Optimum Use of Plastic Waste to Enhance the Marshall Properties and Moisture Resistance of Hot Mix Asphalt

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Abstract: **The vast quantities of plastic waste resulting from the different types and sizes of bottles which are used to contain all types of liquid products such as (Mineral Water, Oils, and detergents ….etc) in municipal solid waste is increasing in the last years due to increase in population, development activities and changes in life style. Thus disposal of plastic waste is a menace and becomes a serious problem globally due to their non-biodegradability and unaesthetic view. This paper focused on Marshall test and index of retained strength to determine the properties of plastic waste particles such as (size, thickness, and percent of content) which provide the ultimate performance of hot mix asphalt. For this purpose plastic wastes were added by six different sizes of particles (passing sieve 3/4" (19.0 mm) to retaining on sieve No.50 (0.3 mm)), four thicknesses (0.2, 0.5, 0.8 and 1.0) mm, and five content percentages (5, 10, 15, 20 and 25) % by weight of total aggregate. On the basis of experimental results, it was concluded that adding plastic waste with fine particles size ,thin thickness and at 15% by weight of total aggregate resulted in improving the Marshall stability and resistance to water damage, as well as they can contribute to relieve some of the environmental problems caused by classical plastic waste disposal means.**

***Keywords*:** **Hot Mix Asphalt, Marshall Properties, Moisture Resistance, Plastic Waste, Bitumen, Asphalt Cement, Index of Retained Strength (I.R.S.), Marshall Stability.**

I. INTRODUCTION

In recent decades, the results of the increasing amounts of plastic waste derived from the bottles form a major part of the world's solid waste management problem. Several attempts were made on the use of plastic wastes in asphaltic cement mix to provide safely solutions to dispose of this waste through the use as an additive or as a partial substitution for the materials used in conventional asphalt concrete mixes. [1]

Amit Gawande, G. S. Zamre, V. C. Renge, G. R. Bharsakale and Saurabh Tayde (2012) used modified bitumen with the addition of processed plastic waste of about (5-10% by weight of bitumen) helps in substantially improving the Marshall stability, strength, fatigue life and other desirable properties of bituminous concrete mix.[2]

V. S. Punith and A. Veeraraghavan (2010) Studies reported in the used of re-cycled plastic, in the manufacture of hot asphalt mixture indicated to reduced permanent deformation in the form of rutting and reduced low – temperature cracking of the pavement surfacing. The field tests withstood the stress and proved that plastic wastes used after proper processing as an additive would enhance the life of the roads and also solve environmental problems. [3]

Shiva Prasad K, Manjunath K. R, K. V R Prasad (2012) studied the effect of adding plastic waste bottles on the bituminous concrete mix performance .Also the effect of soaking conditions of the mix was investigated using two grades bitumen 60/70 and 80/100 with six different contents of plastic (2 to 12)%. The results referred to increase in stability up to 15% and 10% after adding plastic waste to the mix in 60/70 and 80/100 grade bitumen respectively and soaked specimens showed a decreasing stability value. [4]

H. M. Rasel, M. N. Rahman and T. U. Ahmed (2011) investigated the properties of bitumen grade 80/100 mixed with PVC (2.5% to 20 % by weight of bitumen) at optimum bitumen content and to check the design criteria of bituminous mixes using this bitumen-PVC binder. The results indicated the PVC scrap can be utilized to modify the bitumen to obtain high strength mixes and to get better adhesion properties of bitumen. [5]

Prasad. B, Varun. K, Ashok. A, Ganesh. R (2013) Evaluated the performance of recycled bitumen before and after the addition of plastic waste, for this purpose they added (1% - 9%) plastic waste by the weight of the recycled bitumen and the obtained mix showed better binding property, stability, density and more resistant to water. [6]

Abdul Razzakh Abdul Jaleel Al-Essa, Mohammed Ali Mutar ,and Ammar Ali Hussein (2010) used four contents of crumb rubber, plastic waste, polyvinyl alcohol, and resol (2.5, 5.5, 8.0, 10.5)% by weight of aggregate and three contents of crumb rubber, plastic waste, polyvinyl alcohol, and resol are used as additives to asphalt cement representing about 1.3% from the percentage of asphalt cement. It was found that the addition of crumb rubber, plastic waste, polyvinyl alcohol, and resol increased the Marshall stability retained strength, and air voids. [7]

Sabina, Tabrez A Khan, Sangita, D K Sharma and B M Sharma (2009) described the comparative performance of conventional bituminous concrete mixes with bituminous concrete mixes containing plastic/polymer (8% and 15% by weight of bitumen),they concluded that Marshall stability of modified mixes was respectively (1.21 and 1.18) times higher than conventional mixes. [8]

Adnan Qadir, and Mansoor Imam (2008) have used the plastic waste bags (1.2-3mm particle size) in the surface and base mix design up to (2.5% by weight) in bituminous mix to improve desired mechanical characteristics of a particular road mix. By the use of substitution, results have shown improved Marshall stability and flow. [9]

Rahman, Md. Nobinur, and et al. (2013) used the PVC and waste polyethylene as the sort of polymer to investigate the potential prospects to enhance asphalt mixture properties and to check the design criteria of asphalt mixture using these two modifier at optimum binder content. It was concluded that the asphalt mixtures with waste polyethylene modifier up to 10% and waste PVC modifier up to 7.5% can be used for flexible pavement construction in a warmer region from the standpoint of stability, stiffness and voids characteristics. [10]

Hassani A, Ganjidoust H, Maghanaki AA (2007) used five different percentages of waste plastics (poly-ethylene terephthalate) which was in the form of granules of about 3 mm diameter which would replace (by volume) a portion of the mineral coarse aggregates of an equal size (2.36-4.75 mm). The results showed that the aggregate replacement of 20% by volume with (poly-ethylene terephthalate) granules would result in a reduction of 2.8% in bulk compacted mix density and the value of flow in the plastiphalt mix was lower than that of the control samples. [11]

S.E. Zoorob and L. B. Suparma (2000) studied the dense bituminous macadam with recycled plastics, mainly low density polyethylene replacing 30% of (2.36-5) mm aggregates, the recycled plastics composed predominantly of polypropylene and low density polyethylene can be incorporated into conventional asphalted road surfacing mixtures. It has reported use of recycled plastics composed predominantly of polypropylene and low density polyethylene in plain bituminous concrete mixtures increase durability and improved fatigue life, reduced the mix density and showed increase in Marshall stability; the indirect tensile strength (ITS) was also improved in the 'Plastiphalt' mixtures. [12]

II. MATERIAL CHARACTERIZATION

The materials used in this study are locally available and currently used in road construction in northern Iraq.

A. Aggregates

The coarse and fine aggregate used in this investigation was brought from Freba hot mix plant, and these were originally brought from Darbande Zeoi quarry near Sulaimanyah city in Iraq and crushed at the asphalt plant by mechanical crusher. has been selected as basic gradation, as shown in Table (I). The mid limit of the (19mm) maximum size dense gradation

TABLE (I): SELECTED COMBINED GRADATION OF AGGREGATE AND FILLER (%PASSING BY WEIGHT)

Sieve Size	Specification Range	Selected Gradation
3/4"	100	100
1/2"	75-95	85
3/8"	65-88	75
No.4	50-75	60
No.8	32-55	45
No.16	24-42	30
No.50	10-25	15
No.200	6-12	10

B. Asphalt Cement

One type of asphalt cement is used in this work. It is from Baiji refinery with a grade (40 –50) penetration. The physical properties of asphalt cement are presented in Table (II).

TABLE (II): PHYSICAL PROPERTIES OF ASPHALT CEMENT

Properties	Unit	ASTM	Value
Penetration at(25ºC, 100g,5 s)	0.1 mm	D5	46
Specific gravity at 25ºC	----	D70	1.03
Absolute viscosity at 60ºC	poise	D2171	2950
Kinematic viscosity at 135ºC	Cst	D2170	360
Softening point (Ring and Ball)	ºC	D36	54
Ductility (25ºC, 5 cm/min)	cm	D113	121
Flash point	ºC	D92	270
Fire point	ºC	D92	285

C. Filler

The filler used was Portland cement which was brought from Al-Mas cement factory. Its physical properties are presented in Table (III).

TABLE (III): PHYSICAL PROPERTIES OF PORTLAND CEMENT FILLER

Properties	Unit	Value
Specific Gravity	----	3.151
Unit Weight	gm/cm^3	1.165
Passing Sieve No. 200	%	99

D. Plastic Waste

The plastic waste used in this study was derived from the different types and sizes of bottles which are used to contain all types of liquid products such as (mineral water, cooking oil, detergents, milk, water jugs…...etc).

III. PREPARATION OF MIXTURE

The aggregate was first dried to constant weight at 110ºC, separated into desired sizes and recombined with mineral filler in order to meet the required gradation for each specimen. The aggregates are then heated to 155ºC before mixing with asphalt cement. The asphalt cement is heated to the temperature, which produces a kinematic viscosity of (170±

20) centistokes (up to 163ºC as an upper limit).Then, the asphalt cement is weighted to the desired amount (4.5% by the total weight) and added to the heated aggregate then a specific amount of plastic waste was added during mixing until all particles are coated with asphalt.

IV. Asphalt Concrete Tests

The following test methods are used in this work to evaluate the performance of asphalt concrete mixture.

A. Resistance to Plastic Flow (Marshall Method)

The method covers the measurement of the resistance to plastic flow of cylindrical specimens of bituminous paving mixture loaded on the lateral surface by means of the Marshall apparatus according to (ASTM D1559).The prepared mixture is placed in preheated mold (4in) (101.6mm) in diameter by (3in) (76.2mm) in height, and compacted with 50 blows/end with a hammer of 10 lb. (4.536 kg) sliding weight, and a free fall of (18 in) (457.2 mm) on the top and bottom of each specimen. The specimens are then left to cool in room temperature for 24 hours. Marshall stability and flow tests are performed on each specimen according to the method described by ASTM D-1559.The cylindrical specimen is placed in water bath at 60 °C for 30 to 40 minutes, and then compressed on the lateral surface at constant rate of 2 in (50.8 mm/min) until the maximum load resistance and corresponding flow value are recorded. Three specimens for each combination are prepared and the average results are reported. The bulk specific gravity is determined for each specimen in accordance with ASTM D-2726.

B. Index of Retained Strength Test

This method covers the measurement of loss of cohesion resulting from the action of water on compacted specimens prepared in accordance with ASTM D-1074. A set of six specimens is prepared for each mix combination with optimum asphalt content.The tested specimens 4in (101.6 mm) in diameter, and 4 in (101.6 mm) in height are prepared by compressing the mixture under an initial load of 150 psi (1 Mpa) to set against the side of the mold, then a molding load of 3000 psi (20 Mpa) is applied for 2 min. Three specimens are tested for compressive strength at a uniform rate of 0.2 in/min (5.08 mm/min) after storing in air bath at 25 °C for about 4 hours. The other three specimens are placed in a water bath for 24 hours at 60 °C, then transferred to a water bath and maintained at 25 °C for 2 hours, before testing for compressive strength. The index of retained strength is calculated as follows:

$$\text{Index of Retained Strength (\%)} = \frac{S_2}{S_1} \times 100 \quad \text{.........} \quad (1)$$

Where:

S1 = Compressive strength of dry specimens.
S2 = Compressive strength of immersed specimen.

V. Testing Program

To achieve the objectives of this study; one type of bitumen grade (40-50) was blended with aggregate, filler, and plastic waste. The effects of the following parameters of plastic waste have been considered in this study:-

1) Size: by adding (10% by weight of total aggregate) with a specific size of plastic waste in the mixture, where six different sizes of particles (passing sieve 3/4", 1/2", 3/8 ", No.4, No.8, and No.16) were used.
2) Thickness: by adding (10% by weight of total aggregate) with a specific thickness of plastic waste in the mixture, where four different thicknesses of plastic waste (0.2, 0.5, 0.8, 1.0) mm were used.
3) Percent of content: adding five different percentages (5, 10, 15, 20, 25) % of a certain size of plastic waste by weight of total aggregate. See Fig.1

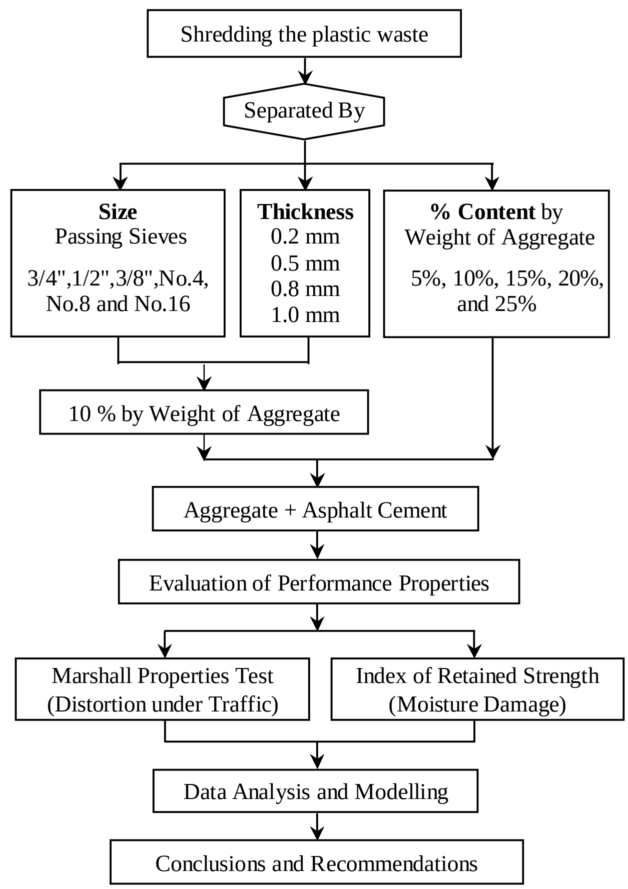

Fig.1 Shows the flow chart of the study

VI. Results and Discussions

A. Optimum Asphalt Content

Marshal molds were prepared for different percentages of asphalt cement grade (40 – 50) by varying the asphalt cement percentage from (3.5% - 5.5%) mixed with aggregate, and

Portland cement filler. Marshall stability test was conducted and the properties of asphalt mixtures such as flow value, bulk density, percentage air voids, voids filled with Asphalt (VFA) and voids filled with mineral aggregates (VMA) were determined. The results showed that optimum asphalt content equal to (4.5%) by using the limitations of above properties.

B. Effect of Plastic Waste Particles Size

To investigate the effect of plastic waste particles size on the performance of asphalt mixture, six different sizes of plastic waste particles were used passing sieve (3/4", 1/2", 3/8", No.4, No.8, and No.16) and were added by (10% by weight of total aggregate) with a specific size, mixed with the optimum asphalt content (4.5%) to prepare each specimen.

1) Resistance to Plastic Flow

The results of Marshal test are shown in Table (IV) and represented in Fig. (2 to 5). They indicate that the Marshall stability, and bulk density increase when the plastic waste particles are finer sizes, whereas the flow and air voids decrease.

TABLE (IV): EFFECT OF PLASTIC WASTE PARTICLES SIZES ON MARSHALL TEST PROPERTIES

Plastic Waste Particles Size		Marshall Test Results			
Passing Sieve	(mm)	Stability (KN)	Flow (mm)	Bulk Density (gm/cm^3)	Air Voids (%)
3/4"	19.0	7.15	4.35	2.057	6.25
1/2"	12.5	7.92	4.50	2.168	6.10
3/8"	9.5	8.37	4.22	2.164	5.54
No.4	4.75	8.83	3.81	2.21	4.52
No.8	2.36	9.65	3.52	2.212	4.30
No.16	1.18	9.72	3.45	2.285	3.92

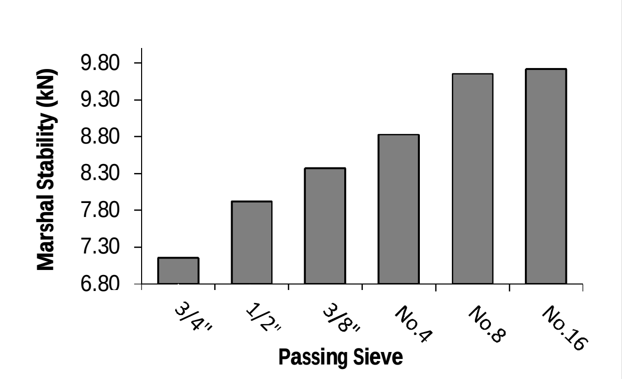

Fig.2 Effect of plastic waste particles size on Marshall stability

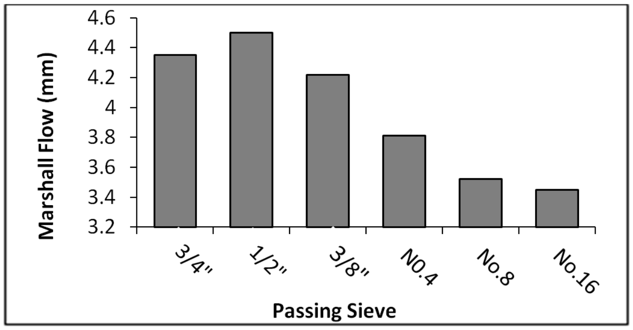

Fig.3 Effect of plastic waste particles size on Marshall flow

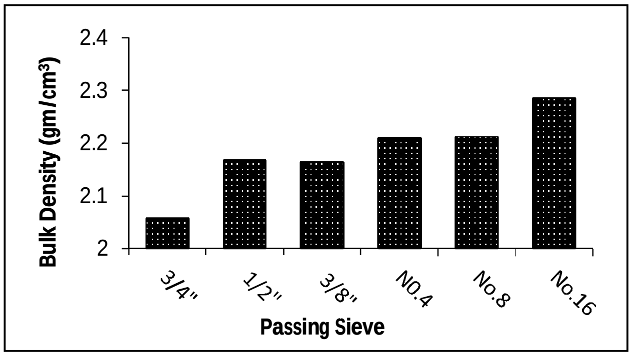

Fig.4 Effect of plastic waste particles size on bulk density

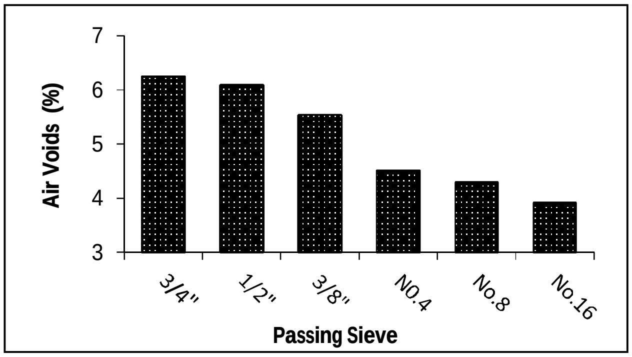

Fig.5 Effect of plastic waste particles size on air voids

2) Moisture Damage

The results of index of retained strength (I.R.S) are shown in Table (V) and represented in Fig. (6) .They indicate that the moisture resistance improved when the finer size of the plastic waste particles were added.

TABLE (V): EFFECT OF PLASTIC WASTE PARTICLES SIZES ON INDEX OF RETAINED STRENGTH

Plastic Waste Size		Compressive Strength (Mpa)		I.R.S
Passing Sieve	mm	Dry	Wet	(%)
3/4"	19.0	2745	1836	66.89
1/2"	12.5	3028	2100	69.35
3/8"	9.5	3310	2405	72.66
No.4	4.75	3394	2650	78.08
No.8	2.36	3565	2945	82.61
No.16	1.18	3604	3045	84.49

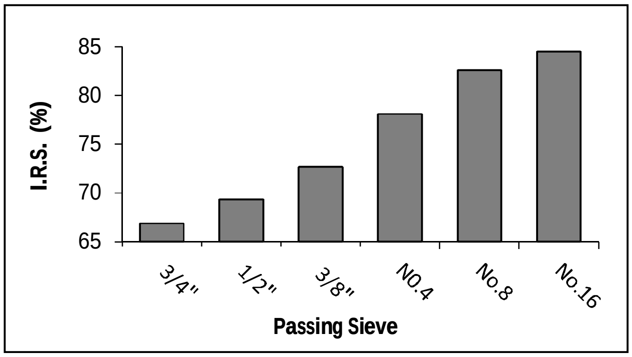

Fig.6 Effect of plastic waste particles size on index of retained strength

C. *Effect of Plastic Waste Thickness*

In order to evaluate the effect of plastic waste thickness on the performance of asphalt mixture, four different thicknesses of plastic waste were used in this study (0.2, 0.5, 0.8, 1.0) mm passing sieve No.16 and retained on sieve No.50 and added by (10% by weight of total aggregate), mixed with the optimum asphalt content (4.5%) to prepare the specimens.

1) *Resistance to Plastic Flow*

The influence of plastic waste thickness on Marshal test properties are represented in Fig. (7 to 10) and shown in Table (VI). As the plastic waste thickness increase, the Marshall stability and bulk density decrease, while the air voids and flow increase.

TABLE (VI): EFFECT OF PLASTIC WASTE PARTICLES THICKNESS ON MARSHALL TEST PROPERTIES

Plastic Waste thickness (mm)	Marshall Test Results			
	Stability (KN)	Flow (mm)	Bulk Density (gm/cm^3)	Air Voids (%)
0.2	9.72	3.45	2.285	3.92
0.5	9.81	3.62	2.292	4.08
0.8	9.32	3.67	2.20	4.11
1.0	8.90	4.02	2.193	4.28

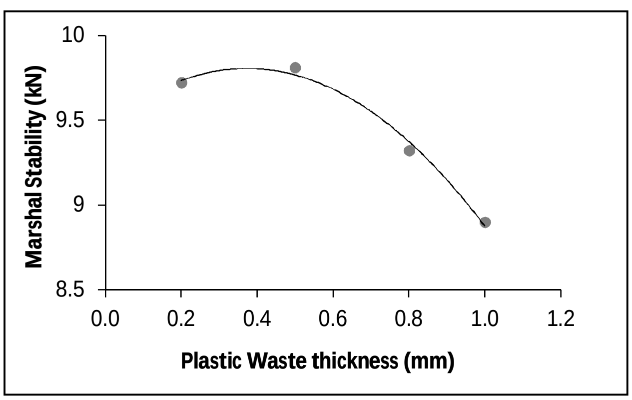

Fig.7 Effect of plastic waste thickness on Marshall stability

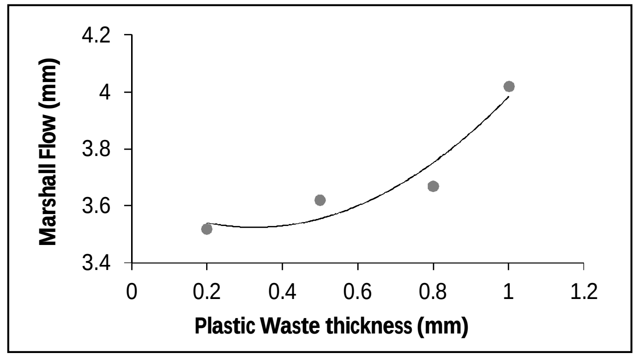

Fig.8 Effect of plastic waste thickness on Marshall flow

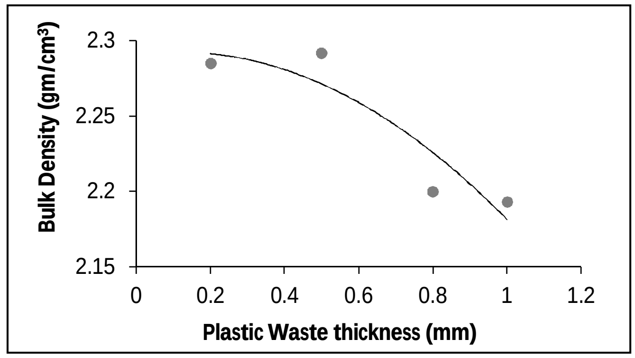

Fig.9 Effect of plastic waste thickness on bulk density

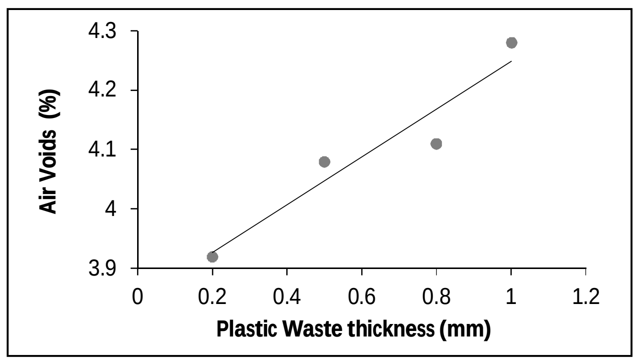

Fig.10 Effect of plastic waste thickness on air voids

2) *Moisture Damage*

The relation between the moisture damage indicated by the index of retained strength (I.R.S) and plastic waste thickness are shown in Fig. (11) and the results in Table (VII). The figure indicates the decrease in the resistance to moisture damage with increase the plastic waste thickness.

TABLE (VII): EFFECT OF PLASTIC WASTE THICKNESS ON INDEX OF RETAINED STRENGTH

Plastic Waste thickness (mm)	Compressive Strength (Mpa)		I.R.S (%)
	Dry	Wet	
0.2	3604	3045	84.49
0.5	3610	3036	84.10
0.8	3502	2710	77.38
1.0	3534	2703	76.49

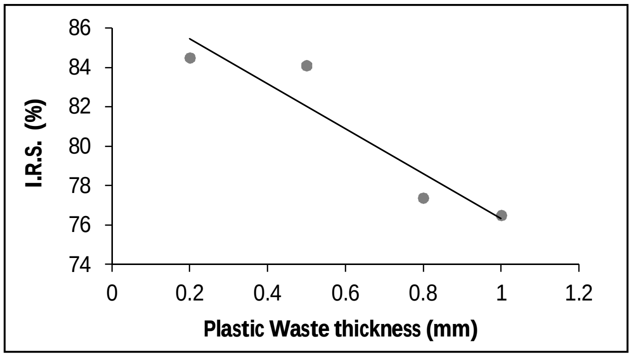

Fig.11 Effect of plastic waste thickness on index of retained strength

D. *Effect of Plastic Content*

To evaluate the effect of plastic waste content on the performance of asphalt mixture, five different percentages of plastic waste which are passing sieve No.16 and retained on sieve No.50 and particles thickness (0.2 mm) were used in this study (5, 10, 15, 20, and 25) % by weight of total aggregate, mixed with optimum asphalt content (4.5) % to prepare the specimens.

1) *Resistance to Plastic Flow*

The influence of plastic waste content on Marshal test properties was shown in Table (VIII) and represented in Fig. (12 to 15). As the percentage of plastic waste content increases, the Marshall stability and bulk density increase to a maximum value then tend to decrease, while the air voids decrease and flow increases.

TABLE (VIII): EFFECT OF PLASTIC WASTE PARTICLES PERCENTAGES ON MARSHALL TEST PROPERTIES

Plastic Waste Content		Marshall Test Results			
		Stability (KN)	Flow (mm)	Bulk Density (gm/cm^3)	Air Voids (%)
% by weight of aggregate	0	8.19	2.92	2.21	4.20
	5	8.77	3.21	2.233	4.15
	10	9.72	3.45	2.285	3.92
	15	9.84	3.57	2.329	3.87
	20	9.55	3.84	2.324	3.93
	25	8.90	4.32	2.282	4.12

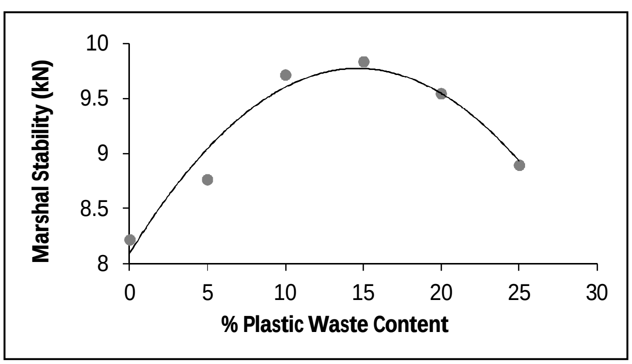

Fig.12 Effect of plastic waste content on Marshall stability

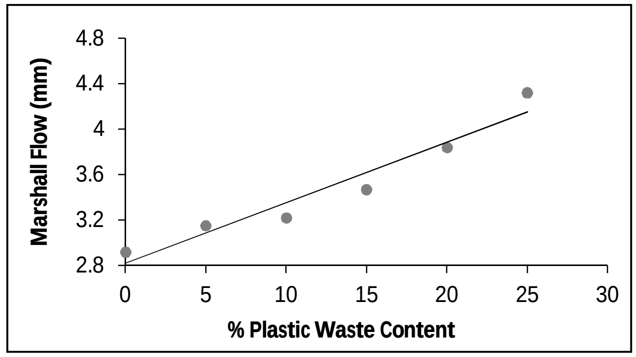

Fig.13 Effect of plastic waste content on Marshall flow

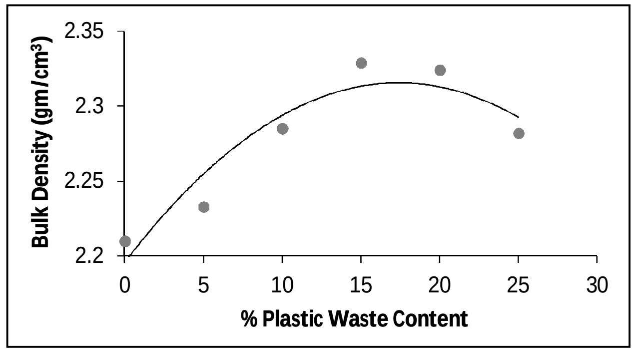

Fig.14 Effect of plastic waste content on bulk density

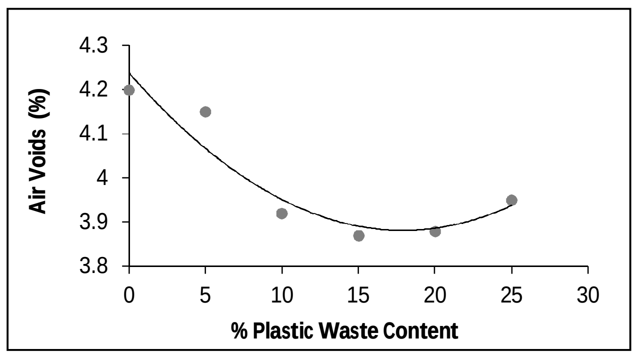

Fig.15 Effect of plastic waste content on air voids

2) *Moisture Damage*

The relation between index of retained strength (I.R.S) and plastic waste content are shown in Fig. (16) and the results in Table (IX). The figure indicates the increase in the resistance to moisture damage with the increase in the plastic waste content to a maximum value then tends to decrease.

TABLE (IX): EFFECT OF PLASTIC WASTE PARTICLES PERCENTAGES ON INDEX OF RETAINED STRENGTH

Plastic Waste Content		Compressive Strength (Mpa)		I.R.S
		Dry	Wet	(%)
% by weight of aggregate	0	3560	2674	75.11
	5	3504	2790	79.62
	10	3604	3045	84.49
	15	3580	3108	86.82
	20	3516	2975	84.61
	25	3450	2880	83.48

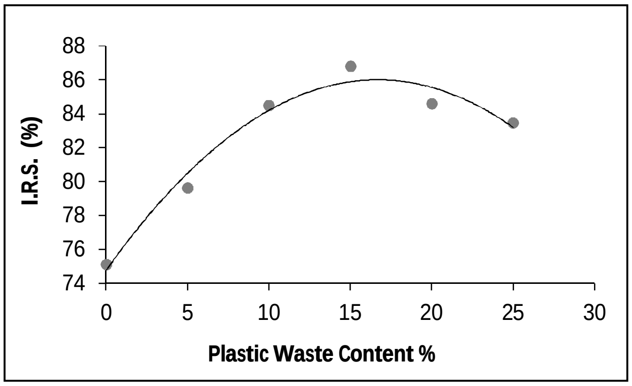

Fig.16 Effect of plastic waste content on index of retained strength

VII. Model Development

The main step in the development of the statistical models was the selection of the form of the relation between the dependent and the independent variables.

Examination of the figures shown in this study, suggests that the linear models may be used as an initial step. This relation was examined using the SPSS statistical package. The package was used to perform the required regression analysis. The performance related properties include:

1) Marshall Stability (MS).
2) Index of Retained Strength (IRS).

The range values of the predictor variables are shown in Table (X) and the results of the statistical analysis are shown in Table (XI). The obtained (R) values are substantially high; this would suggest that the predicted and observed values will approximately be matching if the selected plastic waste parameters values fall within the examined range of data. The comparison of predicted and observed values of Marshall stability and Index of Retained Strength shown in Fig. (17) and (18) respectively.

TABLE (X): THE RANGE VALUES OF THE PREDICTOR VARIABLES

Plastic Waste Particles Properties	Symbol	Unit	Range
Maximum Size	MXS	Sieve mm	(3/4"-No.16) (19.0 - 1.18)
Minimum Size	MNS	Sieve mm	(1/2"-No.50) (12.5 - 0.3)
Thickness	TH	mm	(0.2 – 1.0)
Content	C	%	(5 – 25)

TABLE (XI): THE DEVELOPMENT STATISTICAL MODELS

Model	R
MS = – 0.136 (MXS) + 0.003 (MNS) – 0.428 (TH) – 0.007(C) + 9.801	0.903
I.R.S = – 1.009 (MXS) – 0.037 (MNS) – 7.640 (TH) + 0.157(C) + 84.138	0.947

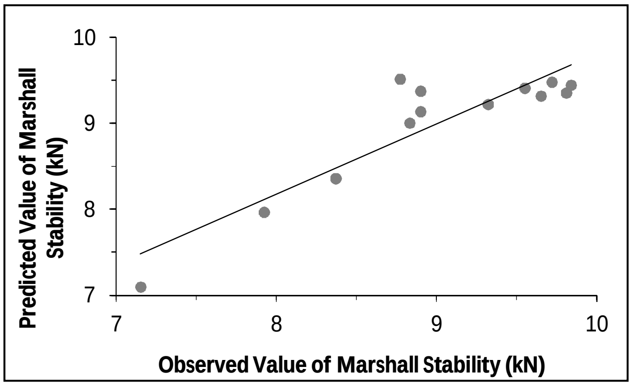

Fig.17 Comparison between the observed and predicted Marshall stability resulted from different parameters of plastic waste particles.

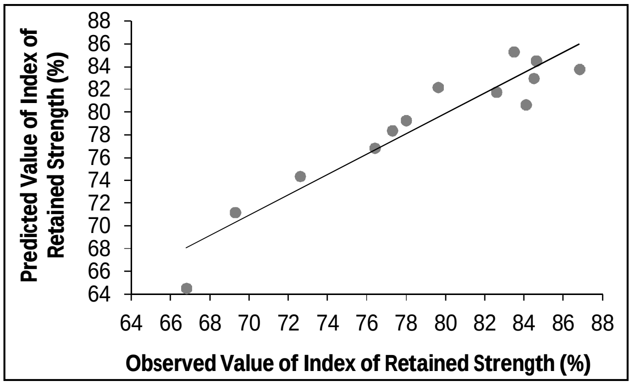

Fig.18 Comparison between the observed and predicted index of retained strength resulted from different parameters of plastic waste particles.

VIII. Conclusions

On the basis of the materials used and laboratory tests performed in this study, the following conclusions can be stated:

1) The plastic waste derived from the different types and sizes of bottles can be utilized to modify the asphalt mixture performance if added to aggregate with a specific (size, thickness and content)
2) Adding fine size of shredded plastic waste particles (passing sieve No.16 (1.18 mm)) to the asphalt mixture, increases Marshall stability and index of retained strength by (18% and 12%) respectively as compared with the conventional mix.
3) The use of plastic waste particles size retained on sieve (3/8" (9.5 mm) and the upper sieves) decrease the Marshall stability and moisture resistance. This can be attributed to poor adhesion between the mixture components due to the presence of coarse plastic particles.
4) Using thick particles of plastic waste in asphalt mixture, decrease the Marshall stability and increase moisture susceptibility as compared with using the thin particles
5) The recommended proportion of the added plastic waste is up to (15% by weight of aggregate) that can be used for construction of road pavement to improve the Marshal stability and moisture resistance

6) The developed numerical models can be used as a guide to predict the effect of the plastic waste parameters on the performance of hot mix asphalt.

Finally, the conclusion of this study, that the added plastic waste to the asphalt mixture with fine particles size (passing sieve No.16 (1.18mm)), thin thickness (0.2mm), and (15% by weight of aggregate), increase the Marshall stability and the index of retained strength by (20% and 15%) respectively more than the conventional mix.

IX. Recommendations

1) Additional research is needed to study the effect of plastic waste particles properties on the resistance of mixture to low temperature cracking, rutting, and fatigue.
2) Further work is required to investigate the effect of chemical compositions of the different types of plastic waste on the performance of hot mix asphalt.
3) It is recommended to install classified plastic waste collection bins in the heavily populated areas in order to make use of them for hot mix asphalt and to help in getting rid of this type of plastic waste as a source of environmental pollution.

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