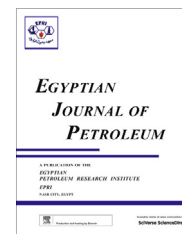




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FULL LENGTH ARTICLE

Environmentally friendly road construction

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KEYWORDS

Asphalt;
 Hot mix asphalt;
 Modified asphalt;
 Waste;
 Marshall

Abstract Environmental pollution is a major problem in developing countries like Egypt. Reuse of waste polymers is considered an attractive solution for environmental white pollution and reducing of the costs of road pavement and maintenance. This research aims to prepare environmentally friendly hot mix asphalt (HMA) for paving using some industrial wastes as polypropylene and polyester fibers. The solid materials in the mix include normal and highly porous aggregates. 5% and 10% of waste polymers by weight of the asphalt were used to prepare special binders. The samples were tested for their physical properties, chemical properties, aging, scanning electron microscopy (SEM) and thermo-gravimetric analysis (TGA). The results revealed that the prepared HMA using 5% of waste polymer had high performance as compared to the ordinary one and the waste polymer could be used in road construction.

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1. Introduction

Bitumen, a residue from crude oil distillation, is a complex mixture of four main families of compounds, referred to as SARA fractions (saturates, aromatics, resins and asphaltenes) [1,2]. The behavior of bitumen depended on the relative concentration and the chemical features of asphaltenes and maltenes; thus, variation in its composition strongly affects its mechanical properties [3,4]. It presents a large set of interesting potential

properties: impermeability, ductility, adhesivity and resistance to the effect of weathering and chemicals, etc. [5,6].

In the last 20 years, a wide spectrum of modifying polymeric materials has been tested with bitumens for their use in road construction. For a polymer to be effective it must blend with bitumen and improve its resistance at high temperatures without making the bitumen too viscous at mixing temperatures or too brittle at low temperatures. It should be capable of being processed by conventional equipment, available, not expensive and physically and chemically stable during storage, application and service. In actual modified bitumens, thermoplastic rubbers, as well as some thermoplastic polymers, were mainly used. The use of secondary (recycled) aggregates, instead of primary (virgin) materials helped in easing landfill pressures, reducing the need for extraction, protecting environment and minimizing the consumption of original resources. [7] Polyester polymer, thermoplastic Polyethylene terephthalate (PET) and mineral fibers are the additives mostly used to produce a strong and durable reinforcement bitumen [8,9].

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Also, different industrial wastes (such as waste polymers, spent toner, marble quarry waste and fibers. . etc.) can be used as asphalt modifiers. Carpet waste fibers were used recently in asphalt mixtures and in fiber reinforced concrete. Such reinforcement improved effectively the shatter resistance, toughness, and ductility of concrete [10–12]. One of the major waste generating industries is the construction and marble production, and, it was reported that the potentials to use this type of waste in low to medium traffic urban roads and as binder courses were very beneficial. There are some literatures that discussed the use of fillers such as limestone powders, rubber silica and carbon black as modifiers for asphalt mixture [13]. In Egypt, the use of waste materials in HMA is not applied yet, in addition to the presence of a large amount of low quality aggregate not suitable for use in paving or other purposes. The present research aims to use the waste of some industries like polypropylene, polyester (as waste of backing and carpet industries respectively) in the preparation of a special type of asphalt to be used in the production of HMA. The solid materials in paving mix were low quality aggregates of high absorptive type and waste marble filler with the final objective to provide added value, to reduce the production costs and keep the virgin solid materials (especially aggregates [14] for a longer period of time. The produced mixes are of similar or of better performance compared to the conventional asphalt mixtures.

2. Experimental

2.1. Materials used

Asphalt cement: two samples of asphalt cement of penetration grade 60/70 produced by El-Nasr Petroleum Company in Suez city and Alexandria Petroleum Company in Alexandria city were used.

Waste polymers: waste polypropylene (PP) fiber discarded from carpet industry at Eastern Wavers Company at 10th of Ramadan city and waste polyester (PE) discarded from El

Farasha Company for packing and printing at 10th of Ramadan city, Egypt were used.

Solid materials:

- Siliceous lime stone was obtained from Abbasa quarry (Cairo governate).
- Lime stone of high absorptive type was obtained from El haram quarry (Giza governate).
- Natural sand was obtained from Abbasa quarry (Cairo governate).
- Filler (Limestone type).
- Marble powder discarded from workshops in Kattameia region in Cairo was used.

Solvents and chemicals: benzene AR (ADWIC), cyclohexane 99.5% (PANREAC QUIMICA), methanol (POCH), petroleum ether 40/60 (SIGMA ALDRICH), aluminum oxide 90, 70–2308 mesh ASTM, (MERCK) were used.

3. Experimental procedure

3.1. Characterization of raw materials

Penetration, softening point, specific gravity and Brookfield viscosity were determined for the virgin asphalt samples (AC 60/70). The samples were separated into SARA fractions. Asphaltene and maltene fractions using *n*-heptane were separated and the liquid–solid chromatography technique was used to fractionate the maltene fraction into saturates, aromatics, and resin components [15,16]. *n*-Paraffin content of saturated components was determined using the gas chromatography technique. The results are illustrated in Tables 1 and 2). FTIR spectra were carried out as shown in Figs. 1a and 2a.

TGA analysis was carried out using SDTQ 600 thermogravimetric analyzer (TA-USA) to test the thermal stability of the virgin asphalt sample and all waste polymers in the temperature range of 25–800 °C and a heating rate of 108 °C/min under dynamic nitrogen gas (Table 3).

Table 1 Characteristics of virgin asphalt samples used (AC).

Test	AC ₁	AC ₂	SP ^a
Penetration (at 25 °C, 100 g, 5 s), 0.1 mm	62	65	60/70
Softening point (ring and ball), °C	50.6	48.5	45/55
Penetration index [12]	−0.54	−0.97	−2: +2
Specific gravity (at 25 °C) using a pycnometer,	1.02	1.019	NS ^b
Flash and fire points (Cleveland Open Cup), °C	250	250	250
Ductility (at 25 °C, 5 cm/min), cm	150	150	150
Kinematic viscosity (at 135 °C), cSt	381	330	> 320
Brookfield viscosity (at 60 °C), C.P	115.7	113.1	NS ^c
<i>Thermal gravimetric analysis (TGA)</i>			
^c Initial degradation temperature, °C	278.76	213.18	NS ^b
^c Final degradation temperature, °C	695.46	688.42	NS ^b
^c Total weight loss (wt.%)	84.16	69.00	NS ^b
<i>Metal analysis</i>			
^c Vanadium (ppm)	180	141.0	NS ^b
^c Nickel (ppm)	251.4	234	NS ^b

^a N.B: standard specification for “general authority for roads, bridges and land transportation in Egypt. Item No. 102.1.

^b Not specified.

^c Shear rate 80 s^{−1}, spindle No. 40 & RPM = 20 using Brook Field viscometer (modelDV-111 + programmable rheometer).

Table 2 Molecular type composition of virgin asphalt samples (AC₁ & AC₂).

Molecular type composition (wt.%)	AC ₁	AC ₂
Saturate content	10.6	7.55
* <i>n</i> -Paraffin content	1.59	1.92
*Iso- & cyclo-paraffin content	9.01	5.63
Aromatic content	34.58	44.71
Resin content	31.7	27.63
Aromatics & resin content	66.28	72.34
Asphaltene content	23.12	20.11
Asphaltenes & <i>n</i> -paraffin content	24.71	22.03

Table 3 TGA for waste polymers used.

Waste polymer type	Result
Polypropylene	
Initial degradation temperature, °C	388.18
Final degradation temperature, °C	503.89
Total weight decomposed (wt.%)	96.87
Polyester	
Initial degradation temperature, °C	424.71
Final degradation temperature, °C	505.47
Total weight decomposed (wt.%)	100

The temperature susceptibility of virgin and modified asphalt sample was expressed in terms of penetration index (P.I) using the penetration (at 25 °C) and softening point values.

P.I can be calculated from the following equation [17]:

$$P.I = \frac{1952 - 500 \times \log(\text{pen}25) - 20 \times \text{soft.Pt}}{50 - \log(\text{pen}25) - \text{soft.pt} - 120}$$

3.2. Preparation and characterization of polymer modified asphalt samples (PMAs)

Blends of virgin asphalt and three levels of polymer modifiers (5, 10 and 15 percent by weight of asphalt) were prepared. The blending conditions were conducted at 163 °C with stirring for 2 h (after complete addition of the polymer into asphalt). The prepared samples were tested for compatibility test using the Shell method [18], and then characterized physically and chemically as previously mentioned in the testing program step No.

Table 4 Physical characteristics of modified asphalt 60/70 (AC₁).

Characteristics	Virgin asphalt AC ₁	Modified asphalt with			
		PP		PE	
		5%	10%	5%	10%
Penetration (at 25 °C, 100 g, 5 s) 0.1 mm	62	40	28	27	17
Softening point (ring and ball), °C	50.6	60	68	80	88
Specific gravity (at 25 °C).	1.02	1.03	1.032	1.038	1.042
Brookfield viscosity (at 60 °C), C.P	115.7	216.3	694.3	580	1010.3
Penetration index (P.I)	-0.54	0.49	1.46	2.83	3.12
Aging (penetration after 5 h)	17	15	9	12	5

1. It was noticed that, the level of 15% (w/w) of each polymer resulted in a very viscous mix which was very difficult to handle. So, this level was omitted from further work. The results of characteristics of PMAs are illustrated in Tables 4 and 7.

3.3. Choosing and evaluation of best polymer modified asphalt samples prepared

FTIR (Figs. 1 and 2), SEM (Figs. 3 and 4), TGA (Figs. 5a and b) analyses were carried out to virgin asphalt and modified AC with 5% of each waste polymer which gave the suitable physical and chemical characteristics. Photographs have been observed using scanning electron microscopy SEM (SEM; Philips). Infrared spectra of all samples were recorded via FTIR spectrophotometer (Model 960 Moog, ATI Mattson Infinity Series, USA).

3.4. Preparation of hot mix asphalt and properties

Hot mix asphalt samples were prepared using virgin asphalt and modified binders and were evaluated using the Marshall Test method (ASTM D-6927). The mixes were designed (Figs. 6a and b) according to the standard limits of surface (wearing) course 4c. The job mix was formulated (%wt.) using coarse and fine aggregates, sand and filler as 33, 30, 32 and 5 wt.%, respectively.

The mixes were tested for maximum load and flow. Density and air voids in mixes and solid materials were determined.

HMA (1a, b) are hot mixes asphalt consisted of normal absorptive aggregate type, virgin asphalt samples (AC₁ and AC₂ respectively) and limestone filler.

HMA (2a, b) are hot mixes asphalt consisted of high absorptive aggregate type, virgin asphalt samples (AC₁ and AC₂ respectively) and limestone filler.

HMA (3a,b& 4a,b) are hot mixes asphalt consisted of high absorptive aggregate type, marble dust, modified asphalt using 5% of waste polypropylene (samples 3a and b) and waste polyester (samples 4a and b) respectively.

4. Results and discussion

4.1. 1 – Characteristics of virgin and modified asphalt samples

4.1.1. A. Physical characteristics and molecular type composition of asphalt samples

Generally, data in Tables 1–7 indicated that the modified samples are more harder than the virgin one. There was an increase

Table 5 Physical characteristics of modified asphalt 60/70 (AC₂).

Characteristics	Virgin asphalt AC ₂	Modified asphalt with			
		PP		PE	
		5%	10%	5%	10%
Penetration (at 25 °C, 100 g, 5 s) 0.1 mm	65	42	30	29	19
Softening point (ring and ball), °C	48.5	56	68	77	86
Specific gravity (at 25 °C)	1.019	1.027	1.03	1.036	1.04
Brookfield viscosity (at 60 °C), C.P	95	180.4	492.6	408.9	830.2
Penetration index (P.I)	-0.97	-0.21	1.28	2.57	2.83
Aging (penetration after 5 h)	35	24	22	18	11

in softening point, specific gravity and dynamic viscosities and a decrease in penetration value with addition and increase in the waste polymer content from 5 wt.% to 10 wt.%. (Tables 1 and 4). This is related to the increase of asphaltenes content and the decrease of aromatic and resin contents with the addition of waste polymers to the virgin asphalt sample and with increasing the polymer content. Also, data reveal that the saturate and consequently n-paraffin contents are slightly increased with the addition of PP modifier to the virgin asphalt sample, while, they clearly decrease with the addition of PE modifier. This is attributed to the nature and accordingly the chemical molecular composition of the waste polymer used. As a result of asphalt modification, its cohesion and elasticity are both enhanced. At higher service temperatures, the stiffness modulus of the polymer phase is higher than that of matrix. These reinforcing properties of the polymer phase contribute to the increase in viscosity. At low temperatures, the stiffness modulus of the dispersed phase is lowered than that of the matrix, which reduces its brittleness. Consequently, the dispersed polymer phase enhances the engineering proper-

ties of asphalt in terms of viscosity, softening point and toughness [19].

4.1.1.1. Infrared spectroscopy analysis. The FTIR spectrum of the base AC asphalt illustrated that, the strong peaks within 2850–2960 cm⁻¹ regions were typical C–H stretching vibrations in aliphatic chains. The peak at 1603.6 cm⁻¹ was attributed to C=C stretching vibrations in aromatics. The CAH asymmetric deforming in CH₂ and CH₃, and the C–H symmetric deforming in CH₃ vibrations were observed at 1458.2 cm⁻¹ and 1375.2 cm⁻¹ respectively. The peak at 1030 cm⁻¹ was ascribed to S=O stretching vibrations. The small peaks within 740–910 cm⁻¹ regions were typical C–H vibrations of the benzene ring.

Comparing spectrum of asphalt modified with 5% pp with that of the spectrum of the base AC asphalt, there was only a new peak appeared at 966.1 cm⁻¹ which illustrated the bending vibration of C–H in the double bonds –CH=CH–.

5% PE when added to asphalt, the FTIR spectrum Figs. 1c and 2c showed the same characteristic peaks of asphalt spec-

Table 6 Molecular type composition of modified asphalt 60/70 (AC₁).

Molecular type composition	Virgin asphalt AC ₁	Modified asphalt AC ₁ with			
		PP		PE	
		5%	10%	5%	10%
Saturate content, wt.%	10.6	10.61	10.89	5.81	3.96
*n-Paraffin content, wt.%	1.59	2.69	2.99	0.96	0.44
*Iso- & cyclo-paraffin content, wt.%	9.01	7.22	7.9	4.85	3.52
Aromatic content, wt.%	34.58	37.01	31.2	31.92	20.55
Resin content, wt.%	31.7	23.08	23.7	20.67	20.49
Aromatics & resin content, wt.%	66.28	60.09	54.9	52.59	41.04

Table 7 Molecular type composition of modified asphalt 60/70 (AC₂).

Molecular type composition (wt.%)	Virgin asphalt AC ₂	Modified asphalt AC ₂ with			
		PP		PE	
		5%	10%	5%	10%
Saturate content	7.55	7.6	7.72	5.56	3.91
*n-Paraffin content	1.92	3.67	3.78	1.49	1.29
*Iso- & cyclo-paraffin content	5.63	3.93	3.94	4.07	2.62
Aromatic content	44.71	34.21	32.74	26.22	22.89
Resin content	27.63	29.18	25.52	26.72	19.2
Aromatics & resin content	72.34	63.39	58.26	52.94	42.09
Asphaltene content	20.11	29.01	34.02	41.5	54
Asphaltenes and n-paraffin content	22.03	32.68	37.8	42.99	55.29

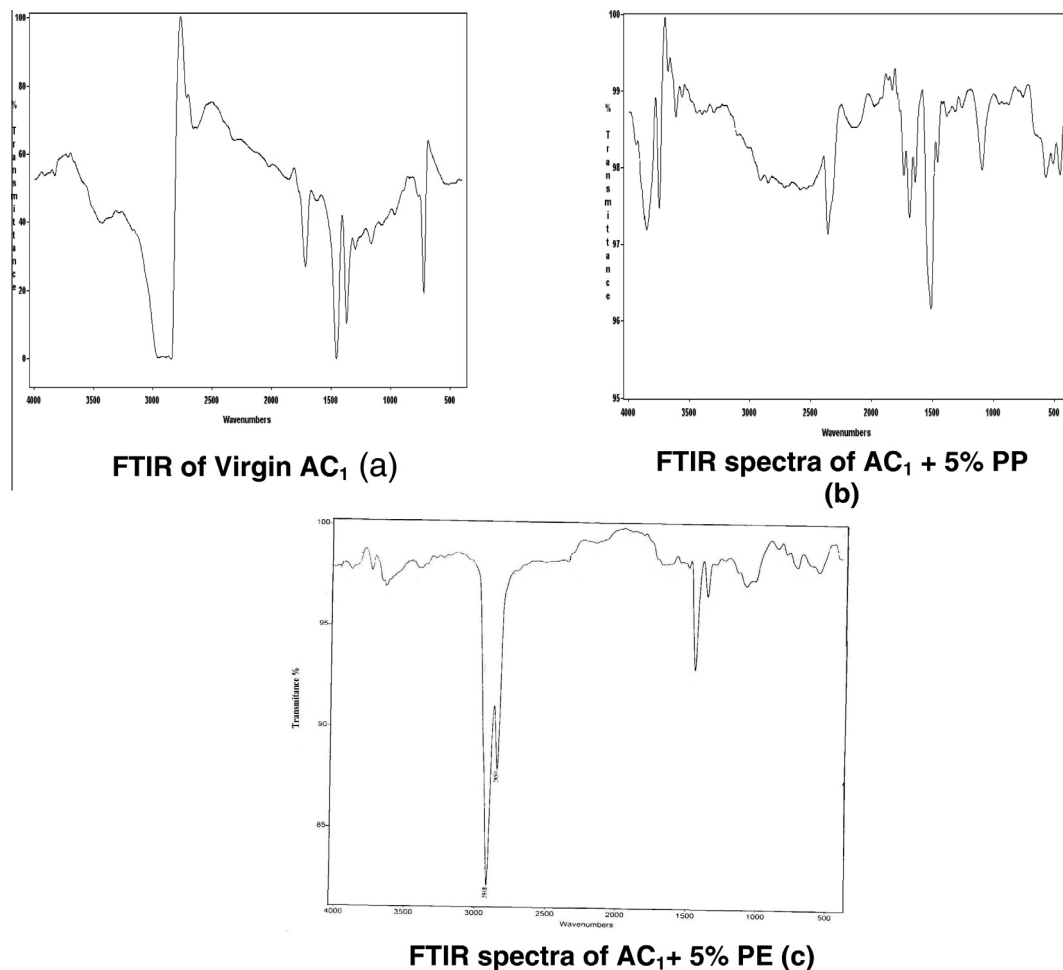


Figure 1 FTIR spectra of AC₁ virgin and AC₁ modified with 5% polymers.

trum except the appearance of C=O group at 1740 cm^{-1} and this was due to addition of polymer which has the ester group.

4.1.1.2. Age hardening. Generally, Hardening of all samples increased with the increase of heating hours. This is due to the evaporation/volatilization of some light chemical constituents of asphalt. Also, metal ions (Nickel and Vanadium) present in asphalt can serve as a catalyst for aging via the propagating hydroperoxide decomposition reaction. The metal ion is reduced and further reaction with some chemical constituents of asphalt takes place forming aldehyde then producing the carboxylic acid groups [18,19].

PMA sample with polyester content 10% was found to be very hard. This may be due to the toughness of PMA sample as a result of the chemical nature of waste polymer.

The age hardening of the virgin and modified samples during bulk storage was evaluated by TFOT. The highest value of mass loss was recorded for virgin asphalt while the lowest for polyester PMA sample. This may be due to the loss of the light fractions under the blending conditions ($163\text{ }^{\circ}\text{C}$) in case of modified samples in the same order depending on the type of polymer.

Rate of aging (hardening) of samples during the bulk storage period decreased with the increase of polymer content. The modification of asphalt reduces the temperature susceptibility

of the virgin asphalt as the P.I values increase. Also, the increase in P.I will increase the resistance of asphalt samples to cracking at low temperature and to permanent deformation (rutting) at high temperature [20].

Waste polypropylene based modified asphalt samples yield lower P.I values than polyester based modified asphalt samples. This may be attributed to the increase of asphaltene content which affects the values of penetration and softening point of each modified sample based on the nature of each additive.

4.1.1.3. TGA analysis. From Figs. 5a and b) it was found that, addition of waste polymers to asphalt (Table 8) produces PMA samples that have lower decomposition percentages comparing to waste polymers themselves. For example, in case of using PE the decomposition percentages decreased from 100% to 85%. This may be attributed to the increase of asphaltene content for PMA as compared to virgin one. The virgin and PMA samples have nearly the same thermal stability. This may be attributed to the nature of each addition as well as to the partial compatibility between virgin asphalt and waste polymers as illustrated in SEM photos (Figs. 2 and 3)

4.1.1.4. SEM of PMAs. In SEM photos of the virgin and polymer modified blends the light phase in the picture represents the swollen polymer and the dark phase is the asphalt. Small

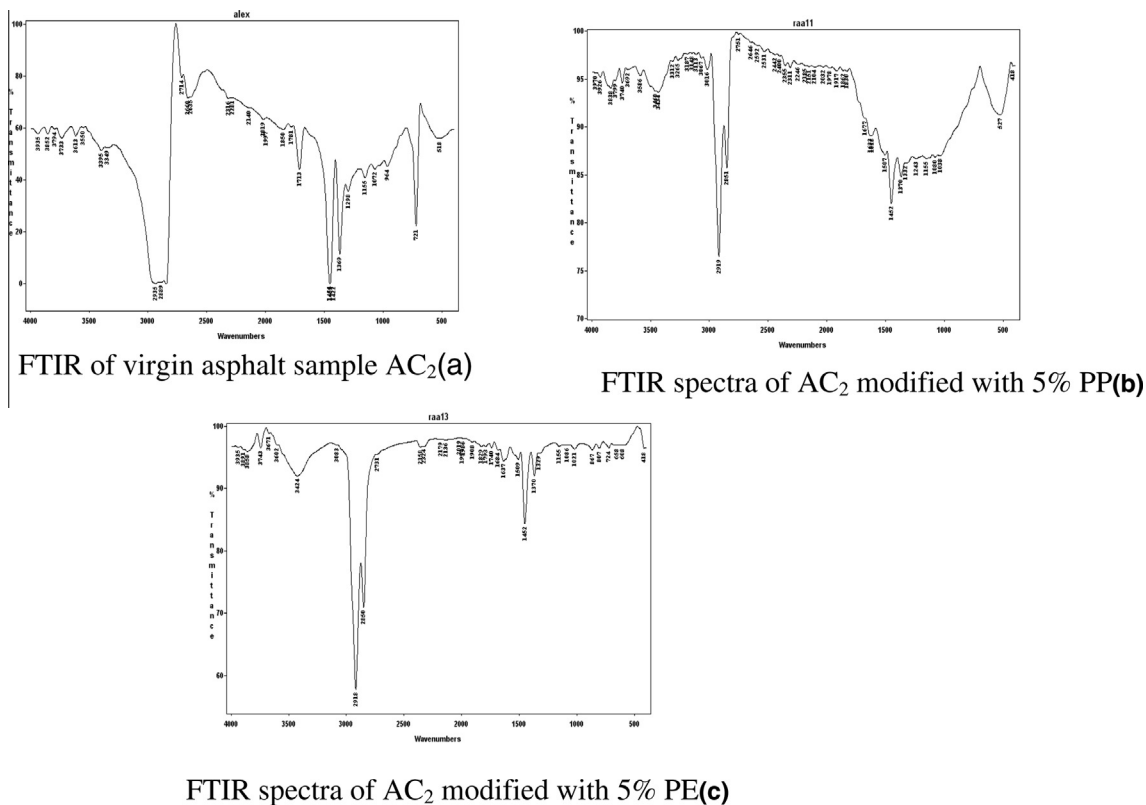


Figure 2 FTIR spectra of AC₂virgin and AC₂ modified with 5% polymers.

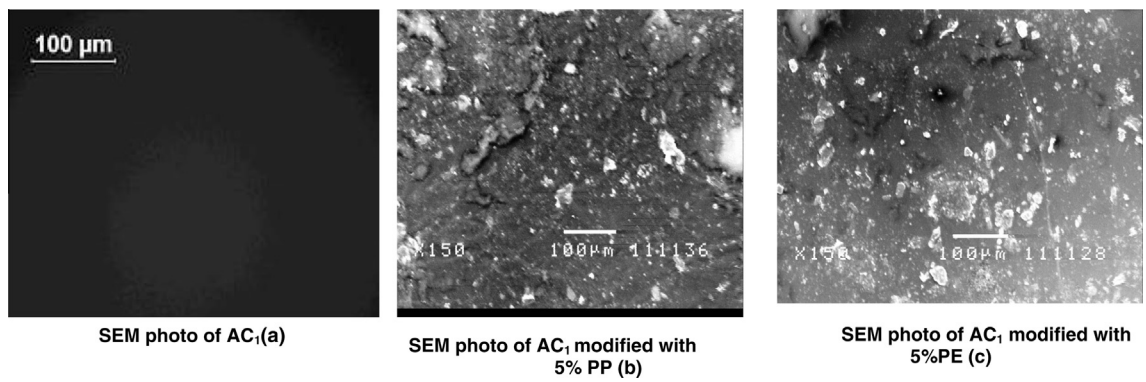


Figure 3 SEM photo of AC₁ virgin and modified with 5% polymers.

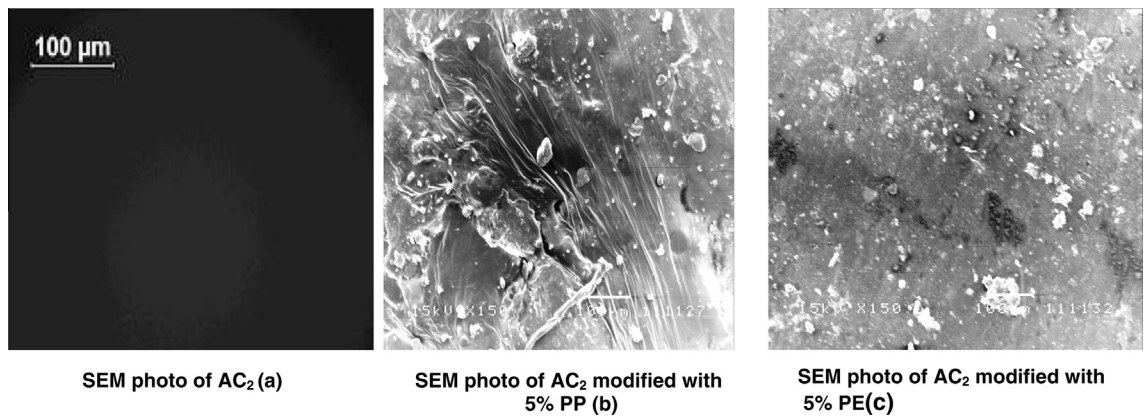


Figure 4 SEM photo of AC₂ virgin and modified with 5% polymers.

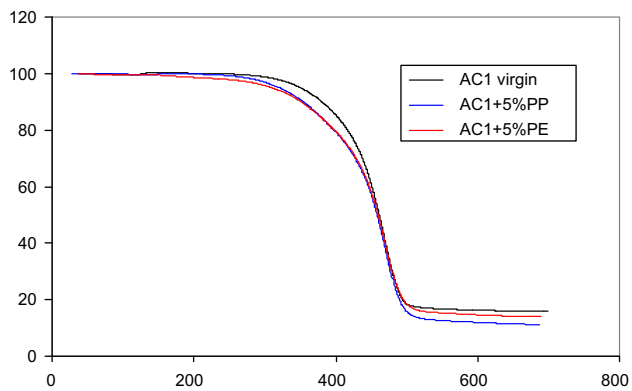


Figure 5a TGA curves of modified asphalt samples (AC₁) containing 5 wt.% polymer modifier.

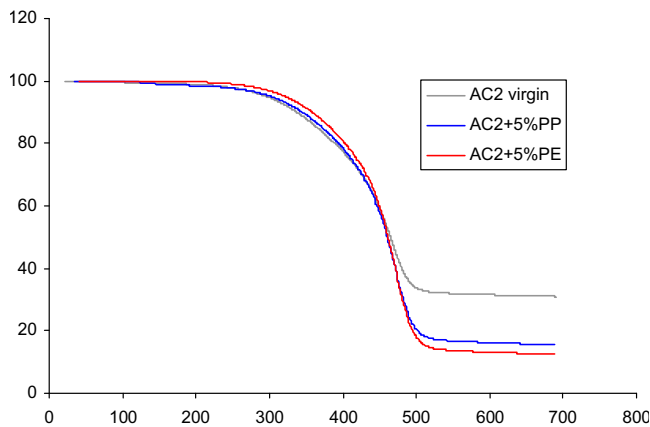


Figure 5b TGA curves of modified asphalt samples (AC₂) containing 5 wt.% polymer modifier.

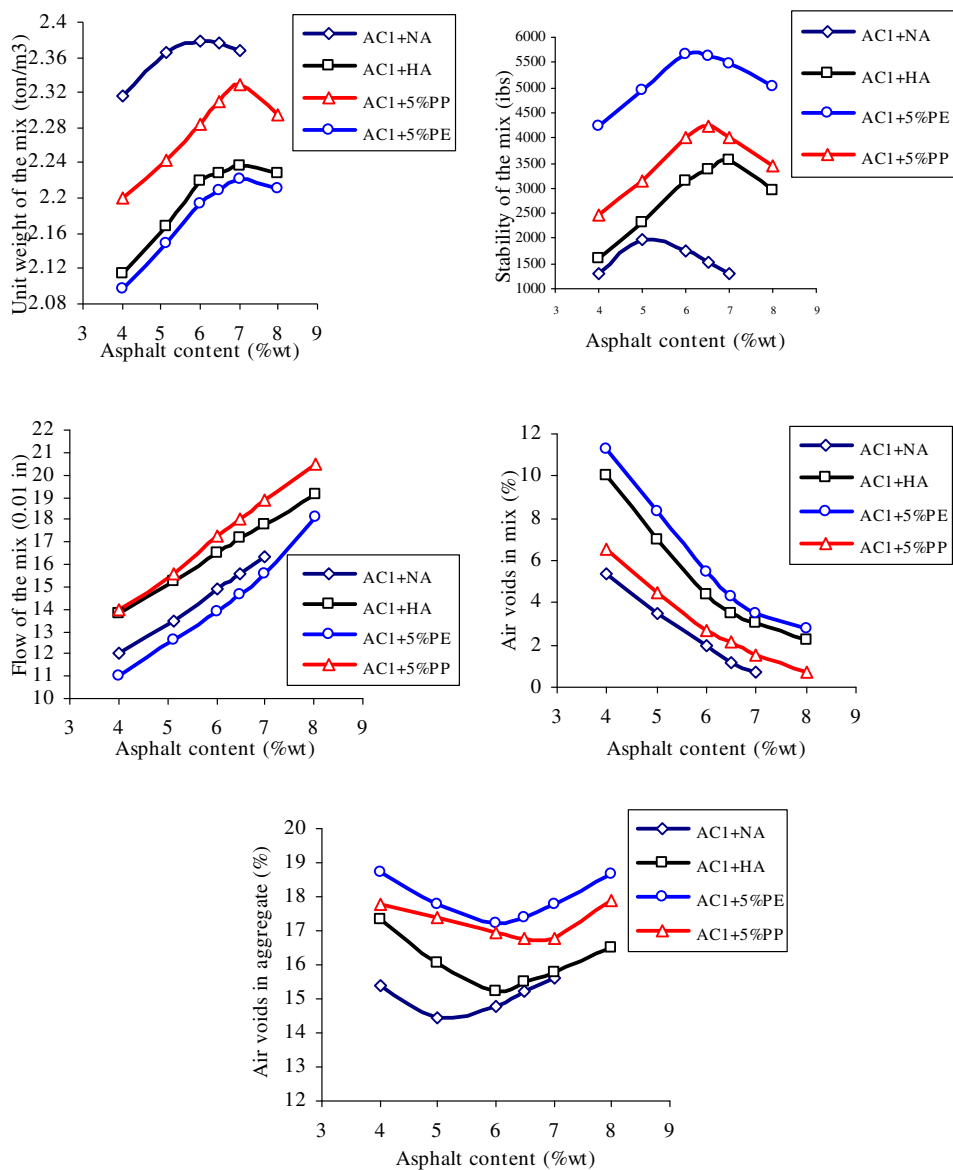


Figure 6a Marshall curves of (AC₁) mixes.

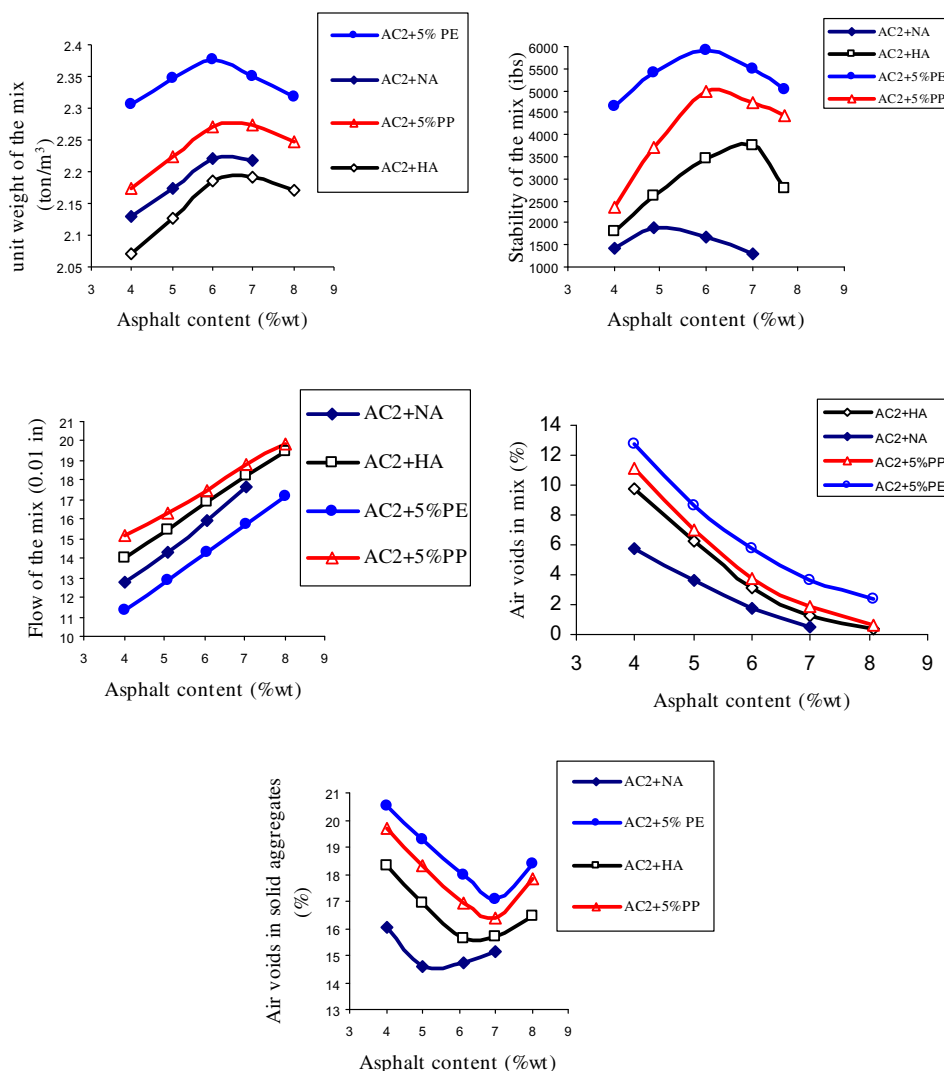


Figure 6b Marshall curves of (AC₂) mixes.

Table 8 Engineering characteristics of aggregate (normal and high absorptive types).

Item	Test						
	Gradation	Bulk specific gravity	Specific gravity (SSD) ^c	Apparent specific gravity	Water absorption (wt.%)	Los Angeles abrasion test (loss wt. %)	Stripping test
Test method	C136 /T27	(C127 /T85) ^d and (C128/T84) ^e				C131/T96	D1664/T182
Aggregate type							
HA ^a	Coarse	2.065	2.267	2.589	9.7	9.7	
	Fine	1.989	2.246	2.581	10.0	10.0	> 95%
NA ^b	Coarse	2.538	2.062	2.713	2.5	2.5	> 95%
	Fine	2.533	2.595	2.701	2.5	2.5	
Standard specification limits	N.S. ^f				< 5 %	< 40%	> 95%

^a N.B: high absorptive aggregate type.

^b Normal aggregate.

^c Saturated surface dry.

^d For coarse aggregate.

^e For fine aggregate.

^f Not specified.

Table 9 Mineral constituents of filler used.

Sample type	Major constituents	Minor constituents	Trace constituents
Limestone	Calcite (CaCO ₃)	Gypsum	Pyrite
Marble	Calcite (CaCO ₃)	Quartz	Pyrite, Kaolinite

Trace: < 5% minor: 5–20% major: > 20%.

N.B: pyrite: iron disulfide (FeS₂).

Gypsum: calcium sulfate dihydrate (CaSO₄·2H₂O).

Quartz: silica (silicon dioxide, SiO₂).

Kaolinite: Al₂Si₂O₅ (OH)₄.

Table 10 Marshall mixes properties of virgin and modified asphalt (AC₁) mixes.

Characteristics	HMA number				Standard limits
	(1a)	(2a)	(3a)	(4a)	
Optimum asphalt content (%)	5.15	6.75	6.25	6.85	ND
Stability of the mix (lbs)	2025	3417	4020	5400	> 1800
Unit weight of the mix (t/m ³)	2.367	2.232	2.224	2.228	
Flow of the mix (0.01 in)	13.9	17	17.6	15	8–18
Air voids in the mix (%)	3.2	3.5	3.1	4	3–5
Air voids in solid Agg. (%)	14.34	15.7	16.8	17.6	> 13.5
Marshall stiffness S/F (lbs/ in)	145.6	193	225.8	360	NS ^a

^a N.B: NS: not standard.

Table 11 Marshall mixes properties of virgin and modified asphalt (AC₂) mixes.

Characteristics	HMA Number				Standard limits
	(1b)	(2b)	(3b)	(4b)	
Optimum asphalt content (%)	5.25	6.43	6.13	6.25	ND
Stability of the mix (lbs)	1890	3300	4800	5560	> 1800
Unit weight of the mix (t/m ³)	2.18	2.222	2.256	2.354	
Flow of the mix (0.01 in)	15.7	17	17.5	14.2	8–18
Air voids in the mix (%)	3.54	3.1	3.8	4.9	3–5
Air voids in solid agg. (%)	14.7	17.2	16.7	17.5	> 13.5
Marshall stiffness S/F(ibs/in)	120.4	191.8	274.3	391.5	NS ^a

^a N.B: NS: not standard.

polymer spheres swollen by asphalt compatible fractions (*e.g.*, aromatic oils) are spread (dispersed phase) homogeneously in a continuous asphalt phase. Polymer particles extensively spread on PMA's surface lead to the decrease in engineering properties such as toughness and tenacity. This may be attributed to differences in molecular weight, polarity and structure of used polymers. A chemical dissimilarity exists between asphalt and polymer. The morphology of PMA samples is the result of the mutual interaction of polymer and asphalt, and, consequently, is influenced by asphalt composition and polymer nature and content. There is a good compatibility between asphalt and waste polymers.

4.2. 2 – Characteristics of asphalt paving mixes prepared

All mixes prepared comply with the standard specification of HMA for surface course in roads having high traffic volume.

Concerning mix 1, it was noticed that for all mixes prepared the increase in asphalt content leads to a higher stability and accordingly higher Marshall stiffness. As the asphalt content increased from 5.15 to 6.89, 6.25 and 6.4 in percentages of 33.7, 21.3 and 24.3 for HMA (2, 3 and 4) respectively the stability in-

creased from 2025 (ibs) to 3417 (ibs) and from 1890 to 3300 (ibs) for AC2. This may be attributed to the increase of asphaltene contents and the use of high absorptive aggregate and marble powder instead of normal type of aggregate and lime stone powder. As illustrated from Table 9, the mineral constituents of marble are calcite, quartz, pyrite and kaolinite which give strength to (Table 10) the filler and accordingly HMA while limestone filler contains weak constituents like gypsum.

A. Effect of using HA aggregate type in mix preparation (HMA (1(a,b)) & (2(a,b))):

- Concerning mixes 1a and 1b a high percent of asphalt content was obtained for HMA (2(a,b)). This may be attributed to using high absorptive aggregate type which increases the quantity of the asphalt absorbed by inter and intra aggregate particles. So, there was an increase in stability, flow and Marshall Stiffness. The increased air voids in mix caused by the increase in viscosity of PMA samples in addition to that of the solid aggregates lead to decreased unit weight.

B. Effect of using modified asphalt in HMA preparation containing HA aggregate (mixes 2(a,b), 3(a,b) and 4(a,b)):

- The use of modified asphalt in mixes preparation lowered the asphalt content as compared to HMA (2(a,b)). This may be attributed to the increase of asphalt viscosity which decrease the quantity absorbed by the aggregate.

HMA (4a, b) was found to have the hardest of modified mixes, as it has the highest stability and air voids in mix and solid aggregate as well as the lowest flow value. This may be attributed to the toughness of waste polyester itself. So, less than 5% of polyester may be recommended for use in surface course.

HMA (3a & b) had the highest value of flow compared to mixes (4a & b). This gave flexibility to the mix which is (Table 11) considered a very important factor for road paving. This may be due to the chemical nature of each modifier.

The Marshall stiffness increased for HMA (2a & b) to HMA (4a & b) in percentages of 13.6%, 29.5% & 93.4%. This may be attributed to the effect of using different types of polymers which affect the Marshall Characteristics of HMA prepared.

5. Conclusion

This research aimed to prepare and use special types of HMA consisting of unordinary materials with the final objective of decreasing the cost of paving and maintenance, keeping the premium aggregate for the longest period of time, and decreasing the land space needed for land filling of undegradable pollutants. To achieve this aim, 5–15% of each of waste polypropylene and polyester were used in asphalt modifying. High absorptive aggregate and marble fillers were used in mixes preparation instead of ordering materials (normal absorptive aggregate and limestone filler). The obtained results showed that:

All the types of waste polymers and solid materials used in the study are suitable in road paving.

The mixes comply with the standards and have reduced temperature susceptibility.

The best modifier was polypropylene waste.

Polyester waste was found to be very tough. The mix can be used as base course or other purpose.

6. Recommendation

High absorptive aggregate and waste polymer must play a very important role in road paving to decrease the cost of construction and maintenance.

The best modifier of asphalt must contain high percentages of iso and cyclo paraffins and lower percentage of asphaltenes similar to asphalt composition itself.

The waste polymer from other industries can be used in future work.

References

- [1] R. Traxler, *Asphalt: Its Composition, Properties and Uses*, Reinhold Publishing Corporation, New York, 1961.
- [2] P. Partal, F. Martínez-Boza, B. Conde, C. Gallegos, *Fuel* 78 (1999) 1–10.
- [3] P. Redelius, *Fuel* 79 (2000) 27–35.
- [4] L. Palade, P. Attané, S. Camaro, *Rheol. Acta* 39 (2000) 180–190.
- [5] D. Lesueur, J. Gerard, P. Claudy, J. Létoffé, J. Planche, D. Martin, *J. Rheol.* 40 (1996) 813–836.
- [6] M. Martín-Alfonso, P. Partal, F. Navarro, M. García-Morales, C. Gallegos, *Eur. Polym. J.* (2008) 1451–1461.
- [7] B. Seyyed, R. Yahya, A. Ali, K. Ali, *Iran. Polym. J.* 19 (3) (2010) 197–205.
- [8] W. Shaopeng, Y. Qunshan, L. Ning, *Constr. Build. Mater.* 22 (10) (2008) 2111–2115.
- [9] S. Abtahi, M. Sheikhzadeh, S. Hejazi, *Constr. Build. Mater.* 24 (6) (2010) 871–877.
- [10] G. Martínez-Barrera, E. Viguera-Santiago, S. Hernández-Lopez, C. Menchac-Campos, W. Brostow, *Polym. Eng. Sci.* 45 (2005) 1426.
- [11] O. Gencel, W. Brostow, C. Ozel, M. Filiz, *Mater. Sci. Medzg.* 16 (2010) 249.
- [12] G. Martínez-Barrera, E. Viguera-Santiago, S. Hernández-Lopez, C. Menchac-Campos, W. Brostow, *J. Mater. Res.* 21 (2006) 484.
- [13] S. Tapkın, *Build. Environ.* 43 (6) (2008) 1065–1071.
- [14] J. Yu, P. Cong, S. Wu, *Constr. Build. Mater.* 23 (6) (2009) 2277–2282.
- [15] B. Mair, F. Rossini, in: *Symposium on Composition of Petroleum Oils Determination and Evaluation*, ASTM, 1985, p. 9, STP224.
- [16] L.R. Snyder, in: E. Heftmann (Ed.), *Chromatography*, Van Nostrand Reinhold Company, New York, 1975.
- [17] H. Wielend, D. Richter, *Justus Liebig's Ann. Chem.* 486 (1931) 226–242.
- [18] Shaker M., *Evaluation and improvement of local asphalt*, Ph.D thesis, Faculty of engineering, Cairo University, 1993.
- [19] Daranga C., *Characterization of aged polymer modified asphalt cements for recycling purposes.*, Ph.D, Tunisiens State University, 2005.
- [20] U. Isacsson, X. Lu, *J. Test. Eval.* 25 (4) (1997) 383–390.