# The Use of Waste Plastics in Hot Asphalt Mixes in Egypt

**Ahmed khaled Mohamed, Hassan A. Mahdy, Khaled A. Kandil**

***Abstract---*** ***Nowadays plastics are used everyday in every aspect of our lives which is a great problem as they are non-biodegradable. They are disposed either by landfilling or incineration of the waste materials which causes environmental pollution and health problems. This paper studies the influence of reusing waste plastic (WP) in hot mix asphalt (HMA). Three different methods were used to add waste plastics to HMA with five different percentages of waste plastic at each method. To determine the best method of adding WP to HMA and the optimum WP content Marshall specimens were prepared and tested to measure their stability, flow, stiffness, indirect tensile strength, and loss of stability. It was concluded that the third method was the best method for adding WP, the optimum WP content differs for each type of WP, using WP improved the mechanical properties of the HMA, and its durability.***

***Index terms---*** ***Hot mix asphalt, Indirect tensile strength, Loss of stability, Marshall, Waste plastics.***

## I. INTRODUCTION

Nowadays plastics are used everyday in every aspect of our lives. It is used in every vital sector of the economy starting from agriculture to packaging, automobile, electronics, and building construction which cause a great problem as plastic is non-biodegradable material and researchers found that it can remain on earth for 4500 years without degradation [1], [2].

Waste plastics (WP) disposal is a concern as they are usually disposed by either landfilling or incineration which causes environmental pollution and health problems like breast cancer, and genital abnormalities; however, banning plastics will not be economically feasible. Hence the solution is the reuse of WP [3], [4].

WP can be used in the hot mix asphalt (HMA) to improve the mix characteristics which is also an eco-friendly way for disposing of plastics. Generally, WP consist of polyethylene (PE), polystyrene (PS), and polypropylene (PP) which soften at 140ºC, do not produce any toxic gases at this temperature, and have binding properties making WP suitable for using in HMA [5]. Many techniques were used in attempt to include the WP in the HMA but the most common two are the dry method and the wet method [6], [7].

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***** Correspondence Author (s)

**Ahmed khaled Mohamed Salah Eldin***, Public Works Department, Ain Shams University/ Faculty of Engineering, Cairo, Egypt, Mobile No.: +201099625166, (e-mail: khaled.ahmed@eng.asu.edu.eg).

**Hassan Abd El Zaher Hassan Mahdy**, Public Works Department, Ain Shams University /Faculty of Engineering, Cairo, Egypt.

**Khaled Anwar Ahmed Kandil**, Public Works Department, Ain Shams University/ Faculty of Engineering, Cairo, Egypt.



In the dry method WP are cleaned, dried, and shredded into small pieces passing sieve no.4, then the aggregate is heated to 160ºC and WP are added to the hot aggregate. WP soften and coat the hot aggregate then hot bitumen is added to the plastic coated aggregate (PCA) [8], [9]. In the wet method 3-4% by weight of bitumen of shredded WP are added to the hot bitumen and mixed together then the plastic modified bitumen (PMB) is mixed with the hot aggregate [10]. Yadav Santosh et al, conducted a study showing that addition of WP by 8% of the bitumen weight to the hot aggregate improved Marshall stability of the PCA mix by 10% more than the traditional mix [11]. Rokade S, conducted a study where he added WP to the HMA using the dry method and crumb rubber to the HMA using the wet method, he found that the addition of WP by 9% of weight of bitumen improved Marshall stability of the mix by 13%, and addition of crumb rubber by 10% of weight of bitumen improved Marshall stability of the mix [12]. Amit Gawande et al, stated that the use of WP of about 5-10% by weight of bitumen helps in substantially improving the Marshall stability, strength, fatigue life and other desirable properties of HMA, which improves the longevity and pavement performance with marginal saving in bitumen usage [13].

In Egypt Solid waste management is becoming a major public health and environmental concern in urban areas, as the existing regulations are still very limited, and the local taxation system is inadequate, while the illegal disposal of domestic and industrial waste remains a widespread practice. Egypt Produces annually about 16.2 million tons of WP, only 30% of WP are recycled and 5% are reused, the other 65% are disposed poorly which cause environmental pollution and health problem [14]. This makes the usage of WP in HMA important as an eco-friendly way of disposing plastic and to improve the HMA mechanical properties to face the increase of traffic load which affects the performance of the flexible pavement in Egypt. This paper aims to evaluate the performance of the plastic modified HMA and compare it with the conventional 4-C surface mixture in the view of the Egyptian Code of Practice (ECP).

## II. MATERIALS AND METHODS

### *A. Waste Plastic*

Depending on their physical properties plastics can be classified as thermoplastic and thermosetting materials. thermoplastics can be formed into desired shapes by applying heat and pressure and become solids on cooling.



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If thermoplastics are subjected to the same conditions of heat and pressure, they can be reshaped. Thermosetting materials once shaped they can not be softened and remolded by the application of heat. Two types of WP were used in this study, the first type consisted of cups, water bottles, cold drinks bottles, and household articles and will be referred as WP1. The second type consisted of plastic sacks and will be referred as WP2. Both types were cleaned and cut into small pieces as shown in Fig.1

### *B. Aggregate and Bitumen*

Aggregate were crushed lime stone (coarse and fine aggregates) from El Berqan stone pits located in Marsa-Matrouh, northern Egypt. The used binder was Alexandria bitumen of grade 60/70 which is the most common type of bitumen in Egypt.

### *C. Bituminous mixtures*

In this study, the 4-C dense gradation for the surface mixture according to the ECP was selected. Then three methods were used to add WP to this mixture making four different mixtures.

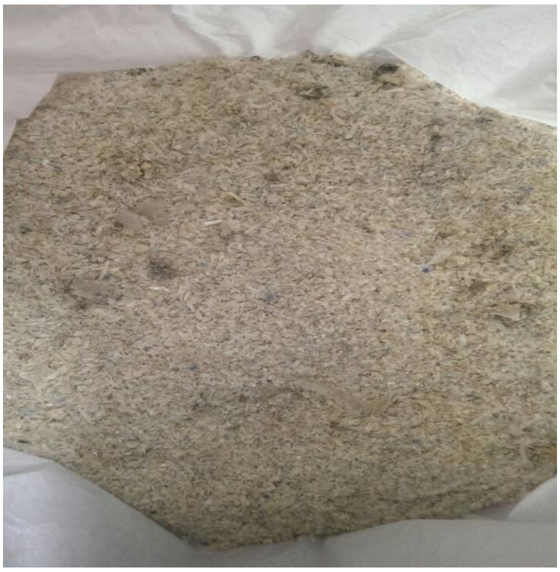

Fig. 1(a) WP1

Fig. 1(b) WP2

Table 1
Characteristics of coarse aggregate

| Test No. | Test | | Type of Aggregate | AASHTO Standards | Results |
|---|---|---|---|---|---|
| 1 | Abrasion After 500 Revolution | | Pin 1 | T - 96 | 24.00% |
| | | | Pin 2 | | 24.00% |
| 2 | Water absorption | | Pin 1 | T-85 | 2.89% |
| | | | Pin 2 | | 1.86% |
| 3 | Specific Gravity | Bulk | Pin 1 | T-85 | 2.51 |
| | | Saturated | | | 2.56 |
| | | Apparent | | | 2.61 |
| | | Bulk | Pin2 | T-85 | 2.54 |
| | | Saturated | | | 2.60 |
| | | Apparent | | | 2.63 |

Table 2
Characteristics of Bitumen

| Test no. | Test | AASHTO Standards | Results |
|---|---|---|---|
| 1 | Penetration,0.1mm | T-49 | 62 |
| 2 | Softening Point,°c | T-53 | 42 |
| 3 | Specific gravity at 25°c | T-228-04 | 1.01 |
| 4 | Rotational viscocity at 135°c | T-201 | 208 |



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## III. EXPERIMENTAL WORK

The experimental work involved testing the aggregate to determine its physical and mechanical properties. Bitumen was also tested to determine its characteristics.

Marshall mix design method was used to determine the optimum bitumen content (OBC) of the control mix, five percentages of bitumen were tested ranging from 4.75% to 5.75% with 0.25% increment. Then WP were added to the mixture by weight of bitumen using three different methods. In the first method the aggregate was heated to 170°C then WP1 were sprayed over the hot aggregate, five percentages were used ranging from 2% to 10% with an increment of 2% while replacing bitumen with the added WP1. The second method was like the first one except that WP1 did not replace the bitumen. In the third method WP1 and WP2 were added separately to the hot bitumen and mixed thoroughly before mixing the PMB with the aggregate. Five percentages were used in the third method ranging from 2% to 6% with 1% increment. All these mixes were tested to determine the optimum method and the optimum WP content (OWPC). The PMB was also tested to determine its characteristics.

### *A. Marshall stability, flow, and quotient tests*

Marshall test was conducted on the control mix to determine the OBC. The bitumen content corresponding to maximum bulk specific gravity, maximum stability, 4% air voids, and 80% voids filled with bitumen was used to determine the OBC. After determining the OBC of the control mix, it was used for the modified mixtures.

Marshall quotient (MQ) (Kg/mm) is calculated as the ratio of stability (Kg) to flow (mm). MQ can be considered as an indication to the material stiffness, higher MQ value means stiffer material.

### *B. Indirect tensile strength (ITS) test*

The ITS is performed using Marshall apparatus (ITS mode) at 25°C to determine the tensile properties of the asphalt mixture which indicates the pavement resistance to cracking. The failure load of each specimen was recorded then the ITS was calculated using the following equation:

$$ITS = \frac{2P}{\pi t d} \qquad [1]$$

Where ITS is the indirect tensile strength (KPa); P is the failure load (Kg); t is the sample thickness (cm); d is the sample diameter (cm).

### *C. Loss of stability test*

Loss of stability test (LOS) is a test to measure the mixture moisture susceptibility by soaking three Marshall specimens in water bath at 60°C for 24 hours then testing it using Marshall apparatus to determine the loss of the stability.

## IV. RESULTS AND DISCUSSION

### *A. Marshall stability, flow, and quotient*

The physical and mechanical properties of aggregate are shown at Table 1. Bitumen characteristics are shown at Table 2. It was found that the OBC of the control mix was 5.25%. After adding WP to the mixture using the first and the second method and testing the modified mixes using Marshall test it was observed that Marshall stability of the modified mixes decreased as shown in Table 3 and Table 4. The decrease in Marshall stability was due to the big surface area of the fine particles in the mix which prevented WP from coating the aggregate and caused the deterioration in the mix properties.

Table 3
Marshall test results for the first method

| % plastic | Stability (kg) | Flow (mm) | MQ (Kg/mm) |
|---|---|---|---|
| 0 | 1280 | 2.7 | 474.07 |
| 2 | 1105.8 | 3.4 | 325.24 |
| 4 | 1055.68 | 3.8 | 277.81 |
| 6 | 1020.14 | 4.1 | 248.81 |
| 8 | 1003.6 | 4.3 | 233.40 |
| 10 | 985.4 | 4.7 | 209.66 |

Table 4
Marshall test results for the second method

| % plastic | Stability (kg) | Flow (mm) | MQ (Kg/mm) |
|---|---|---|---|
| 0 | 1280 | 2.7 | 474.07 |
| 2 | 1114 | 3.1 | 359.35 |
| 4 | 1063.37 | 3.6 | 295.38 |
| 6 | 1042.5 | 3.8 | 274.34 |
| 8 | 1024.35 | 3.9 | 262.65 |
| 10 | 1002.4 | 4 | 250.60 |

The third method which were used to add WP1 and WP2 to the mixture improved the mechanical and the physical properties of the mixture as shown in Table 5 and Table 6. Marshall stability and MQ for the modified mixes were higher than the values obtained from testing the control mix which indicates that the modified mixes will have better resistance to permanent deformation. The percentage of WP1 which gave the highest stability and MQ was 4% while the percentage of WP2 was 3% which indicates that the OWPC is different for each type of WP.

### *B. Indirect tensile strength*

The results of the ITS test for the first and second method are presented in Fig. 2. The ITS values of the mixtures were found to be less than the ITS value of the control mix while ITS values of the third method were better as shown in Fig. 3 which indicates a better cracking resistance for the PMB mixes.

Table 5
Marshall test results for the third method using WP1

| % plastic | Stability (kg) | Flow (mm) | MQ (Kg/mm) |
|---|---|---|---|
| 0 | 1280 | 2.7 | 474.07 |
| 2 | 1372.4 | 3.05 | 449.97 |
| 3 | 1470 | 3.2 | 459.38 |
| 4 | 1602.4 | 3.3 | 485.58 |
| 5 | 1406.7 | 3.5 | 401.91 |
| 6 | 1351.25 | 3.6 | 375.35 |


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Table 6
Marshall test results for the third method using WP2

| % plastic | Stability (kg) | Flow (mm) | MQ (Kg/mm) |
|---|---|---|---|
| 0 | 1280 | 2.7 | 474.07 |
| 2 | 1325 | 2.97 | 446.13 |
| 3 | 1614.3 | 3.4 | 474.79 |
| 4 | 1412.3 | 3.15 | 448.35 |
| 5 | 1565.8 | 3.5 | 447.37 |
| 6 | 1433.6 | 3.63 | 394.93 |

### *C. Loss of stability*

The loss of stability results for the first and second method are shown in Fig. 4 while the results of the third method are shown in Fig. 5.

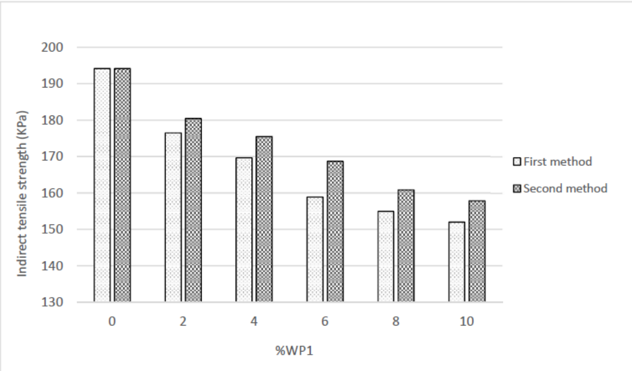


*Fig. 2 ITS values for the first and second method*

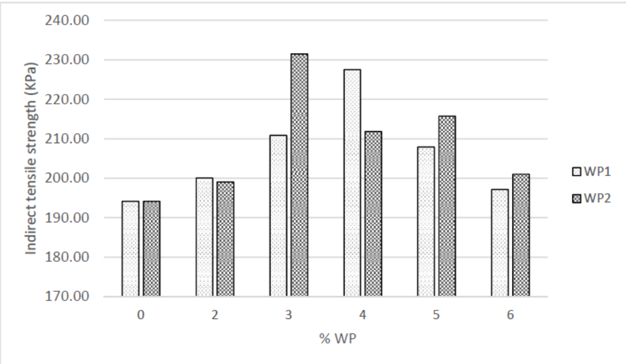


*Fig. 3 ITS values for the third method*

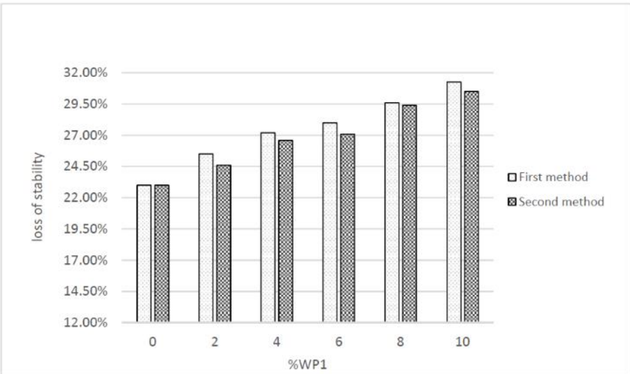


*Fig. 4 loss of stability for the first and second method*

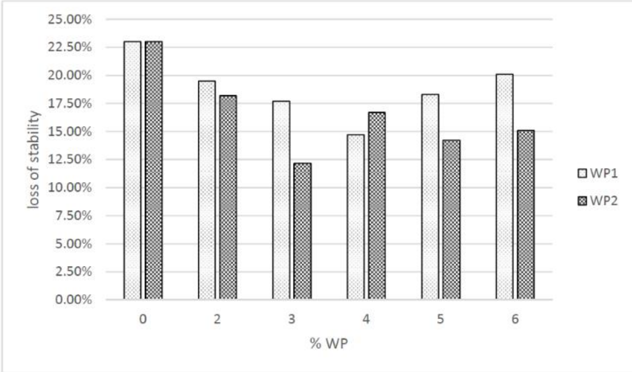


*Fig. 5 loss of stability for the third method*

The loss of stability for the PMB mixtures is less than the control mix which indicates a better moisture susceptibility.

### *D. Bitumen tests.*

The PMB was tested to determine its characteristics and compare it with the virgin bitumen. The softening point and the rotational viscosity at 135°C were determined for the PMB as shown in Fig. 6 and Fig. 7. The addition of WP to the bitumen improved its characteristics which reflected on the performance of the tested mixtures which were prepared by PMB.

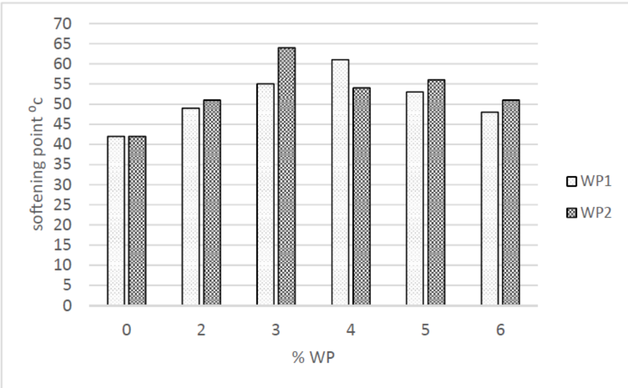


*Fig. 6 softening point values of the PMB*

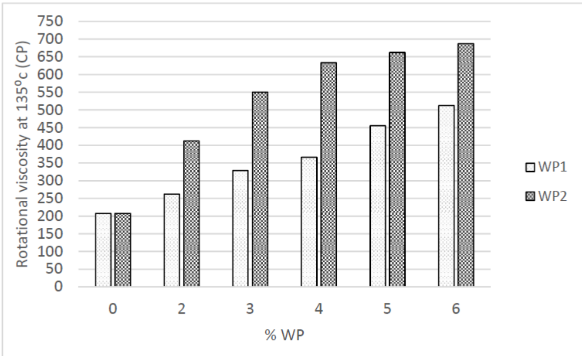


*Fig. 7 rotational viscosity values of PMB at 135°C*

## V. CONCLUSIONS

In this research three methods to include WP in the HMA were investigated and two types of WP were used in the process to determine the best method to add WP to HMA and the OWPC to be added.



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Various tests were made to the control and modified mixtures which were Marshall test, ITS, and loss of stability.

The following conclusions were deducted:

- The best method to add WP to HMA is by mixing the bitumen with WP then add the PMB to the hot aggregate.
- The OWPC to be added to the mix using the third method for WP1 was 4% while the OWPC for WP2 was 3%.
- The OWPC to be added to the HMA depends on the type of the used WP that is why a new OWPC must be determined for each new type of WP.
- The PMB mixtures performance was superior to the control mixture which indicates that WP can be used in HMA in Egypt according to ECP.

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