323	10.66170
0.02993	0.012056	2.48228	0.037976	0.00213	0.05773
-2.92242	0.943493	-3.09745	0.014723	-5.09812	-0.74672
-0.08341	0.058610	-1.42311	0.192510	-0.21856	0.05175

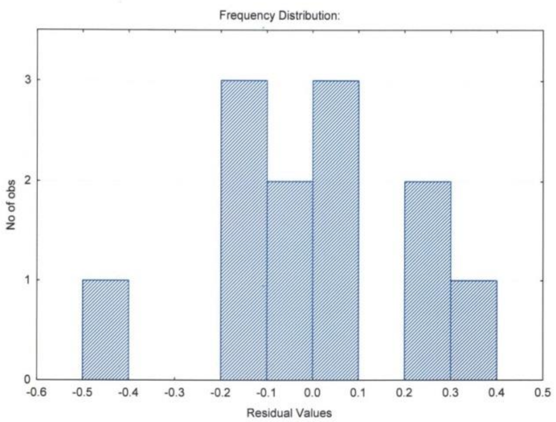
b- Normal probability plot of residuals.



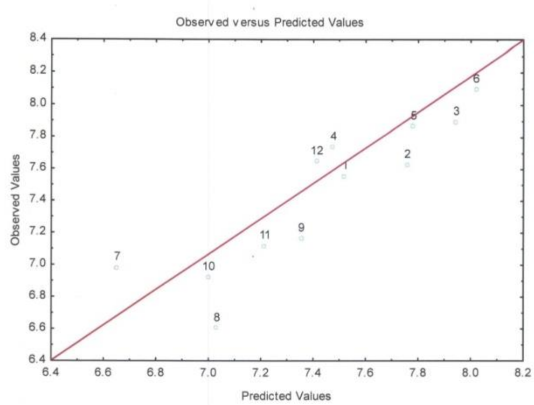
c- Normal probability plot of residuals.



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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