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USE OF WASTE POLYETHYLENE AS A BITUMEN MODIFIER IN ASPHALT CONCRETE MIXTURES

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ABSTRACT

The main objective of this research is to study the possibility of using plastic wastes containing medium density polyethylene (MDPE) as polymer additives to asphalt concrete. It was investigated that the influence of MDPE-modified binder obtained by various mixing time, mixing temperature and MDPE content on the Marshall Stability, flow and Marshall Quotient (Stability to flow ratio). The binders used in Hot Mix Asphalt (HMA) were prepared by mixing the MDPE in 4 and 6% (by the weight of optimum bitumen content) and AC-60/70 at temperatures of 155 and 165 °C for 5 min and 10 min of mixing time. MDPE-modified asphalt concrete results in a significant increase in the Marshall Stability value and a Marshall Quotient value. The 4 % MDPE, 165°C of mixing temperature and 10 min of mixing time were determined as optimum conditions for Marshall Stability, flow and Marshall Quotient (MQ). MQ increased by 30% compared to control mix. It can be said that waste MDPE-modified bituminous binders provide better resistance against permanent deformations due to their high stability and high Marshall Quotient and it contributes to recirculation of plastic wastes as well as to safety of the environment.

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INTRODUCTION

In latest years, several waste materials result from manufacturing operations, service industries and households all over the world. Waste utilization is an attractive alternative to disposal, in that disposal cost and potential pollution problems are reduced or even eliminated along with the achievement of resource conservation. On the other hand, recent highway construction costs have showed a significant rise. It is well known that the addition of both some waste materials and certain polymers to asphalt binders can improve the performance of asphalt concrete [1–9]. Polyethylene has also been found to be one of the most effective polymer additives [10, 11]. In Egypt, there are thousands tons of materials containing MDPE. From the economic viewpoint, it may be quite possible that waste MDPE material improve the initial engineering properties of HMA pavement and increase its service life. However, since the mixing conditions for the bitumen and polymer have considerable effect on the behavior of polymer modified bitumen, the most suitable mixing conditions should be determined for bitumen and polymer.

For this purpose, modified bitumen is obtained by mixing the bitumen and modifier at a certain temperature and time. If the consistent mixing time and mixing temperature are not provided for bitumen–modifier mix, modified bitumen cannot exhibit good performance in situ, thus premature failures will occur. In addition, modifier content is also an important factor affecting the performance of the polymer-modified asphalt concretes. Therefore, there are certain recommended mixing time, mixing temperature and modifier content for all the polymers with a trademark. Stability of an HMA pavement, the most important property of the bitumen mixture in the wearing course design, is its ability to resist shoving and rutting under traffic. Therefore, stability should be high enough to handle traffic adequately, but not higher than the traffic conditions required. The lack of stability in an asphalt mixture causes unraveling and flow of the road surface. Flow is the ability of an HMA pavement to adjust to gradual settlements and movements in the subgrade without cracking. The flow may be regarded as an opposite property to the stability, determining the reversible behavior of the wearing course under traffic loads and affecting plastic and elastic properties of the asphalt concrete [11]. The Marshall quotient, calculated as the ratio of stability to flow and thereby representing an approximation of the ratio of load to deformation under the particular conditions of the test, can be used as a measure of the material's resistance to permanent deformation in service [12].
The purpose of this study is to investigate the usability of the waste material containing MDPE in the HMA as a bitumen modifier. Considering their deterministic role in the performance of polymer-modified bitumen blends, the study was focused on the effects of the modifier (MDPE) content, modifier–bitumen mixing time and mixing temperature on the Marshall stability, flow and Marshall Quotient.

2. MATERIALS AND METHODOLOGY

The materials and experimental design procedure used in this study are as shown below. The bitumen used was AC-60/70 asphalt penetration grade. This asphalt was subjected to typical standard laboratory tests. The results of these tests are incorporated in Table (1). In this investigation, waste MDPE in the powder form was used as a modifier. The specific gravity of the modifier was measured to be 0.5 g/cm^3. The gradation of MDPE is presented in Table (2). Crushed Limestone was used as the aggregate material. Five aggregates were blended to meet the target gradation and the specific gravity of this aggregate blend was 2.625 g/cm^3. Some properties of the crushed limestone and specific gravities of aggregates are given in Table (3). The selected gradation and the specification limits are shown in Table (4). The Marshall Mix design method was used for determining the resistance to plastic flow of bituminous mixtures prepared with or without MDPE-modified bitumen.

Initially, optimum bitumen content was found to be 5.35% (by weight of total mix) for unmodified mixtures. A speed adjustable vertical shaft mixer was used to mix the MDPE and bitumen. Temperature control during mixing was achieved by using thermostat running with a thermocouple attached to the mixer . The machine was operated at 200 rpm for MDPE–bitumen mixing. The utilization strategy must be coupled with environmental and energy considerations to use available materials most efficiently. Since the amount of MDPE, bitumen –MDPE mixing temperature and bitumen–MDPE mixing time play a critical role in determining the performance of MDPE-modified asphalt concrete, these were considered as factors affecting the performance of asphalt concrete in the design of experiment. The binders used in HMA were prepared by mixing the MDPE in 4 and 6 % (by the weight of optimum bitumen content) and AC-60/70 at mixing temperatures of 155°C and 165°C for 5 min and 10 min mixing time. After obtaining the MDPE-modified bitumen, aggregate and MDPE-modified bitumen were heated separately to 165°C and 155°C, respectively, and then mixed with the aggregate in a mechanical mixer. The mixture was placed in a Marshall mold and compacted by applying 75 blows on each side of the specimen at 145°C. The standard dimensions of the samples were 63.5 mm height and 101.5 mm diameter. After having cooled at room temperature for one day and then conditioned in water at 60°C for 30-40 min, the samples were tested with Marshall Test apparatus. All results are recorded as an average of the results of three test specimens. Figure (1) illustrates a flow chart for the experimental program.

Table (1): Properties of proposed control mix.

Pb absorbed	0 .47%
Specific Gravity of Bitumen	1.02
Viscosity (min = 320)	364
Softening point (45 – 55 °C)	51
Penetration, 25°C, 100 g, 5 sec (1/10 mm)	63

Table (2): The gradation of medium density polyethylene.

Sieve Size (#)	mm	Passing (%)
#30	0.6	67.24
#50	0.3	48.94
#100	0.15	21.24
#200	0.12	9.86

Table (3): Specific gravity, absorption, and (LOS) of aggregate .

Type / Properties	SEN-1	SEN-2	SEN-1"	Sand	Filer
Bulk specific gravity (gm/cm^3)	2.55	2.54	2.54	2.458	2.066
Saturated Surface Dry sp. Gravity (gm/cm^3)	2.60	2.59	2.60	-	-
Apparent specific gravity (gm/cm^3)	2.68	2.67	2.69	2.634	2.476
Absorption (%)	1.92	1.89	1.06	2.9	9.2
LOS Anglos (%)	19.56	9	20	-	-

Table (4): Aggregate gradations and required specifications.

Sieve #	Final Gradation	Specifications min	max
25	100.0	100	100
19	99.4	80	100
9.5	77.6	60	80
4.75	54.2	48	65
2.36	42.1	35	50
0.6	23.9	19	36
0.3	18.3	13	23
0.15	11.1	7	15

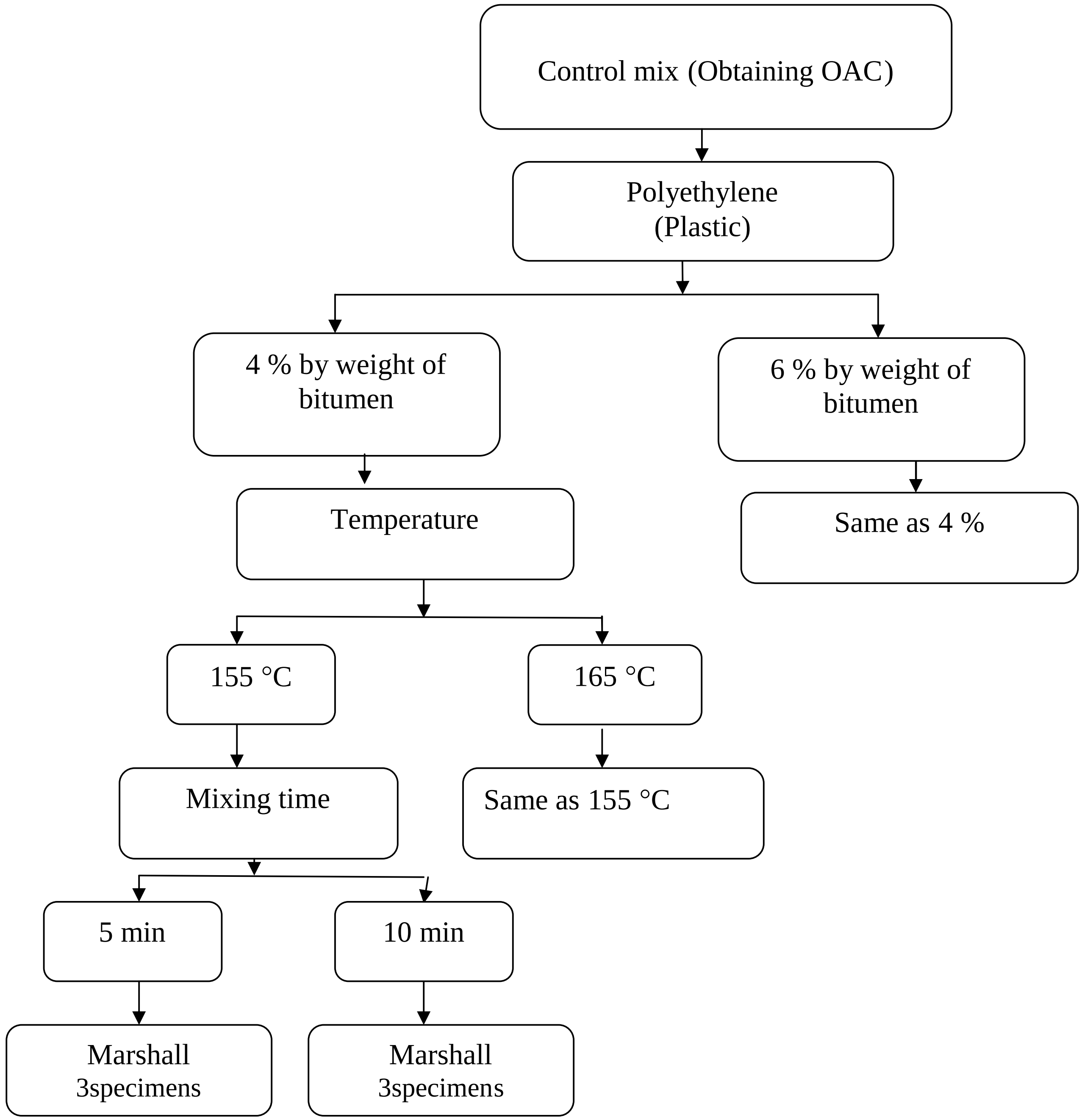

Figure (1): Flowchart of experimental program design.

RESULTS AND DISCUSSION

Stability

Figure (2) shows the variation of stability with the various bitumen and waste MDPE mixing temperature and time. It is shown that stability decreases with increasing MDPE content for all mixing temperature and mixing time. Stability of the control mixture is 1060 kg. For both 4% and 6% MDPE mixes, stability is higher than the control mixture. The effect of the mixing time is more apparent at 165°C mixing temperature. The maximum stability is reached at 4% MDPE, 165°C mixing temperature and 10-min mixing time. Marshall stability value increased by 32% when 4% MDPE was replaced with AC-60/70. The decreases in stability while increasing MDPE content may be attributed to the decreases in the adhesion.

Flow

The results of flow values are illustrated in Figure (3). The figure shows that flow increases with increasing the MDPE content. Flow is found to be 3.7 mm for the control mixture. Although flow decreases with increasing the mixing temperature and mixing time, all flow values are higher than the control specimen. This may imply that increase in the amount of MDPE affects the interior friction of the mixture in a negative manner. The smallest flow value, 3.8 mm, is reached at 4% MDPE, mixing temperature of 165°C and mixing time of 10 min.

Marshall Quotient

Since Marshall Quotient (MQ) is an indicator of the resistance against the deformation of the asphalt concrete [12], MQ values are calculated to evaluate the resistance of the deformation of the MDPE-modified specimens. A higher value of MQ indicates a stiffer mixture and, hence, indicates that the mixture is likely more resistant to permanent deformation [13]. The specimen having higher MQ than that of the control mixture is prepared with 4% MDPE at 165°C mixing temperature and 10 min mixing period as shown in Figure (4). The specimen under conditions above-mentioned provided all the specification limits for Marshall Design parameters. Waste MDPE content of 4% (by weight of optimum bitumen content), 165°C of mixing temperature and mixing time of 10 min satisfy all the specification limits given. Results of the Marshall Design parameters and values of MQ for both control and waste MDPE-modified asphalt concretes mix are shown for comparison purposes in Table (5). The table shows that MQ increased by 30% when waste MDPE was added compared to the control mix.

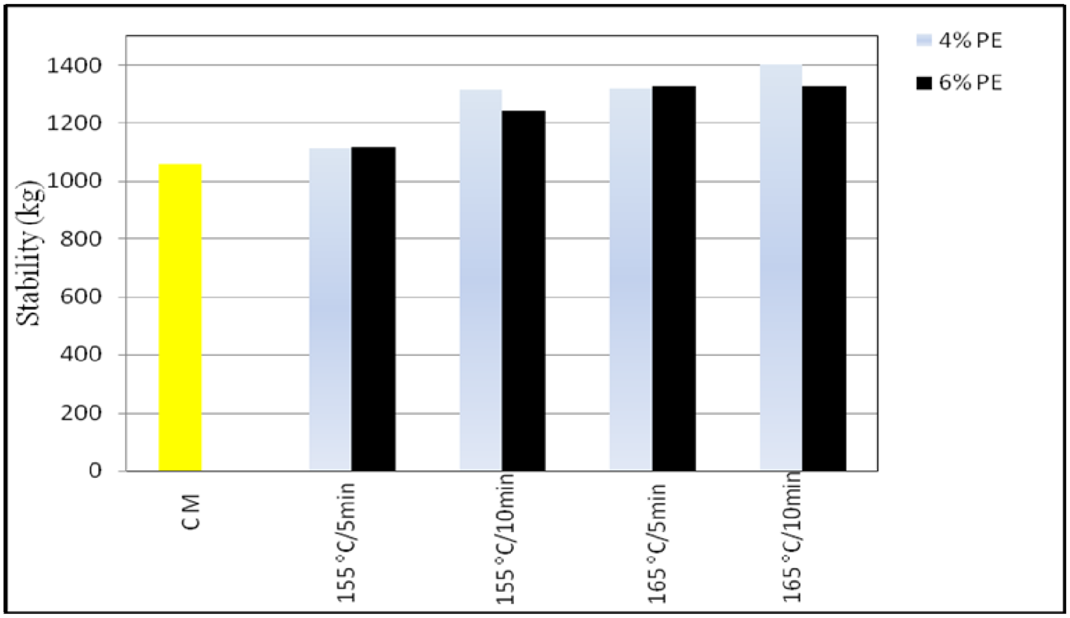

Figure (2): Mixing temperature/mixing time vs. stability.

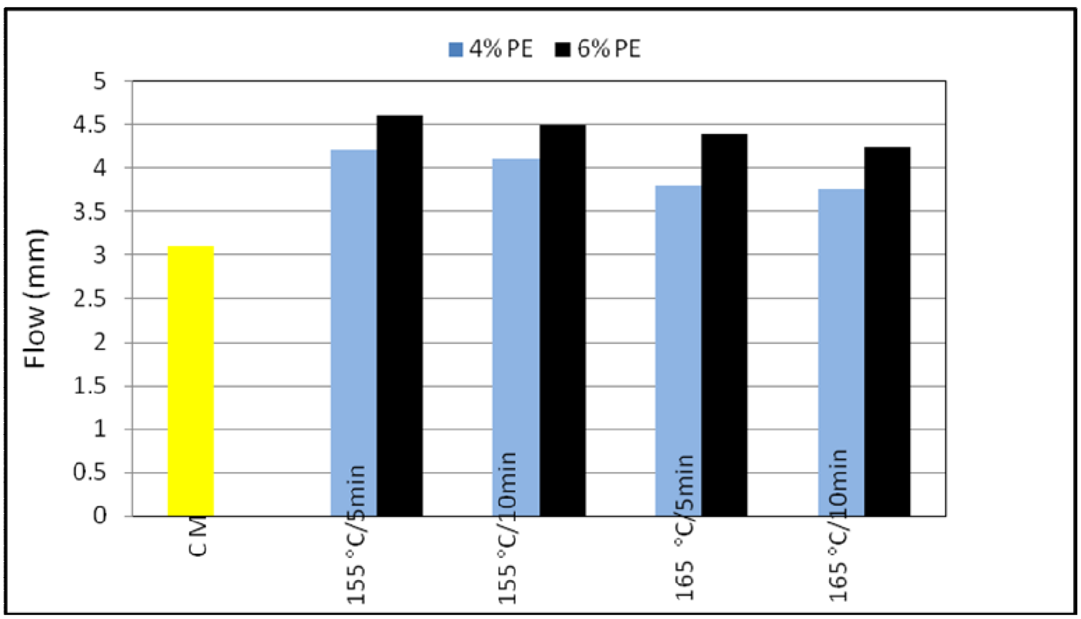

Figure (3): Mixing temperature/mixing time vs. flow.

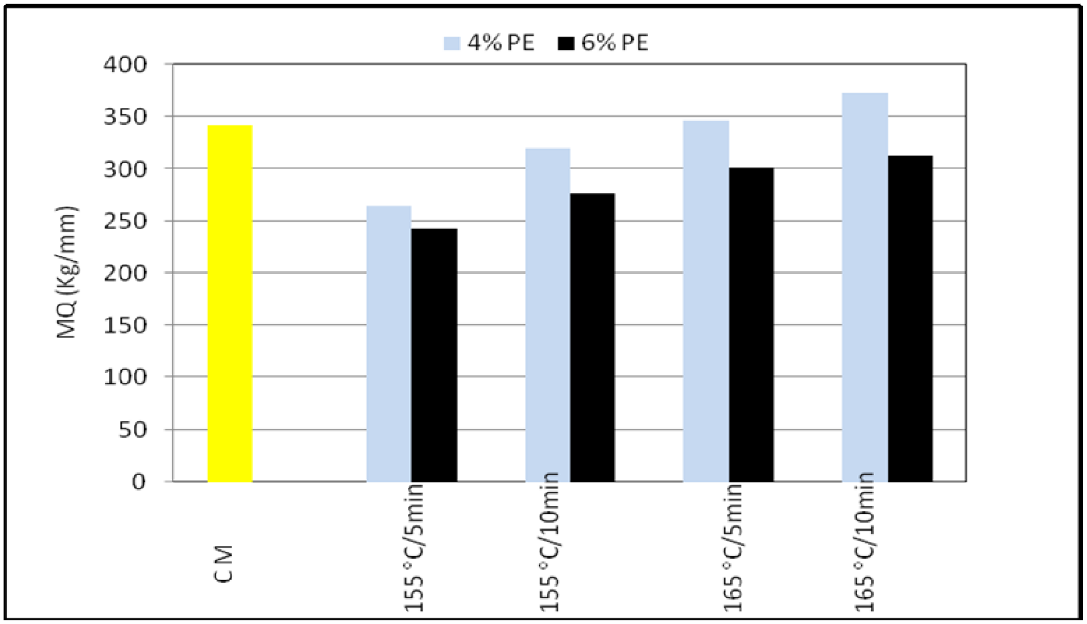

Figure (4): Mixing temperature/mixing time vs. MQ

Table (5): Comparison of the control and waste MDPE-modified asphalt concrete Mixtures.

	Control mixture	Mixture with 4% MDPE	Specification limits (%)
Void ratio (%)	4.55	4.43	3-5
VMA (%)	14.05	14.1	≥ 13
Voids filled with binder (%)	67	68.99	
Stability (kg)	1060	1401.14	
Flow (mm)	3.7	3.8	2-4
Marshall Quotient (kg/mm)	284.2	368.7	-

Binder was prepared by mixing the bitumen and 4% waste MDPE at the temperature of 165°C and 10 min of mixing time

CONCLUSIONS

Based on the results of this study, the following can be concluded:

- The specimens prepared at 165°C mixing temperature and 10 min mixing time with 4% MDPE have the higher stability and smaller flow, as well as higher Marshall Quotient compared with that using 6 % MDPE.
- A stability increase indicates that the MDPE-modified mixes are much stronger than the control mix.
- This mix is highly resistant to permanent deformation (rutting) in asphalt concrete.
- Although the flow value of MDPE-modified asphalt concrete is almost the same as the control mix, higher values of MQ are obtained due to higher stability values.
- MQ increased by 30% compared to control mix. It means that asphalt concrete having higher MQ values indicates a high stiffness mix with a greater ability to spread the applied load. Thus, the pavements being more resistant to permanent deformation are obtained and a solid waste disposal problem is relatively solved.

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