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# Economic Benefit of Using Polyethylene and Polyester Wastes in Asphalt Mixes

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**ABSTRACT**

In this paper the economic benefit of using wastes of polyethylene and polyester in asphalt mixes was investigated. The objective of this research was accomplished through using the properties of three different mixes; control mix (CM) polyethylene mix (PE) and polyester mix (PS). For polyethylene, 4% by weight of optimum bitumen content, determined by Marshall Mix Design Method, was added to the asphalt mixture. Polyester fibers were also used with fiber length of 1 cm and a percentage of 0.35% by total mix weight. To conduct an economical study, thickness of the surface layer was determined by AASHTO Design Method based on the resilient moduli of CM, PE, and PS. The results showed that the thickness of surface layer was reduced by 13% when adding polyethylene waste and by 9% when adding polyester waste. Design life was also calculated using the Kenlayer program. For single wheels, the results showed that design life of the pavement containing polyethylene was higher by 19% compared to that of the CM. This percentage was 15% when polyester fibers were used. Under dual-tandem wheels, the design life of the pavement increased by 11% and 8% for PE and PS mixes respectively compared to the CM.

***Key words:*** Polyethylene, Polyester, Waste, Asphalt Mixtures.

## Introduction

Polymer modified bitumen could improve the properties of asphalt mixes the stability, rutting resistance, and in turn decreases maintenance cost. For these advantages, polymer modified bitumen has found potential application in road and highway projects. Initial construction cost using polymer modified bitumen is more than that of conventional mix, but polymer waste modified bitumen may be requires lesser cost (El-Desouky *et al*., 2012a, El-Desouky *et al*., 2012b and Valkering *et al*., 1990). King *et al*. (1986) reported that the polymer increases the softening point, lowers the flash breaking point and improves the aging resistance of the binder in addition to imparting high elasticity. The results of rutting resistance test showed that polymer modified bitumen mix was able to withstand four to ten times more loading cycles than conventional mix before ruts of various specified depths occurred. Collins *et al*. (1991) found that the modified bitumen increases softening point, decreases penetration, increases elastic modulus and in turns increase the fatigue life to more than two times compared to that of conventional mix.

El-Desouky *et al*. (2012a, 2012b) emphasized the benefit of using polyethylene and polyester wastes to enhance the basic properties of asphalt mixes. In addition, El-Desouky and Abbas (2014) concluded that asphalt mixes containing polyethylene and polyester wastes have better long-term performance in terms of higher resilient modulus, higher indirect tensile strength and lower rut depth under repeated loads at high temperatures. Pandey (2008) carried out investigation to improve the pavement design standard used in India with polymer modified bitumen. Improved design methodology has considered the fatigue life of polymer modified bitumen as two times greater than that of conventional bituminous mix design. As a result, thickness requirement for polymer modified bitumen is lesser than that of conventional mix.

## Methodology

The benefit of using modified PE and PS mixtures in flexible pavements could be expressed in term of a decrease in surface layer thickness and/or an increase in pavement life. Results of a previous study conducted by El-Desouky and Abbas (2014) to evaluate the resilient modulus (Mr) of CM, PE and PS were used in this study. AASHTO design method of flexible pavements would be used to study the effect of using PE and PS mixtures that have higher moduli compared to CM to decrease the surface layer thickness. In addition, Kenlayer program would be used to study the benefit of using PE and PS mixtures of the same thickness as CM to increase pavement design life.

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## Decrease in Surface Layer Thickness

AASHTO design method of flexible pavement was used to estimate thickness of surface layer ($d_1$) for different asphalt mixtures. AASHTO design method is mainly empirical, based on the AASHO road test. Pavement structure required on top of a specific layer is expressed in terms of a structural number (SN) (AASHTO, 2004). Five different equivalent single axle loads (ESAL) were used to determine the thickness of surface layer. Reliability level was chosen to be 95% and standard deviation was set as 0.45. For each ESAL, three different base modulus (Mb) values of $30\times10^3$ psi, $35\times10^3$ psi, and $40\times10^3$ psi were used. Moduli of CM, PE, and PS were determined to be $200.7\times10^3$ psi, $270.2\times10^3$ psi and $242.5\times10^3$ psi, respectively. Based on modulus of surface layer, the layer coefficient ($a_1$) is determined and $d_1$ could be calculated. Table (1) shows the studied cases to calculate the thickness of surface layer.

Results are shown in Tables (1-6) where required surface layer thickness were determined for the three studied mixes under different ESAL and base layer modulus values. The percentages of reduction in required surface layer thickness are also presented in these tables. Knowing that PE was used in modified mixture instead of 4% bitumen, this means that value of bitumen in mixture will be decreased by 4%. Fig. (1) summarizes the results of this phase of the study. The results indicate that modified polyethylene mixture could decrease the required thickness of the asphalt surface layer by about 13%, while modified polyester mixture decreased asphalt surface layer thickness by about 9 %. Results showed that the benefit of using PE and PS to reduce surface layer thickness is independent of base layer modulus and traffic in terms of ESAL.

**Table 1:** Determination of asphalt layer thickness (ESAL = $5x10^6$).

| | CM | | | PE | | | PS | | |
|---|---|---|---|---|---|---|---|---|---|
| Mr asphalt ($10^3$ psi) | 200.7 | | | 270.2 | | | 242.5 | | |
| Mb ($10^3$ psi) | 30 | 35 | 40 | 30 | 35 | 40 | 30 | 35 | 40 |
| $SN_1$ | 2.5 | 2.4 | 2.3 | 2.5 | 2.4 | 2.3 | 2.5 | 2.4 | 2.3 |
| $a_1$ | 0.3 | 0.3 | 0.3 | 0.345 | 0.345 | 0.345 | 0.33 | 0.33 | 0.33 |
| $d_1$ (inch) | 8.33 | 8 | 7.67 | 7.25 | 6.96 | 6.67 | 7.58 | 7.27 | 6.97 |
| Decrease (%) | - | - | - | 13 | 13 | 13 | 9 | 9 | 9 |

**Table 2:** Determination of asphalt layer thickness (ESAL = $4x10^6$).

| | CM | | | PE | | | PS | | |
|---|---|---|---|---|---|---|---|---|---|
| Mr asphalt ($10^3$ psi) | 200.7 | | | 270.2 | | | 242.5 | | |
| Mb ($10^3$ psi) | 30 | 35 | 40 | 30 | 35 | 40 | 30 | 35 | 40 |
| $SN_1$ | 2.3 | 2.1 | 2 | 2.3 | 2.1 | 2 | 2.3 | 2.1 | 2 |
| $a_1$ | 0.3 | 0.3 | 0.3 | 0.345 | 0.345 | 0.345 | 0.33 | 0.33 | 0.33 |
| $d_1$ (inch) | 7.67 | 7 | 6.67 | 6.67 | 6.1 | 5.8 | 6.97 | 6.36 | 6.1 |
| Decrease (%) | - | - | - | 13 | 12.9 | 13 | 9 | 9 | 8.5 |

**Table 3:** Determination of asphalt layer thickness (ESAL = $10^6$).

| | CM | | | PE | | | PS | | |
|---|---|---|---|---|---|---|---|---|---|
| Mr asphalt ($10^3$ psi) | 200.7 | | | 270.2 | | | 242.5 | | |
| Mb ($10^3$ psi) | 30 | 35 | 40 | 30 | 35 | 40 | 30 | 35 | 40 |
| $SN_1$ | 2.3 | 2.0 | 1.7 | 2.3 | 2.0 | 1.7 | 2.3 | 2.0 | 1.7 |
| $a_1$ | 0.3 | 0.3 | 0.3 | 0.345 | 0.345 | 0.345 | 0.33 | 0.33 | 0.33 |
| $d_1$ (inch) | 7.67 | 6.67 | 5.67 | 6.67 | 5.8 | 4.93 | 6.97 | 6.1 | 5.2 |
| Decrease (%) | - | - | - | 13 | 13 | 13 | 9 | 8.5 | 8.3 |

**Table 4:** Determination of asphalt layer thickness (ESAL = $5x10^5$).

| | CM | | | PE | | | PS | | |
|---|---|---|---|---|---|---|---|---|---|
| Mr asphalt ($10^3$ psi) | 200.7 | | | 270.2 | | | 242.5 | | |
| Mb ($10^3$ psi) | 30 | 35 | 40 | 30 | 35 | 40 | 30 | 35 | 40 |
| $SN_1$ | 1.7 | 1.6 | 1.5 | 1.7 | 1.6 | 1.5 | 1.7 | 1.6 | 1.5 |
| $a_1$ | 0.3 | 0.3 | 0.3 | 0.345 | 0.345 | 0.345 | 0.33 | 0.33 | 0.33 |
| $d_1$ (inch) | 5.67 | 5.33 | 5 | 4.93 | 4,64 | 4.35 | 5.15 | 4.85 | 4.55 |
| Decrease (%) | - | - | - | 13 | 12.9 | 13 | 9.2 | 9 | 9 |

**Table 5:** Determination of asphalt layer thickness (ESAL = $4x10^5$).

| | CM | | | PE | | | PS | | |
|---|---|---|---|---|---|---|---|---|---|
| Mr asphalt ($10^3$ psi) | 200.7 | | | 270.2 | | | 242.5 | | |
| Mb ($10^3$ psi) | 30 | 35 | 40 | 30 | 35 | 40 | 30 | 35 | 40 |
| $SN_1$ | 1.6 | 1.5 | 1.4 | 1.6 | 1.5 | 1.4 | 1.6 | 1.5 | 1.4 |
| $a_1$ | 0.3 | 0.3 | 0.3 | 0.345 | 0.345 | 0.345 | 0.33 | 0.33 | 0.33 |
| $d_1$ (inch) | 5.33 | 5.00 | 4.67 | 4.64 | 4.35 | 4.06 | 4.85 | 4.55 | 4.24 |
| Decrease (%) | - | - | - | 12.9 | 13 | 13.1 | 9 | 9 | 9.2 |

**Table 6:** Determination of asphalt layer thickness (ESAL = $10^5$).

| | CM | | | PE | | | PS | | |
|---|---|---|---|---|---|---|---|---|---|
| Mr asphalt ($10^3$ psi) | 200.7 | | | 270.2 | | | 242.5 | | |
| Mb ($10^3$ psi) | 30 | 35 | 40 | 30 | 35 | 40 | 30 | 35 | 40 |
| $SN_1$ | 1.4 | 1.3 | 1.2 | 1.4 | 1.3 | 1.2 | 1.4 | 1.3 | 1.2 |
| $a_1$ | 0.3 | 0.3 | 0.3 | 0.345 | 0.345 | 0.345 | 0.33 | 0.33 | 0.33 |
| $d_1$ (inch) | 4.67 | 4.33 | 4 | 4.1 | 3.77 | 3.48 | 4,24 | 3.94 | 3.64 |
| Decrease (%) | - | - | - | 12 | 12.9 | 13 | 9 | 9 | 9 |

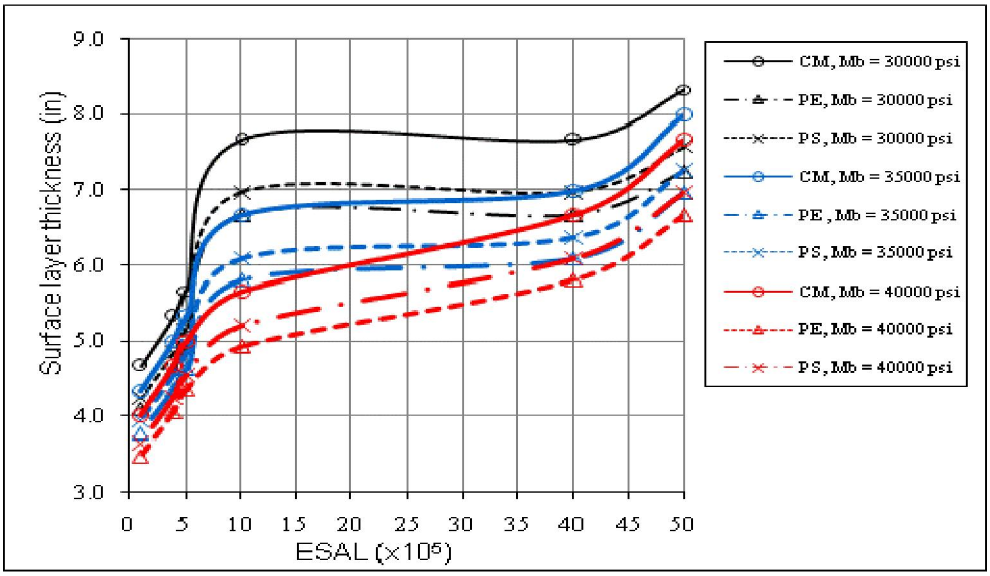


**Fig. 1:** Effect of using polyethylene and polyester wastes on the required surface layer thickness ($d_1$).

## Increase in Pavement Life

Kenlayer program was used to study pavement life for different asphalt surface layer have the same thickness. Kenlayer program was developed at the University of Kentucky for flexible pavement design and analysis. It can be applied to a multilayered system under stationary or moving multiple wheel loads. The program is capable to deal with linear-elastic, non-linear-elastic, or viscoelastic pavement layers (Huang, 1993). For multiple wheels, the superposition principle is applied directly in Kenlayer for a linear system. In a non-linear elastic system, the superposition principle is also applied but with a method of successive approximations. First, the system is considered linear, and the stresses due to multiple-wheel loads are superimposed. Based on the stresses computed, a new modulus is determined. Then, the system is considered linear again, and the process is repeated until the modulus converges to a specified tolerance (Huang, 1993).

The program was used considering three different surface layers CM, PE and PS of the same layer thickness of 6 in. Base layer thickness ($d_2$) was assumed to be 10 in. and ESAL was chosen to be $10^6$. Both single wheel and dual-tandem tires were applied to the pavement structure and the design life was obtained.

Results are presented in Tables (7, 8) and Fig. (2). The results shows that using of PE in surface layer resulted in an increase in pavement design life by 19% and 15% than that of CM under single wheel and dual-tandem tires, respectively. The increase in pavement life was found to be 11% and 8% compared to CM when PS was used.

**Table 7:** Design life under single wheels.

| Mix | ESAL | Design life (year) | Increase in design life (%) | ESAL | Design life (year) | Increase in design life (%) |
|---|---|---|---|---|---|---|
| CM | $10^6$ | 4.46 | --- | $5\times10^5$ | 8.67 | --- |
| PE | | 5.3 | 18.8 | | 10.34 | 19.3 |
| PS | | 4.95 | 11.0 | | 9.63 | 11.1 |

**Table 8:** Design life under dual-tandem wheels.

| Mix | ESAL | Design life (year) | Increase in design life (%) | ESAL | Design life (year) | Increase in design life (%) |
|---|---|---|---|---|---|---|
| CM | $10^6$ | 1.97 | --- | $5\times10^5$ | 3.77 | --- |
| PE | | 2.26 | 14.7 | | 4.34 | 15.1 |
| PS | | 2.13 | 8.1 | | 4.08 | 8.2 |

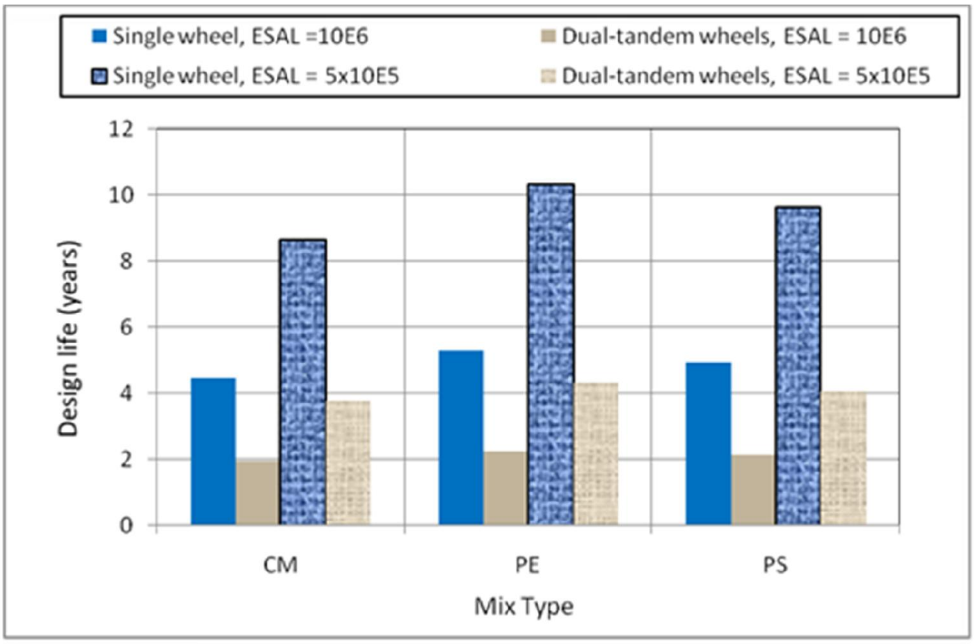


**Fig. 2:** Effect of using polyethylene and polyester wastes on pavement design life.

## Conclusions:

Based on the results of this study, using of polyethylene and polyester wastes in asphalt mixes could decrease the required layer thickness and increase the pavement design life. This conclusion is supported by:

1. Modified polyethylene mixture could decrease thickness of the asphalt surface layer by about 13%, while modified polyester mixture could decrease the asphalt surface layer thickness by about 9 %.
2. The decrease in surface layer thickness is independent of base layer modulus and traffic volume in terms of ESAL.
3. Design life of PE and PS are 19% and 11% higher than that of CM under single wheel axle, respectively. The percentage of increase in pavement life decreased to 11% and 8% compared to CM when PE and PS were used, respectively, under dual-tandem tires.

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