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Modification of Bitumen for use in Road Construction

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Polymer Modified Asphalt, EPRI. Bitoplast, Permanent deformation, service life.

ABSTRACT

Since 1873 polymers have played an important role in the asphalt industry. There are a large variety of polymers currently being used in asphalt modification. The purpose of modification depends on the problem it addresses or the type of asphalt mixture it will be used to modify. Polymer modified mixtures have been shown to have reduced temperature susceptibility providing better resistance to permanent deformation and high service life.

The purpose of this paper is to assess the laboratory behavior of (**EPRI Bitoplast**) polymer modifier for penetration grade local asphalt 60/70 (this type of polymer is a special type of atactic polypropylene, 100% recyclability and water unsoluble) with the objective of producing a superior paving grade product resulting in reducing rutting & cracking and increasing service life of paving mixture with lower life cycle cost.

INTRODUCTION

It is known that, the primary pavement distresses in asphalt concrete pavements are; high temperature pavement deformation, low temperature thermal cracking and load associated fatigue cracking. Aging and moisture susceptibility compound these deficiencies[1]. Considerable research effort has been expended in improving or modifying the properties of bituminous binders since 1873[2,3,4] to found new applications of low quality asphalt and also to improve the quality of performance of asphalt mixtures used with respect to distresses observed in pavements. One major type of modifier that has been found inward acceptance in the profession is the polymer modified asphalt. The main reasons that asphalt modification has become more accepted are[5]:

1. *Traffic factors have increased including:* heavier loads, higher volumes and higher tire pressures (in Egypt; the inter city passenger demand was 2.0 Million/day in 1992 and will increase to 5.7 million/day in 2012 whereas the total inter city vehicle traffic demand of private car, taxi, bus and truck in terms of trip end demand was 270 thousands vehicle/day in 1992 and will increase to 730 thousands in 2012 with annual investment on intercity roads is in the rate of 78 M.L.E.[6]).
2. Higher costs have created a tendency to construct thinner pavements, thus reducing the service life of the pavement.
3. Environmental and economic pressures to dispose of industrial waste materials.

In general, polymers may be viewed as: (1) **dispersed systems** or (2) **reacted systems.**

While dispersed systems are the most common as:

(SBS: Styrene – Butadiene – Styrene)

(SBR: Styrene – Butadiene – Rubber)

(Neoprene)

(SEBS: Styrene – Ethylene – Butylene – Styrene)

(EVA : Ethyl Vinyl Acetate)

and (PE: Polyethylene).

Some of these polymers create a polymer network but always remain in a separate phase from the original asphalt cement. Separation of phases and compatibility problems may often be a concern.

In contrast to dispersed systems, reacted polymers are not as common but are characterized by the fact that a chemical reaction between the polymer and asphalt occurs, thus eliminating the potential problem of separation. EGA (Ethylene. Glycidyl-Acrylate) is a reacted polymer produced by Dupont and Chevron Co. within the last decade[7].

Also, two classes of polymers are typically used in modification of asphalt; Elastomers & plastomers[8]. Elastomers are the most popular class of modifier used to modify asphalts and are chosen to give a more resilient & flexible pavement. SBR&SBS are elastomeric polymers most commonly used. Plastomers form a tough, rigid, three dimentional network. These polymers give high early strength to resist heavy loads. Plastomeric asphalt modifiers include EVA&PE.

In general, the modification results are highly dependent upon the concentration, the molecular weight, the chemical composition and the molecular orientation of a particular polymer as well as the crude composition, the refining process and the grade of the base asphalt used.

EXPERIMENTAL

A) Raw Materials Used :

The raw materials used in this study were as follows:

(1) Local asphalt of penetration grade 60/70 produced from El Nassr for Petroleum Co. in Suez.

(2) Coarse and fine aggregates are siliceous linestone.

(3) Siliceous sand

(4) Artificial sand

(5) Limestone mineral filler.

(6) EPRI Bitoplast. (E.B.P) additive.

Aggregates, sand and mineral filler used for the production of unmodified and modified asphalt paving mixtures are identical to eliminate the effect of variation of type on their final properties.

B) EXPERIMENTAL PROGRAM

Table (1) illustrates methods of determination of the various materials, whereas the experimental program includes the following steps:

1- Preparation of modified asphalt binder.

2. Preparation of asphalt mixes using Marshall procedure.

3. Resistance of asphalt mixes to plastic deformation.

4. Effect of polymer on service life of asphalt mixes.

1. Preparation of Modified Asphalt Binder:

The procedure of mixing EPRI Bitoplast polymer with the virgin asphalt binder was as follows:-

- The calculated amount of virgin asphalt was heated in its original container in an oven (temperature ranging from 130-140°C) until it soften and became pourable, stirred until homogeneous and then poured into suitable blending containers.
- The container of asphalt was then heated to 160-170°C for 10 minutes before adding the polymer.
- The desired amount of (E.B.P) was then slowly added into the virgin asphalt and the blend was stirred continuously for a total of two hours.
- The blend was placed into containers covered tightly. These containers were then placed in an oven at 180°C for another two hours.
- The resulting binder was ready for use and subsequent testing.

Two percentages of E.B.P. polymer as 5% & 7% of weight of virgin asphalt were used in producing modified binder. The characteristics of virgin and modified asphalt are illustrated in Table (2).

2. Properties of Asphalt Mixes Using Marshall Procedure.

In order to select target "design" asphalt contents "Marshall" mix design was developed. The test criterion selected was for a 75 blow Marshall compaction. Also, in order to determine the optimum asphalt content, four levels of asphalt content (4,5,6&7%) were used for each mix. At each asphalt content, two replicates were prepared and the average of the two were then used to develop the typical Marshall test result plots. The characteristics of aggregates used are illustrated in Table (3), also, Table (4) shows gradation of the selected job mix formula and the provisional specification limits of 4-C gradation used.

According to the selected job mix formula, the proportion of the aggregates in the blend are:

Aggregate Type	% in Blend
- Coarse Aggregates	26
- Fine Aggregates	36
- Siliceous Sand	17
- Artificial Sand	17
- Limestone mineral filler	4

Table (5) and Fig. (1) illustrates Marshall mix properties of the produced mixes.

3. Mix Resistance to Plastic Deformation Using Wheel Tracking Machine

Wheel tracking experiment had been performed on both virgin and modified asphalt mixtures using the Transport and Road Research Laboratory (TRRL) device[10]. The TRRL method is designed to measure the rutting depth of asphalt concrete under repeated loads of 6.25 kg/cm^2 and the rutting deformation was recorded by means of a can and springless dial gauge reading to 0.1271mm (0.005 in) with time or number of wheel passes (n). The test temperature was 60°C.

- Deformation /time curves were drawn as shown in Fig. (2) and illustrated in Table (6). Also, log deformation versus log number of passes curve was shown in Fig. (3) and the failure point of each mix is considered when the plots deviates from the straight line as deseribed by Sharif[11 & 12].

4. Effect of Polymer on Service life of Asphalt Mix[13]:

As known, it was believed that if the penetration of the asphalt in the asphalt carpets in the field drop below a datum of about 20, the carpets will harden to the degree that brittlness cracking will develop, which is a very reasonable assumption and is adopted by many states in U.S.A. On the other hand, according to the data given by the Egyptian Roads and Bridges Authority (RBA), the average approximation life of penetration grade asphalt 60/70 produced from El Nasr for Petroleum Processing Co. until hardening and shrinkage cracks start to develop in Egyptian dense asphaltic concrete defined for voids between 3:5 is about 10 years. So, in this step accelerated aging test in thin film oven test and penetration after heating (@ 163°C) for 5, 10 & 15 hours was determined then the relative life accepted to accepted Laboratory aging results for the two types of asphalts are illustrated in Table (7). Also, a correlation between laboratory and filed aging is quite necessary. The regression equations which illustrate this correlation was determined.

RESULTS AND DISCUSSION

A) Effect of Polymer on Properties of Modified Asphalt

As seen from Table (2), the following facts were obtained:

- The mixing of polymer with virgin asphalt resulted in a "Modified Asphalt Binder" having higher hardening and a little difference in chemical constituents as compared to the virgin sample. Once a polymer is added to the asphalt binder there is a dramatic increase in the viscosity (in percentage of 298.8 & 704.5 for samples (1&2) at 135°C and 1369.6 & 1579.5 at 60°C respectively) but for the penetration at 25°C only a few pen points decrease (in percentages of 23.1 & 30.8 for samples (1&2) respec.)
- Increasing the content of polymer in the virgin asphalts increases the hardening of the final product. This may be attributed to the chemical composition of the polymer as it is a thermoplastic and dispersed material. The polymer domains represent polymer swollen with the solvating phase of asphalt (oil phase) or in the other words, this type of polymer create a polymer network to the asphalt molecules.
- The difference in chemical constituents for the two modified samples may be attributed to molecular orientation of the polymer molecules itself.

B) Effect of Polymer On Marshall Mix Properties of Virgin Mix

From Table (5) & Fig. (1) the following facts were obtained:-

- Marshall mix properties for mix produced using modified binder (5%) was not within Egyptian Standard Specification Limits of asphalt concrete mixture; so this mix was omitted in further test. We take only in our consideration the mix using 7% as modifier of asphalt.
- The table indicated that, a slight improvement in stability, air voids (in both mix & mineral aggregates) in percentages of 14.2,9,4, respectively as compared to the virgin mix occur as the E.B.P 7% is used.

- Also, from table it was seen that an other Marshall parameter of interest is the stability/ flow ratio (sometimes referred to as the Marshall quotient). This parameter is thought to be an empirical indicator of the mix stiffness. The Marshall quotient appears to slightly increase in percentage of 16.1 as (compared to virgin mix) using polymer. The increase of the ratio values with respect to virgin mix is the result of increase in stability value for this mix

C) **Effect of Polymer On Plastic Deformation of Virgin Asphalt Mix**

As seen from Table (6) and Fig. (2), the addition of polymer significantly reduces the permanent deformation (rutting depth) of asphalt mixture after 45 minutes in percentage of 88.2 as compared to mixture using conventional (virgin) binder source. This may be attributed to chemical composition of the polymer.

Also, from Fig. (2) (based on vertical deformation of the two asphalt mixes versus the number of wheel passes) it is noticed that; the deformation of the mixes significantly different in behavior. The plots of virgin mix start out as straight line after that, the plots show a deviation upward from straight lines at a number of passes equals 1260 wherein for modified mix the deformation plot had no deviation yet from the straight line. *This means that the modified mix had longer fatigue life than the virgin mix.* From this figure the measurements of fatigue which is considered the failure point for virgin mix was as follows:

ΔH = Vertical deformation = 0.0244 in.

N = Number of wheel passes = 1260

In addition, from table (6), the rate of deformation in the third part of the curve is calculated as follows:

1. For Virgin Asphalt Mix :

$y = 0.0122\,x + 0.2481$ $R^2 = 0.9734$

Rate of deformation = 0.0122 (mm/min.)

2. For Modified Asphalt Mix

$y = 0.0035\,x - 0.057$ $R^2 = 0.9857$

Rate of deformation = 0.0035 (mm/min.)

It is obvious that; the rate of deformation for modified Asphalt Mix is approximately lowering by 71.3% as compared to the Virgin Mix.

D) Effect of Polymer on Asphalt Mix Service life:

According to the data given in Table (7); the regression equations which give the relation between laboratory aging time and penetration was as follows where penetration is noted as "y" & time in hours as "x"

For Virgin Asphalt Cement:

$$y = e^{(a+b\sqrt{x})}$$

where a & b = constants

a = 4.01658, b = - 0.27199 R^2= 0.9821

For Modified Asphalt

$$y = \frac{1}{a+b\sqrt{x}}$$

a = 0.01285, b = 0.00479 R^2= 0.99124

From the above equations, the relative life accepted to laboratory aging results for the asphalt types are:

Virgin Asphalt	*10 years*
Modified Asphalt	*32 years*

CONCLUSION

The polymer-modified binders obtained by mixing EPRI Bitoplast macromolecular materials with pure road asphalt AC 60/70 produced from El Nasr Co., produced a satisfactory technical solution to certain special problems. The experimental work conducted on (EPRI Bitoplast) appear that it is suitable for road applications in fact, it grant high plastic deformation resistance (88.2% lower) and higher service life (nearly equals 32 years) as compared to virgin mix. So the results show that we were able to produce "Polymer Modified Asphalt". The heavier vehicle loads, higher traffic volumes and increased tire pressures have forced user agencies to explore polymer modification for asphalt pavement applications so polymer modification of asphalt binders become a more accepted method for addressing pavement distresses.

RECOMMENDATIONS

1. The Laboratory investigation of modifying asphalt indicated clearly it can be applied in Egypt, so the practical field scale must be taken into consideration.
2. Considerable research effort must be expended in improving or modifying the properties of bituminous binders.

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Table (1): Parameters Used

Test	Designation Number	
	ASTM	AASHTO
1. Asphalt Phase:		
- Penetration (@25°C, 100g, 5s)0.1mm	D5	T49
- Softening point (Ring & Ball)°C	D36	T53
- Ductility (@25°, 5cm/min.) cm	D113	T51
- Absolute viscosity (@ 60°C) poise	D2171	T202
- Dynamic viscosity (@ 135°C) Pa.s	D2196	---
- Specific gravity (@ 25/25°C) using a pycnometer	D70	T43
- Chemical constituents and wax contents	Using Holde's method[9]	
- Effect of heat & air on asphaltic materials (TFOT)	D1754	T179
2. Aggregate Phase:		
- Sieve analysis of fine & coarse aggregate	C 136	T27
- Sieve analysis of mineral filler	---	T37
- Resistance to abrasion (using Los Angeles Machine)	C131	T96
- Bulk specific gravity of coarse aggregate & absorption	C127	T85
- Bulk specific gravity of fine aggregate & absorption	C128	T84
3. Asphalt Concrete Mixtures Phase:		
- Resistance to plastic flow of bituminous mixtures using Marshall apparatus	D1559	T245
- Resistance to plastic deformation of bituminous mixtures using Wheel Tracking Machine	Wheel Tracking Test[10]	

Table (2): Characteristics of Virgin and Modified Asphalt Used

Characteristic	VA(*)	MA (**)	
		(1)	(2)
- Physical Properties:-			
* Penetration (@ 25°C, 100g, 5s)0.1 mm	65	50	45
* Viscosity (@ 135°C) mPas	348	1388	2800
* Absolute Viscosity (@ 60°C) Poise	1974	29010	33155
* Softening Point (Ring & Ball) °C	47	49	54
* Ductility (@ 25°C, 5cm/min)cm	+ 150	46	36
* Specific Gravity (@ 25/25°C)	1.0196	0.9612	0.8901
- Chemical Constituents:			
* Oils (%wt)	33.3	36.5	31.9
* Resins (%wt)	41.6	42.4	48.0
* Asphaltenes (%wt)	25.0	21.0	20.0
* Wax (%wt)	5.4	5.0	5.1

N.B: (*) : Virgin Asphalt

(**) : Modified Asphalt

Table (3): Characteristics of Aggregates Used

Item	Sample No. (1)	Sample No. (2)	Sample No. (3)	Sample No. (4)	Sample No. (5)	Standard specification Limits
1. Type	Crushed siliceous linestones	Crushed siliceous linestones	Artifical sand	Natural silicous sand	Limestone dust	
2. Size	No (2)	No (1)				
3. Gradation						
Sieve Size						
1"	100					
¾ "	86					
½ "	20	100				
3/8"	5	85				
No(4)	0.3	32	100	100		
No(8)		21	98	98		
No(16)		11	85	89		
No(30)		5	68	69		100*
No(50)		2.4	49	25	100	--
No(100)		1.4	27.4	5	89	> 85*
No(200)		1.2	16	3	77.5	> 65*
4. Abrasion Resistance (Loss% wt)						
- After 100 revolutions	5	6				< 10**
- After 500 revolutions	25	25				< 40**
5. Specific Gravity						
- Bulk Specific Gravity	2.562	2.538		2.65	2.75	
- Bulk Specific Gravity (SSD basis) ***	2.595	2.578				
- Apparent Specific Gravity	2.650	2.644				
6. Absorption (%wt)	1.3	1.6				< 5**
7. Disintegration (%wt)	0.5	0.6				--**
8. Plastic & Liquid Limits			Nil		Nil	<8**** <32****

N.B. : (*) Standard Specification Limits of Limestone Mineral filler

(**) Standard Specification Limits of Mineral Aggregates

(***) Saturated Surface Dry basis

(****) Standard Specification Limits for plastic & liquid limits respectively of limestone dust.

Table (4) : Design Gradation of Mixture Used

Sieve Size	Design Gradation	Specification Limits (4-C)
1"	100	100
¾ "	96.4	80/100
½ "	79.2	68/88
3/8 "	69.9	60/80
No.4	49.6	48/65
No.8	45	35/50
No.30	29.1	19/30
No.50	17.5	13/23
No.100	9.7	7/15
No.200	6.7	3/8

Table (5): Marshall Mix Properties of the Produced Mixes

Item	Results Using			
	"VA"	"MA"		ESSL**
		(1)	(2)	
- Optimum Asphalt content (%)*	5.4 ± 0.25	5.7 ± 0.25	5.4 ± 0.25	
- Stability of the mix, (lbs)	2113	2300	2415	Min. 750
- Unit weight of the mix (t/m^3)	2.343	2.339	2.326	
- Flow of the mix (0.01 in.)	12.7	12.4	12.5	8-18
- Air voids in the mix (%)	3.3	2.3	3.6	3-5
- Air voids in the mineral aggregates. (%)	15	15.3	15.6	Min. 13.5
- Marshall quotient (S/F) (lb/in.)	166.3	185.5	193.2	

N.B.: (*) : Based on total weight of solid materials

(**) : Egyptian Standard Specification Limits for dense graded asphalt mixture

Table (6): **Rutting Depth of Virgin & Modified Asphalt Mixes**

Time (minutes)	Number of wheel passes (n)	Rutting Depth			
		Virgin Asphalt Mix		Modified Asphalt Mix	
		R.D* ($x10^{-4}$ in.)	R.D (mm)	R.D ($x10^{-4}$ in.)	R.D (mm)
0	0	0	0	0	0
5	210	50	0.127	1.3	0.003
10	420	90	0.228	3.8	0.009
15	630	117	0.298	7.1	0.018
20	840	150	0.381	13.4	0.034
25	1050	200	0.508	14.6	0.037
30	1260	244	0.622	18.5	0.047
35	1470	275	0.698	24.8	0.063
40	1680	300	0.762	29.9	0.076
45	1890	217	0.806	37.4	0.095
50	2100	341	0.867	49.1	0.125
55	2310	360	0.914	54.7	0.139
60	2520	375	0.952	59.8	0.152

N.B.: (*) **Rutting Depth**

Table (7) : Accelerated Aging of binders produced

Test	Results	
	VA	MA
- Thin Film Oven Test:		
* Heating for 5 hours :		
Loss on heating (%wt)	0.2	0.01
Penetration of Residue (0.1mm)	40	31
* Heating for 10 hours:		
Loss on heating (%wt)	0.1	0.008
Penetration of Residue (0.1mm)	30	28
* Heating for 15 hours:		
Loss on heating (%wt)	0.09	0.005
Penetration of Residue (0.1 mm)	22	24

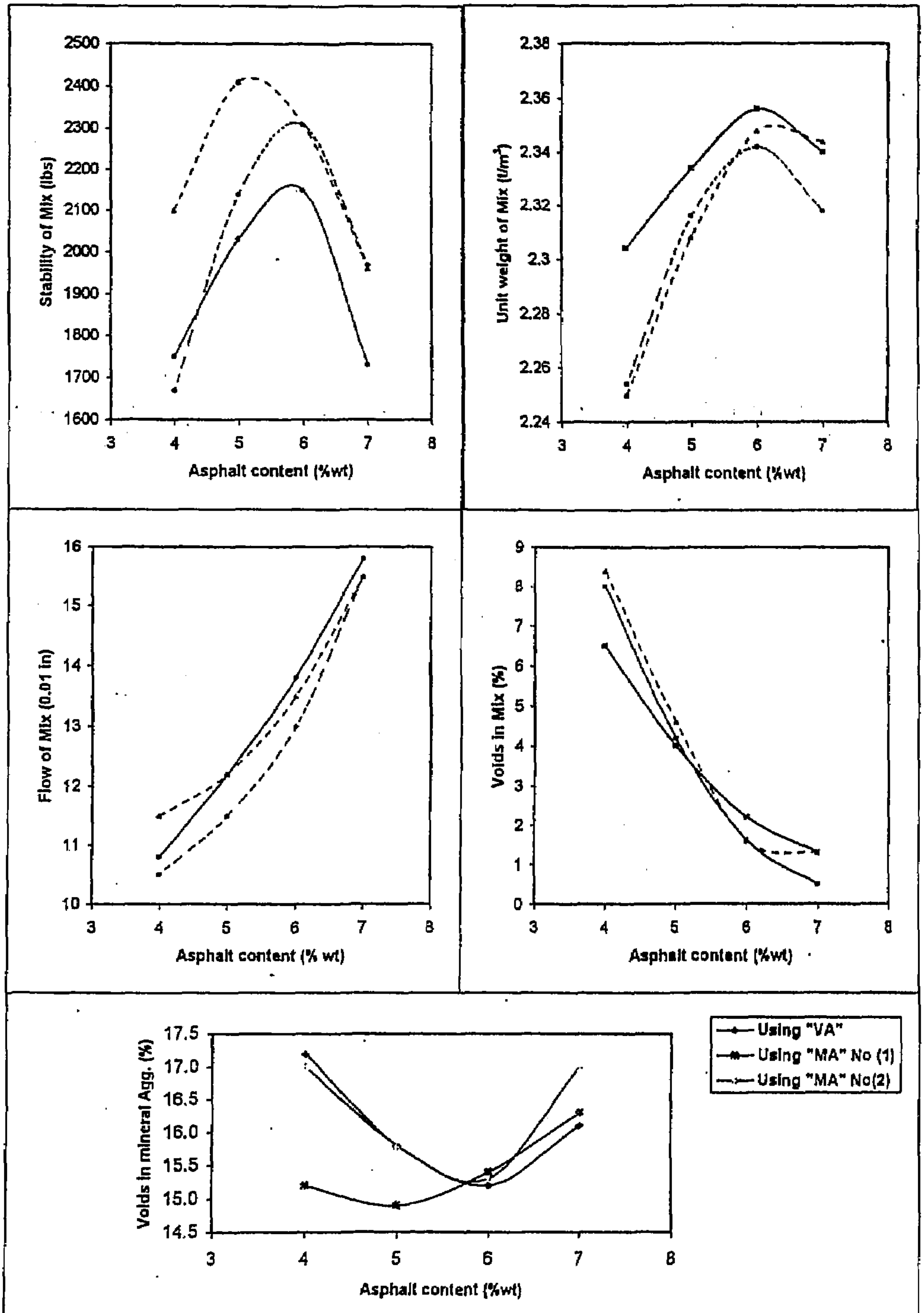

Fig. (1): Marshall Mix Properties of the Produced Mixes

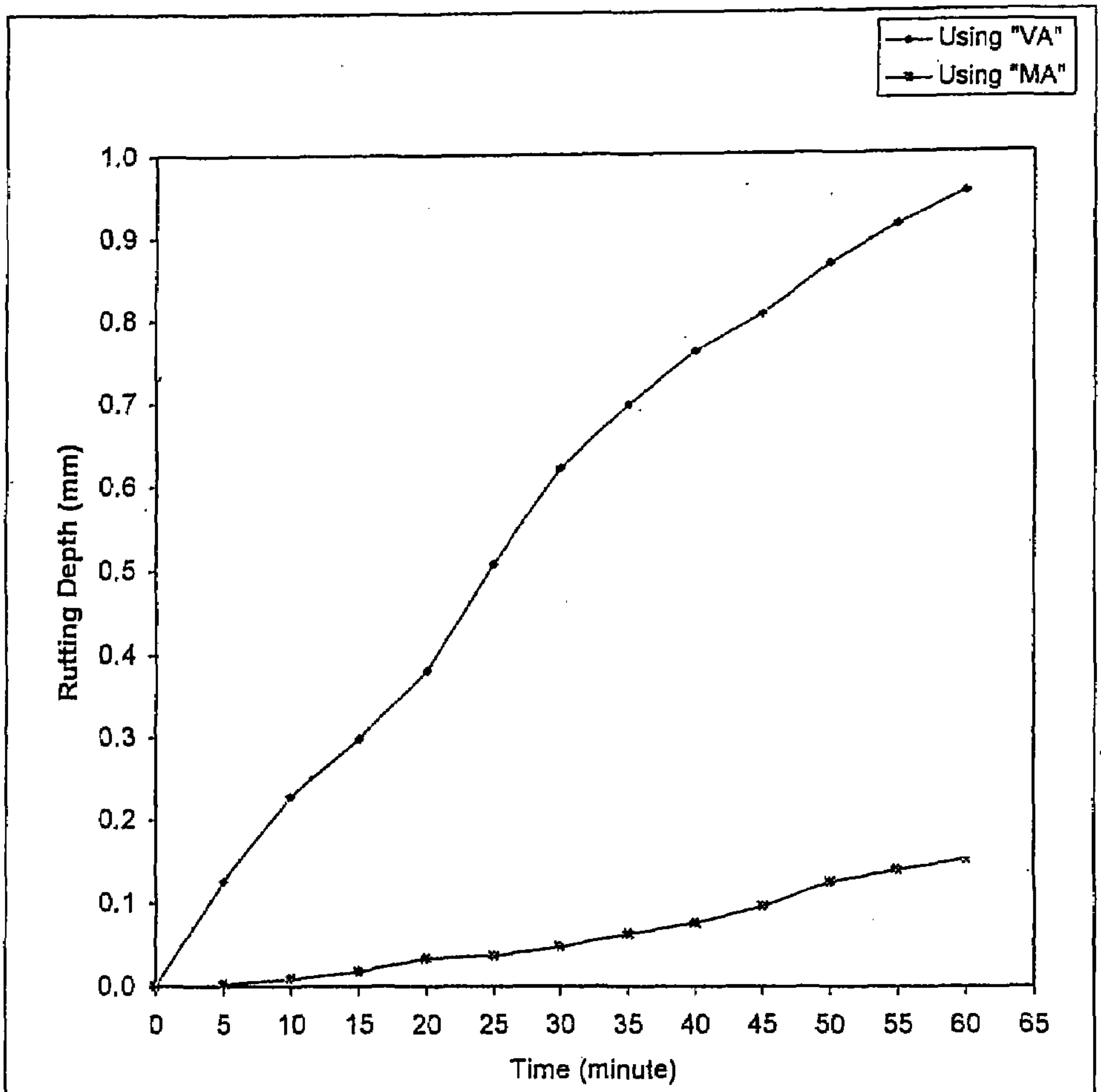

Fig. (2): Rutting Depth of Asphalt Mixes Produced

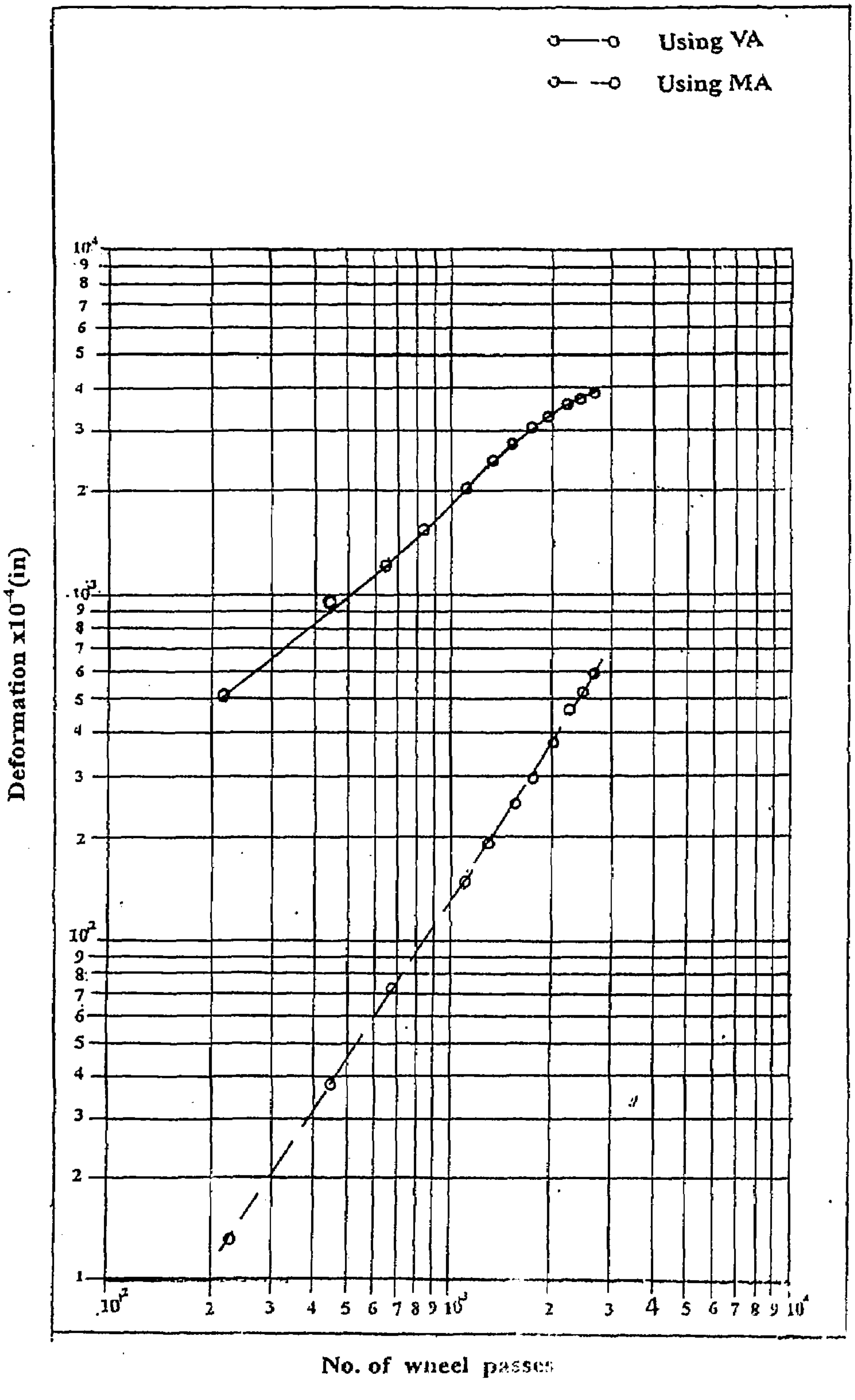

Fig. (3): Plastic Deformation of Asphalt Mixes