Cost Analysis of Using Some Types of Polymers to Asphalt Concrete Mixtures

تحليل تكلفه استخدام بعض انواع البوليمرات في الخلطات الاسفلتيه

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الملخص العربي

تزايد الاهتمام لاستخدام الاسفلت المعدل باستخدام البوليمرات لان خلطات الاسفلت التقليديه لا تتحمل الاحمال المحوريه العاليه. وكان الهدف الرئيسي من هذا البحث هو تقييم الجدوي الاقتصاديه من اضافه الانواع المختلفه من البوليمرات الي الخلطات الاسفلتيه في مصر. وقد وجد ان استخدام الانواع المختلفه من البوليمرات تؤدي لزياده عمر الرصف. البولي ايثيلين عالي الكثافه يعطي افضل تحسين في العمر التصميمي للطريق ثم النوفولاك ثم البولي فينيل كلوريد واخيرا مخلفات الاكياس البلاستيك (احدي منتجات البولي ايثيلين منخفض الكثافه). وتم الحصول علي الحد الادني من التكلفه باستخدام مخلفات الاكياس البلاستيك ثم البولي ايثيلين عالي الكثافه ثم البولي فينيل كلوريد واخيرا النوفولاك. وتم الحصول علي الحد الادني من التكلفة بالنسبه للفائده باستخدام مخلفات الاكياس البلاستيك ثم البولي ايثيلين عالي الكثافه ثم البولي فينيل كلوريد واخيرا النوفولاك.

ABSTRACT

Attention has been increasing towards the use of polymer modified asphalt, because conventional asphalt mixtures cannot resist the high axle loads and tire pressures. The main objective of this research was to evaluate economic feasibility of adding several types of polymers on asphalt mixtures in Egypt. Study program involved four steps. The first step was presentations and discussions results of lab work. The second step was estimating the cost per one cubic meter of asphalt mixtures using four types of polymers. The third step was calculating pavement life of virgin and modified asphalt concrete mixtures using Mechanistic Empirical Pavement Design Guide (MEPDG) program. The fourth step was calculating cost/benefit ratio. It was found that using polymers increased pavement life for all different types of used polymers. HDPE gave the best improvement in percent increase in design life followed by novolac followed by PVC and then waste plastic bags. The minimum cost was obtained by waste plastic bags, followed by HDPE, followed by PVC and then novolac. The minimum cost per benefit ratio obtained by waste plastic bags followed by HDPE followed by PVC and then novolac.

KEYWORDS: Asphalt mixtures; cost analysis; MEPDG; polymers.

1 INTRODUCTION

The increase in road traffic during the last two decades, in addition with an insufficient degree of maintenance, has caused an accelerated deterioration of road structures in many countries [1-7]. The modification of asphalt with polymers is considered one of the best options to improve asphalt properties. Polymers increase considerably the useful temperature range of the binders [2, 3]. The added polymer can strongly enhance the binder properties and permit the building of safer

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roads and the reduction of maintenance costs by increasing the stiffness of the bitumen and improves its temperature susceptibility [3-7].

Using polyethylene terphthalate (PET) in asphalt concrete mixtures was more economic than virgin asphalt concrete mixtures. The cost of 1m^3 of virgin asphalt concrete mixtures was 226 LE while the cost of 1m^3 of PET modified asphalt mixtures was 210 LE. This reduction in cost was due to the low percent of optimum asphalt content (OAC) in PET modified asphalt mixtures. But this paper did not take into consideration road life in estimating cost analysis [8].

Economic analysis was carried out considering the material requirement for paving 10.16 cm thick wearing course on standard 3.66 m wide lane of one kilometer length roadway section. It was found that using modified asphalt mixtures with waste plastic beverage bottles (one of HDPE products) reducing the cost by approximately 16324 LE per kilometer per lane in comparison to using conventional (unmodified) asphalt mix in road construction [9].

Using asphalt concrete mixtures modified by fibers increase initial cost by 29.76% but there was an increase in the strength values of the modified mixtures so these results can be justified because these increases in test values increase the life of pavement. So maintenance cost will be decreased during future life of pavement. But this paper did not take into consideration road life in estimating cost analysis [10].

2 STUDY OBJECTIVES

The main objective of this research is to evaluate the effect of polymers on asphalt concrete mixtures and study cost analysis of adding different types of polymers on asphalt concrete mixes in Egypt.

3 STUDY METHODOLGOY:

This study aimed to evaluate the effect of using polymers as additives to asphalt concrete mixtures through the following steps:

- Experimental work (measuring the properties of asphalt concrete mixtures),
- Evaluating pavement life,
- Calculating cost per one cubic meter of asphalt concrete mixtures,
- Calculating cost / benefit ratio.

Figure (1) shows study methodology steps.

4 EXPERIMENTAL CONSIDERATIONS

In this study one source of asphalt, one source of aggregate and different types of additives were used. One source of asphalt was used in this study. This was Suez asphalt cement, 60/70 penetration grade and 1.02 specific gravity was used in preparing all the investigated asphalt mixtures. One source of aggregate and one gradation was used in the study. Coarse aggregate was crushed dolomite stone obtained from Burdein mixer (located in Zagazig city, Al Sharqia governorate). The fine aggregate was silicous sand obtained from Burdein mixer. The mineral filler was lime stone dust. Four types of additives were used. These additives are:

- Poly vinyl chloride (PVC),
- Phenol formaldehyde solid resin (novolac),
- Waste plastic bags (one of LDPE products),
- High Density Polyethylene (HDPE).

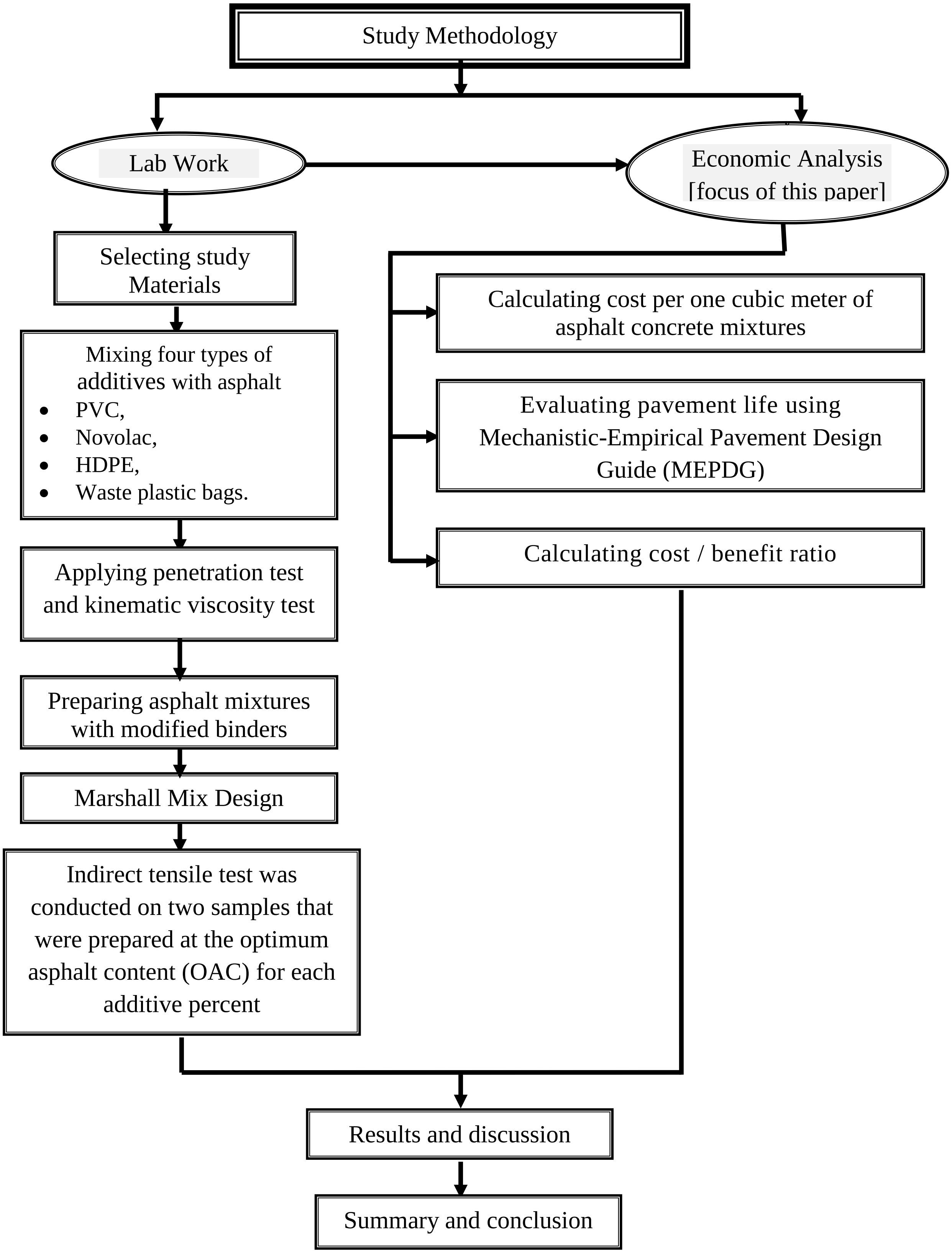


Figure (1): Study methodology steps.

The experimental work was divided into two phases. The first phase was modifying the asphalt. The measured properties of asphalt and modified asphalt cement were penetration at 25°C (according to AASHTO Designation T49) and kinematic viscosity at 135°C (according to AASHTO Designation T201).

The second phase was obtaining the properties of the modified asphalt mixtures. Marshall test according to AASHTO Designation T245 and indirect tensile strength (ITS) test according to manual of testing procedures, 1966 (Texas high way department)[11] were used to evaluate properties of virgin and modified asphalt concrete mixtures. Indirect tensile test was conducted on two samples that were prepared at the optimum asphalt content OAC for each additive percentage. The OAC was defined following asphalt institute method as the average of three values (asphalt content at 4% air voids, asphalt content at maximum stability and asphalt content at maximum density). More details about experimental program were presented in paper entitled “Effect of Using Polymers on Bituminous Mixtures Characteristics in Egypt” [12].

5 EXPERIMENTAL RESULTS:

5.1 Effect of Polymers on Hot Mix Asphalt (HMA) Properties (Marshall stability, flow and indirect tensile strength):

Figure (2-a) presents the effect of different additives on Marshall stability at OAC. The addition of PVC increased the stability up to 4% PVC, and above this percent the stability decreased. The addition of novolac increased the stability up to 4% novolac, and above this percent the stability decreased. The addition of HDPE increased the stability at 2% HDPE, above this percent the stability decreased up to 4% HDPE, and above 4% HDPE the stability increased. The addition of waste plastic bags increased the stability up to 4% waste plastic bags, and above this percent the stability decreased.

Figure (2-b) presents the effect of different additives on Marshall flow at OAC. The addition of PVC reduced the flow up to 4% PVC, and above this percent the flow increased. The addition of novolac reduced the flow up to 3% novolac, and above this percent the flow increased. The addition of HDPE reduced the flow for all percents of HDPE except for the two percents of 3% and 6% HDPE the flow increased. The addition of waste plastic bags reduced the flow for all percent of waste plastic bags except for 4% waste plastic bags the flow remained constant.

Figure (2-c) presents the effect of different additives on the indirect tensile strength at OAC. The addition of PVC increased the indirect tensile strength up to 4% PVC, and above this percent the indirect tensile strength remained constant up to 5%, then ITS decreased at 6% PVC. The addition of novolac increased the indirect tensile strength up to 4% and above this percent the indirect tensile strength decreased. It is noticed that novolac did not show clear effect on ITS up to 2% then it started to show clear effect at when novolac increased to 4%. The addition of HDPE caused increase in the indirect tensile strength up to 5% and above this percent the indirect tensile strength decreased. The addition of waste plastic bags increased the indirect tensile strength up to 4% and above this percent the ITS decreased. It is noticed that 2% waste plastic bags had same impact on indirect tensile strength as 4%. It is also noted that this results differs than that obtained based on stability results.

Waste plastic bags gave the best improvement in the mix properties followed by HDPE, followed by novolac and then PVC. According to Marshall Stability, flow and indirect tensile strength results the optimum percent of PVC, novolac and waste plastic bags was 4%, and the optimum percent of HDPE was 5% by weight of asphalt. Results of the HMA parameters were presented in detail in [12].

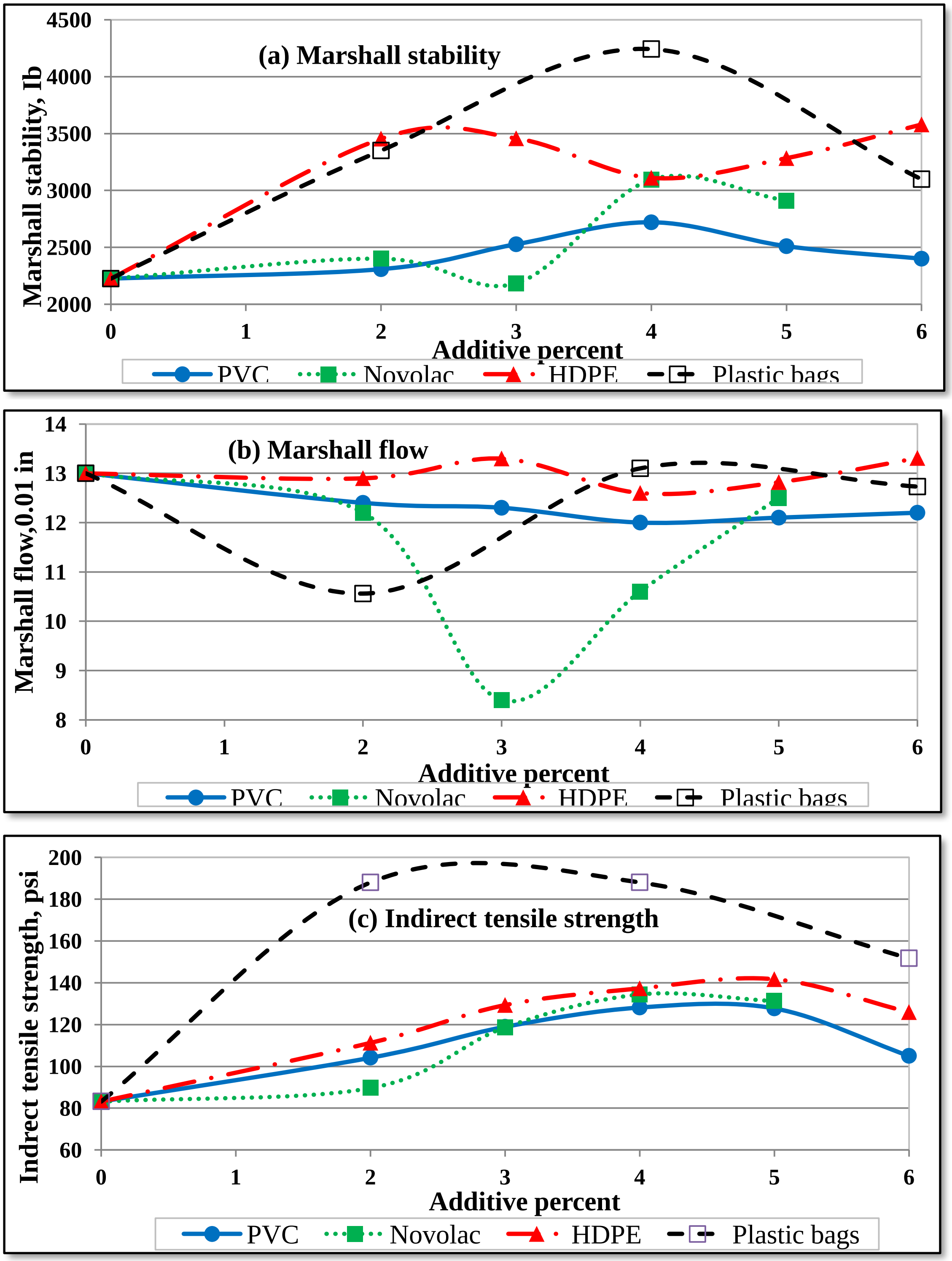


Figure (2): Effect of polymers on hot mix asphalt (HMA) properties

6 COST ANALYSES

Cost analysis was carried out to compare the cost between modified bituminous mixes to nominal mixes. Table (1) shows cost of different materials (obtained from Laboratory of general authority for roads and bridges at Sharqia governorate and Plastic factories in 10th of Ramadan City) and cost of HMA modified with different types of polymers.

Table (1): Cost analysis for HMA modified with different types of polymers.

1- Cost of different materials			**2- Cost of HMA modified with different types of polymers**					
Item	Unit	Cost (LE/unit)	Item	Cost (LE/m^3)				
Bitumen	Ton	4000		No additive	PVC	Novolac	HDPE	Plastic bags
Coarse aggregate	m^3	75	Bitumen	498.96	508.48	489.72	444.80	443.20
Fine aggregate	m^3	37	Coarse aggregate	48.75	48.75	48.75	48.75	48.75
Mineral filler	Ton	300	Fine aggregate	11.10	11.10	11.10	11.10	11.10
PVC	Ton	8000	Mineral filler	32.15	32.14	32.82	32.80	33.71
Novolac	Ton	25000	Additive cost	----	40.64	122.25	55.60	13.29
HDPE	Ton	10000	Total cost	590.96	641	704.64	593.05	550.05
Waste plastic bags	Ton	**3000**						

7 COST ANALYSIS RESULTS:

Figure (3) shows the effect of using different types of polymer modified concrete mixtures to the cost per 1 m^3 . Figure (3) shows that adding 4% PVC or 4% novolac to HMA increased cost. Adding 5% HDPE to HMA slightly increased cost. Adding 4% waste plastic bags to HMA reduced cost.

8 EFFECT OF POLYMERS ON PAVEMENT LIFE USING MECHANISTIC-EMPIRICAL PAVEMENT DESIGN GUIDE (MEPDG):

Calculating design life was performed using (MEPDG) for Portex road in Zagazig city using three alternatives of asphalt thickness (2inch, 6inch and 8inch) to show the effect of using additives on different cases of asphalt thickness. The main input data variables as shown in tables (2).

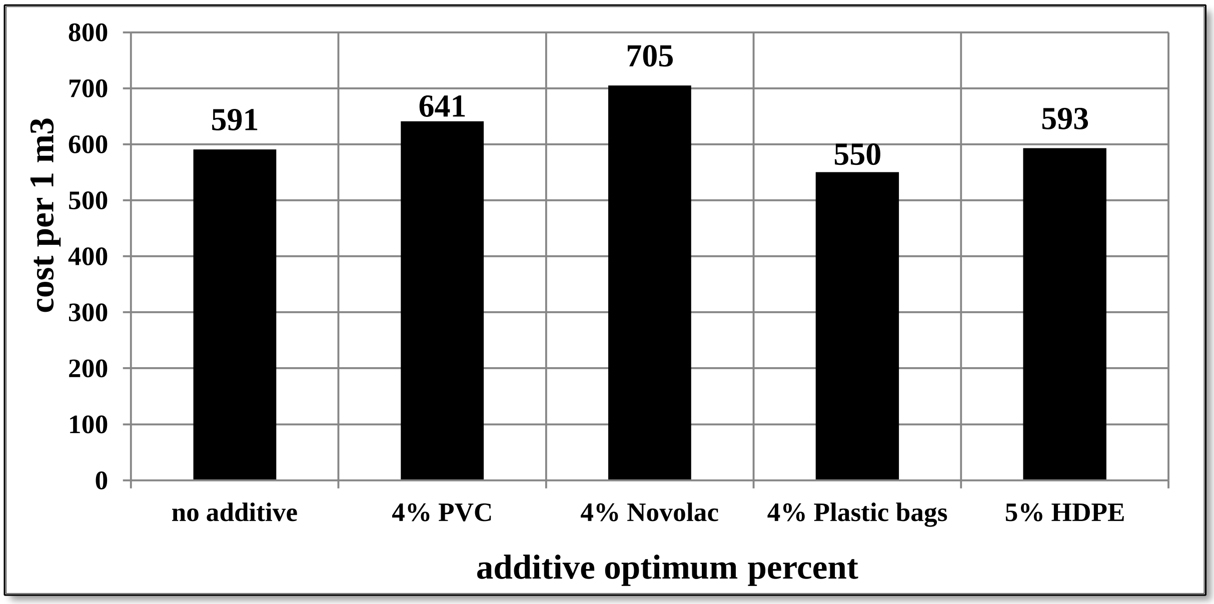


Figure (3): Cost of mixtures per 1 m^3 for each additive optimum percent.

Table (2): Main inputs data in MEPDG for Portex road in Zagazig city.

1- Traffic data	
Initial two-way AADTT (truck / day)	7000
Reliability level (%R)	90%
2-Asphalt layer properties	
Layer thickness	2 inch
	6 inch
	8 inch
3-Base layer properties	
Layer thickness	40 cm (15.75 inch)
Stone type	Crushed stones
4-Subgrade layer properties	
Subgrade type	A-2-4

9 EVALUATION OF PAVEMENT LIFE USING MEPDG:

The effect of different additives on pavement life based on permanent deformation (rutting) and bottom up cracks (fatigue). Failure criteria of rutting was selected at 0.75 inch rutting depth. This criteria (0.75 inch) was selected based on MEPDG criteria [13]. Failure criteria of fatigue was selected at 20 percent alligator cracking [14, 15].

Figure (4-a) shows results of rutting at 90% reliability for the 2 inches asphalt concrete mixtures (original mixture and mixtures modified with polymers). Figure (4-a) shows that pavement life increased by using polymers in asphalt concrete mixtures (the best improvement obtained by HDPE then PVC or novolac or waste plastic bags). Figure (4-b) and shows results of fatigue cracking at 90% reliability for the 2 inches thickness of asphalt concrete mixtures (original mixture and mixtures modified with polymers).Figure (4-b) shows that pavement life increased by using polymers in asphalt concrete mixtures (the best improvement obtained by waste plastic bags then novolac then PVC and finally by HDPE). From rutting and fatigue results for the 2 inches thickness of asphalt concrete mixtures, critical distress is rutting.

Figure (5-a) shows results of rutting at 90% reliability for the 6 inches asphalt concrete mixtures (original mixture and mixtures modified with polymers). Figure (5-a) shows that pavement life increased by using polymers in asphalt concrete mixtures (the best improvement obtained by HDPE then PVC or novolac and finally by waste plastic bags). Figure (5-b) and shows results of fatigue cracking at 90% reliability for the 6 inches thickness of asphalt concrete mixtures (original mixture and mixtures modified with polymers). Figure (5-b) shows that pavement life increased by using polymers in asphalt concrete mixtures. From rutting and fatigue results for the 6 inches thickness of asphalt concrete mixtures (the best improvement obtained by waste plastic bags then novolac then PVC and finally by HDPE critical distress is rutting.

Figure (6-a) shows results of rutting at 90% reliability for the 8 inches asphalt concrete mixtures (original mixture and mixtures modified with polymers). Figure (6-a) shows that pavement life increased by using polymers in asphalt concrete mixtures (the best improvement obtained by HDPE then novolac then PVC and finally by waste plastic bags). Figure (6-b) and shows results of fatigue cracking at 90% reliability for the 8 inches thickness of asphalt concrete mixtures (original mixture and mixtures modified with polymers). Figure (6-b) shows that pavement life increased by using polymers in asphalt concrete mixtures (the best improvement obtained by waste plastic bags then novolac then PVC and finally by HDPE). From rutting and fatigue results for the 8 inches thickness of asphalt concrete mixtures, critical distress is rutting.

Based on average total rutting at 50% reliability and rutting at 90% reliability (for 2inch, 6inch and 8inch asphalt thickness), it was noticed that using polymers increased design life, the best improvement was obtained by using 5% HDPE then 4% novolac then 4% PVC and finally by using 4% waste plastic bags. Based on average total fatigue at 50% reliability and fatigue at 90% reliability (for 2inch, 6inch and 8inch asphalt thickness), it was noticed that using polymers increased design life.

Figure (7) shows the effect of using different types of polymers at the optimum percent on design life of road (based on rutting at 90% reliability). It shows that for three alternatives (2 inch, 6inch and 8inch asphalt thickness), the best improvement was obtained by using 5% HDPE then 4% novolac then 4% PVC and finally by using 4% waste plastic bags

Table (3) shows the effect of addition polymers on cost and pavement life. It shows that waste plastic bags reduced cost by 6.9% from original cost **(according to equation (1))** [16]. Cost was reduced due to reduction of OAC percentage and low price for waste plastic bags. Also waste plastic bags increased design life of road by 20, 8 and 6% of the original design life at 2, 6 and 8 in asphalt thickness respectively **(according to equation (2))** [16]. Waste plastic bags reduced cost / benefit ratio by -0.35, -0.86 and -1.15% at 2, 6 and 8 in asphalt thickness respectively **(according to equation (3))** [16]. The second additive is HDPE since it slightly increased cost by 0.33 % from original cost. HDPE increased design life by 40, 33 and 24% of the original design life at 2, 6 and 8 in asphalt thickness. HDPE reduced cost / benefit ratio by 0.008, 0.01 and 0.014% at 2, 6 and 8 in asphalt thickness respectively. The third additive is PVC since it increased cost by 8.46 % from original cost. PVC increased design life by 20, 17 and 12% of the original design life at 2, 6 and 8 in asphalt thickness respectively. PVC reduced cost / benefit ratio by 0.42, 0.49 and 0.71% at 2, 6 and 8 in asphalt thickness respectively. The forth additive is novolac since it increased cost by 19.2% from original cost. Novolac increased design life by 20, 17 and 18 % of the original design life at 2, 6 and 8 in asphalt thickness respectively. Novolac reduced cost / benefit ratio by 0.96 at 2 in asphalt thickness. Novolac increased cost / benefit ratio by 1.13 and 1.07% at 6 and 8 in asphalt thickness respectively.

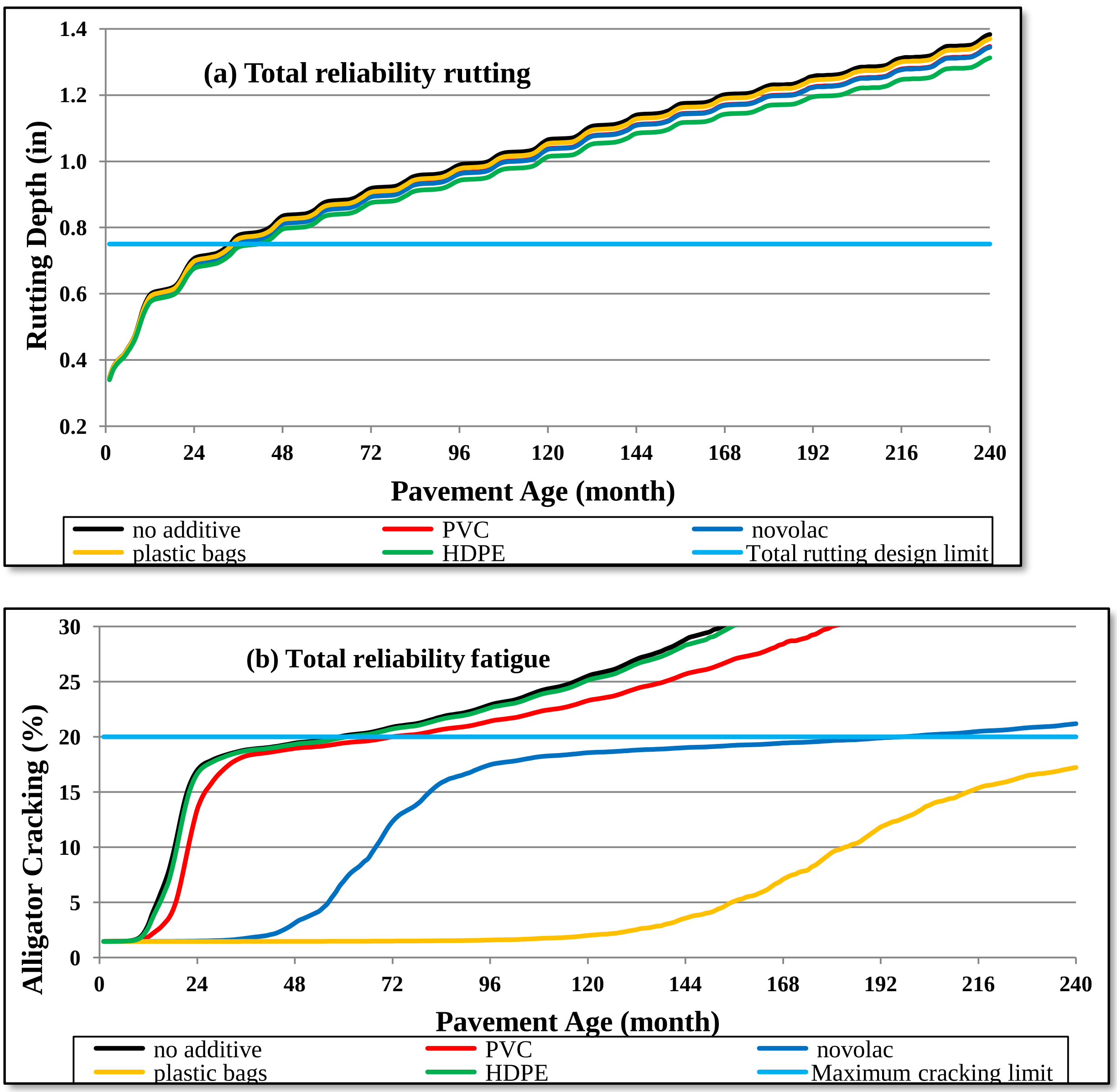
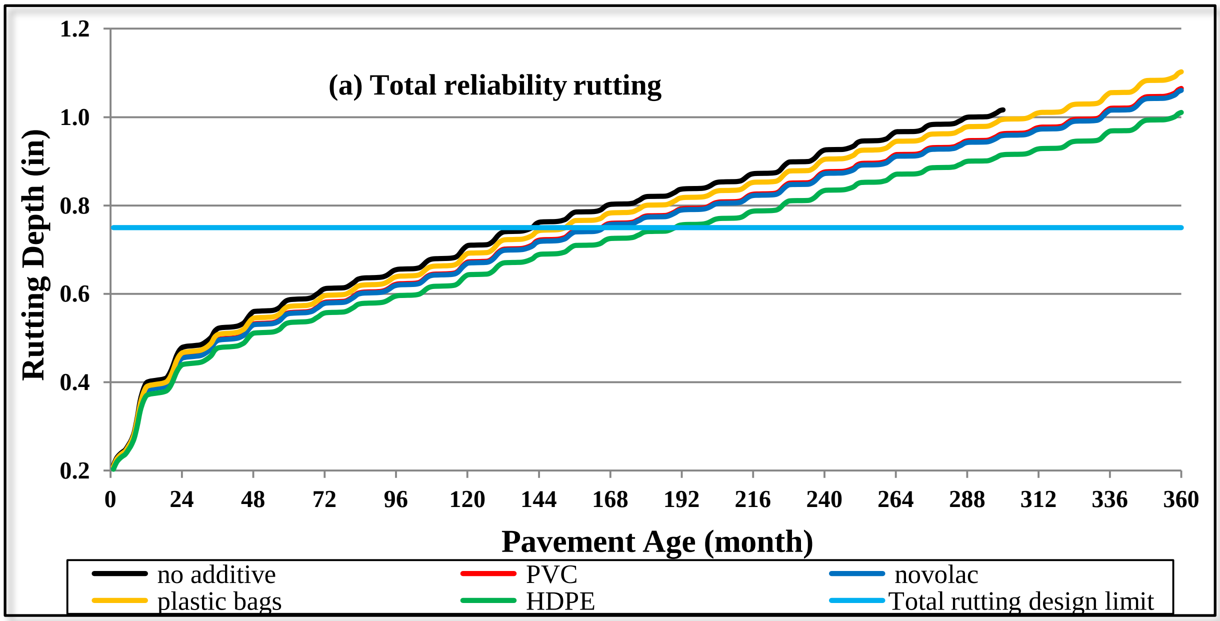


Figure (4): Rutting and fatigue at 90% reliability results for 2 inch thickness asphalt concrete.



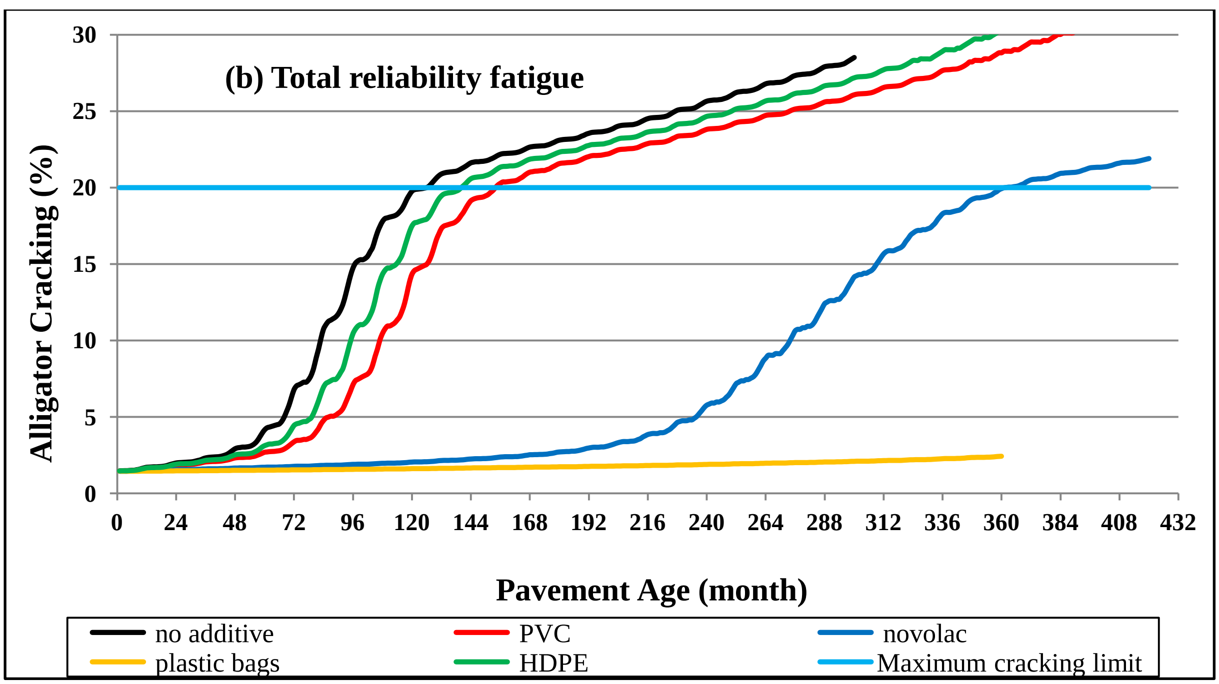


Figure (5): Rutting and fatigue at 90% reliability results for 6 inch thickness asphalt concrete.

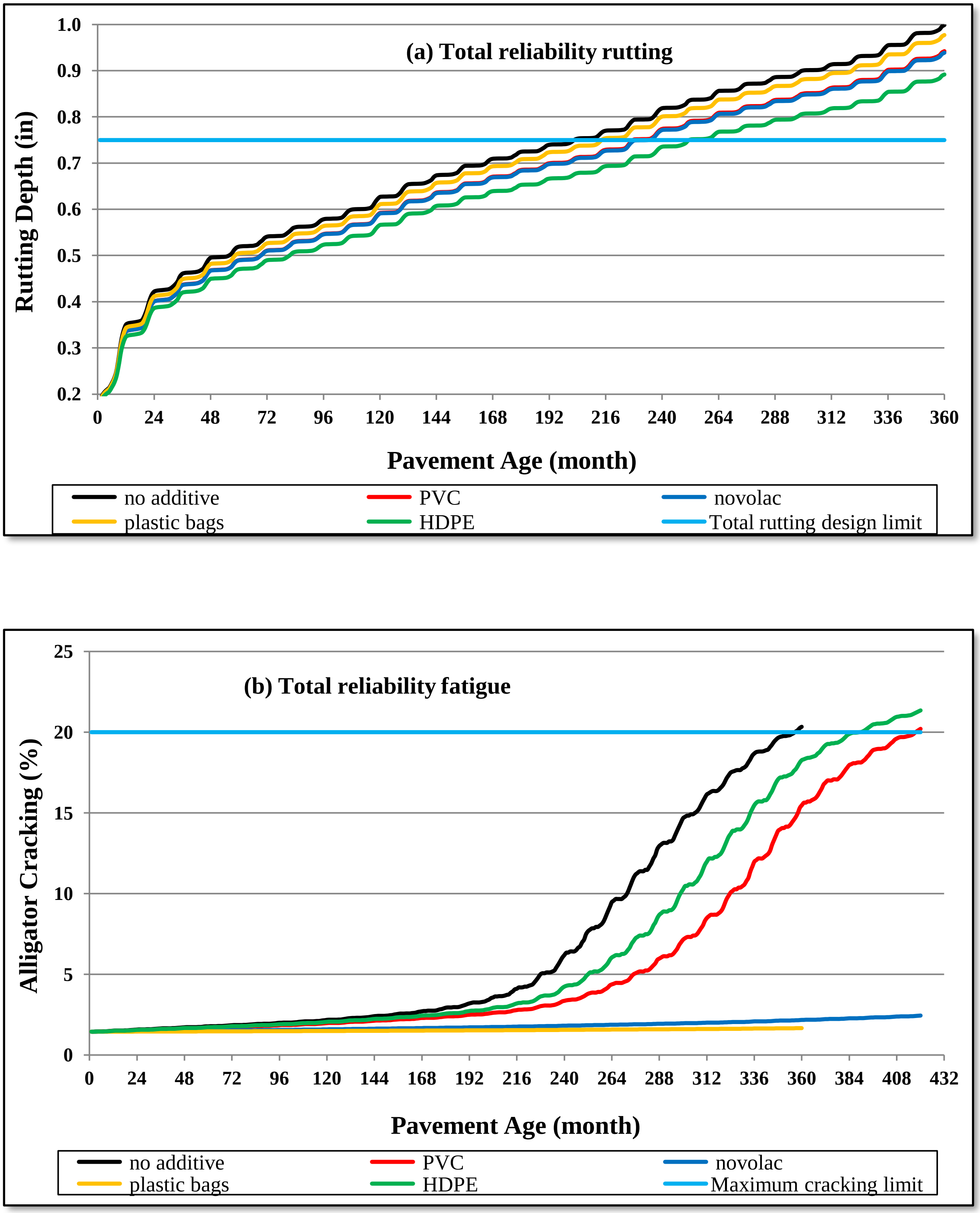


Figure (6): Rutting and fatigue at 90% reliability results for 8 inch thickness asphalt concrete.

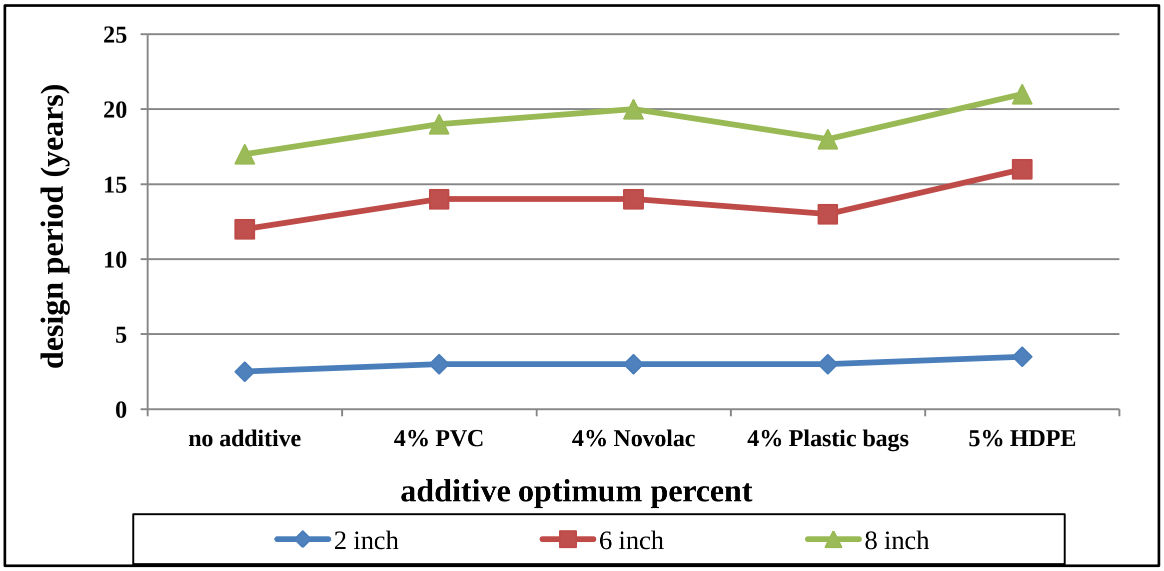


Figure (7): Relation between additive optimum percent and design life at different asphalt thickness (based on 90% reliability rutting).

Percent increase in cost=

$$\left(\frac{\text{cost of HMA modified with polymers per } 1m^3 - \text{cost of original HMA per } 1m^3}{\text{cost of original HMA per } 1m^3}\right)*100 \qquad \textbf{Equation (1)}$$

Percent increase in pavement life =

$$\left(\frac{\text{pavement life of HMA modified with polymers} - \text{pavement life of original HMA}}{\text{pavement life of original HMA}}\right)*100 \qquad \textbf{Equation (2)}$$

$$\textbf{Cost / benefit ratio} = \left(\frac{\text{percent increase in cost}}{\text{percent increase in pavement life}}\right) \qquad \textbf{Equation (3)}$$

Table (3): Effect of addition polymers on cost and pavement life.

Additive name		PVC	Novolac	Waste plastic bags	HDPE
Additive percent		4	4	4	5
Percent increase in cost		8.46	19.2	- 6.9	0.33
Percent increase in pavement life based on rutting and fatigue at 90% reliability (at 25% max cracking limit)	**2 in**	20	20	20	40
	6 in	17	17	8	33
	8 in	12	18	6	24
Cost / benefit ratio	**2 in**	0.42	0.96	-0.35	0.008
	6 in	0.497	1.13	-0.86	0.01
	8 in	0.71	1.07	-1.15	0.014

+ve: increase and –ve: reduction.

10 CONCLUSION

The main objective of this research was to study economics of using several types of polymers on asphalt mixtures in Egypt.

Study program involved four steps. The first step was presentations and discussions results of lab work. The second step was estimating the cost per one cubic meter of asphalt mixtures using four types of polymers. The third step was calculating pavement life of virgin and modified asphalt concrete mixtures using Mechanistic Empirical Pavement Design Guide (MEPDG) program. The fourth step was calculating cost/benefit ratio.

From lab work it was found that the optimum percentage of PVC, waste plastic bags and novolac was 4%, and the optimum percentage of HDPE was 5% by weight of asphalt. These percentages caused increase in kinematic viscosity, increase in stability, increase in indirect tensile strength and reduction in penetration. When those additives were used above these percentages, the stability and indirect tensile strength values decreased while the flow values increased.

Adding 4% PVC or 4% novolac to HMA increased cost. Adding 5% HDPE to HMA slightly increased cost. Adding 4% waste plastic bags to HMA reduced cost. The minimum cost was obtained by waste plastic bags, followed by HDPE, followed by PVC and then novolac HDPE gave the best improvement in percent increase in design life followed by novolac followed by PVC and then waste plastic bags. The minimum cost per benefit ratio obtained by waste plastic bags followed by HDPE followed by PVC and then novolac.

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