Journal of Engineering and Applied Sciences 13 (18): 7656-7661, 2018
ISSN: 1816-949X

Permeability Measurements of Surface Asphalt Mixture Modified by Polymer Combination

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Abstract: Permeability can be defined as the capacity of porous material to let water flow through its voids that has been associated with the moisture damage occurrence. One of the most common method for reducing the permeability of HMA is polymer modification of asphalt binder. The best polymer combination (plastomer-elastomer) that related with lowest permeability value for both surface layer A and B is 4% PE-1% SBR and 2% PP-3% SBS. By modification with polymer combinations (plastomer-elastomer), the permeability values decrease to 1.49 times for HMA surface layer A and two 2.04 times for HMA of surface layer B when compared with control ones.

Key words: Permeability, HMA, polymer combination, plastomer, elastomer, compared

INTRODUCTION

Permeability measurements of asphalt mixture: Traffic and environmental conditions can increase the pore water pressure in moist voids within Hot Mix Asphalt (HMA). That may introduce internal stress, result in acceleration of asphalt film distortion around the aggregate adages. This phenomena usually happens in the surface layers and the interface between the within HMA (Lu, 2005).

Permeability can be defined as the capacity of a porous material to let water flow through its voids. This parameter has long been associated with the occurrence of moisture damage and consequently, several agencies have prescribed maximum values of in-place air voids in an effort to minimize the effects of moisture damage and maximize the durability of the pavement (Mercado, 2007). As shown in Fig. 1, they have classified the asphalt mixes based on their air void structure as effective, semi-effective and impermeable.

Effective mixes show a high number of interconnected voids and therefore, allow a free flow of water, semi-effective mixes have a smaller number of connected voids and the connections span only part of the mix pavement layer thickness and the air voids in impermeable mixes are usually isolated with a very small amount of connectivity (Mercado, 2007).

Permeability measurements of pavement materials largely have been limited to laboratory settings (Maupin, 2010).

Previous attempts have been made to develop a device that could quantify permeability in asphalt concrete pavements. A study was conducted evaluating the permeability of different types of surfaces and also evaluating the devices used in the study (White and Ivy, 2009).

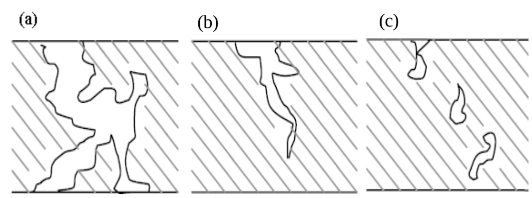

Fig. 1: Classification of air voids based on connectivity (Mercado, 2007): a) Effective; b) Semi-effective and c) Impermeable

For measuring the permeability, two adopted test methods are utilized, constant and falling head ones (Russell *et al*., 2005).

Falling head test method is more suitable for asphaltic mixtures. That allowed just low-pressure differentials to measure water flow in semi-porous materials like HMA (Maupin, 2000).

Some main factors like, air voids, aggregate gradation, MMS and sources and layer thickness which can affect the permeability lab compacted HMA specimen (Allen *et al*., 2001).

Polymer modifiers: Asphalt modifier is defined as a material which would normally be added to the binder or the mixtures to improve its properties. The main reason for using of modifiers on the asphalt mixtures as asphalt modification is to improve the performance of paving mixture to meet requirements under prevailing conditions from loading and environmental effects.

One of the most common method for reducing the permeability of asphaltic mixture is polymer modification of asphalt cement binder. These polymers are usually consist of smaller molecular units jointed together end to end which reflect the physical and chemical properties of modifiers. Elastomers and plastomers are considered the main asphalt cement modifiers.

Elastomers: Thermoplastic materials soften and become plastic-like when heated but return to their hardened state upon cooling. Such as Styrene Butadiene Styrene (SBS) and Styrene Butadiene Rubber (SBR).

Plastomers: Thermosetting materials flow under stress when heated but once cooled cannot be re-softened by heat. Such as Polyethylene (PE) (low density and high density), Polypropylene (PP).

SBR (Elastomers) additives: Liquid anti-strip additives have been used effectively to reduce the permeability of hot-mix asphalt materials. Liquid anti-strip agents can affect the engineering properties of the asphalt binder and the engineering properties of the hot mix asphalt mixture.

(PE) (Plastomers) additives: It was used to modify asphalt cement. Adding <10% PE leads to increase flow value and decrease the air voids in total mix (Yi-Qiu and Al-Hadidy, 2011).

PP (Plastomers) additives: Is a fiber modifier used in asphalt paving mixtures to satisfy the following objectives:

- Air voids and VMA tend to decrease
- There is a slight improvement in the retention of asphalt coating (Al-Hadidy and Yi-Qiu, 2009)

MATERIALS AND METHODS

The materials employed in this research are broadly used in asphalt paving works in most parts of Iraq. One type of asphalt cement is used. One type of aggregate with two nominal maximum sizes (12.5, 9.5 mm) and four types of modifiers are used the properties of aggregates and asphalt cement are evaluated using routine type of tests and the obtained results are compared with the SCRB/R9 specification requirements.

Asphalt cement: One type of asphalt cement was used with (40-50) penetration grade brought from Al-Durahrefinery. The physical properties and tests of the asphalt cement used are shown in Table 1. The test above where carried out in Roadway Lab., Civil Engineering Department, University of Babylon.

Aggregate: Coarse aggregate can be brought from Najaf quarry which is usually used in asphaltic roadway project at the region. The fine aggregate source is the quarries of Al-Najaf. It was sieved and recombined in the proper proportions to meet the gradations required by SCRB specifications. Wearing course type (III A and III B). The physical properties set by the SCRB specification limits are summarized in Table 2. The gradation of aggregate, a nominal maximum size of (12.5, 9.5 mm) is shown in Table 3. Test results show that the chosen aggregate met the SCRB specifications.

The wearing courses are selected because these layers are always in direct contact with traffic loadings and variations in environmental conditions, therefore, these layers must be improved by modifier to withstand these conditions. Test where carried out in Roadway and Construction Material Labs., Civil Engineering Department, University of Babylon.

Mineral filler: In this research, one type of mineral fillers has been utilized: portland cement, the percentage of

Table 1: Physical properties of asphalt cement

Test	Units	Asphalt cement type Durah	(SCRB in 2009) specification
Penetration (25°C, 100 g, 5 sec) ASTM-Ds	1/10 mm	47	(40-50)
Kinematics Viscosity at 135°C ASTMD2170	CST	365	
Ductility (25°C, 5 cm/mm) ASTM-D113	cm	110	>100
Flash point (cleveland open-cup) ASTM D92	°C	260	Min. 232
Specific gravity at 250°C ASTM-D70		1.04	(1.01-1.05)

Table 2: Physical properties of the aggregate

Property	ASTM designation	Coarse aggregate	Fine aggregate
Bulk specific gravity	C-127C-128	2.36	2.34
Apparent specific gravity	C-127C-128	2.65	2.52
Water absorption (%)	C127C-128	1.44	2.07
Wear (LosAngeles) (%)	C-131	25 (%) Max 35 (%)	-
Angularity	D 5821	93 (%)	-

Table 3: Asphalt mixture grading

		Surface or wearing course (Passing by weight of total aggregate+Filler (%))			
		Type 3A		Type 3B	
Sieve size	mm	Sp. limits	Gradation	Sp. limits	Gradation
1 1/2 in	37				
1	25.9				
3/4	19.0	100			
1/2	12.5	90-100	100	100	
3/8	9.5	76-90	88	90-100	100
No.4	4.75	44-74	67	55-85	70
No. 8	2.36	28-58	45	32-67	50
No. 50	300 μm	5-21	15	7-23	15
No. 200	75 μm	4-10	7	4-10	6
Asphalt	Cement	4-6	4-7	4-6	4-8

Table 4: Physical characteristics of the used filler

Property	Cement
Specific gravity	3.10
Finness (cm^2/g)	3020
Passing sieve No. 200 (%)	94

Table 5: Mechanical characteristics of LDPE

Requirements	Characteristics
Density (g/cc)	0.925
Elongation at break, MD-310, TD-550	%
Dart drop impact strength (g/f.50)	142

fillers have been used in this research (7%) for wearing courses. The physical characteristics of filler are presented Table 4. Test where carried out in Roadway and Construction Material Labs., Civil Engineering Department, University of Babylon.

Additives: Polymer modified binder were produced in the laboratory using (60 min) as blending time for each percent content of selected 4 types of polymers as Low-Density Polyethylene (LDPE), Styrene Butadiene Styrene (SBS), Styrene Butadiene Rubber (SBR) and Polypropylene (PP) (Al-Bana'a, 2010).

The blending temperature in this research were in range of 175°C for LDPE and SBR, 155°C for PP, 180 °C for SBS (Al-Bana'a, 2010).

LDPE is a plastomers polymer, the most common branch length is four carbons long. Themechanical characteristicsof LDPE are presented in Table 5.

Polypropylene (PP): Polypropylene is used as a modifier in asphalt concrete, to satisfy the desire mechanical properties of asphalt pavement. The characteristic of polypropylene are presented in Table 6.

Styrene Butadiene Rubber (SBR): SBR has been widely used as commercial binder modifier material, usually as dispersion in water (latex). The characteristics of styrene butadiene rubber are presented in Table 7.

Table 6: Properties of PP

Form	Virgin polypropylene fiber
Sp. Gr.	0.91
Fiber thickness	18-30 μ
Tensile strength	350 MPa
Melting point	150-160 ^{0}C
Fiber length	6-12 mm

Table 7: Characteristic of SBR (Anonymous, 2010)

Property or characteristic	Unit	Requirement or value
Density	g\cm^3	0.93
Tensile strength (σt)	MPa	5.05
Flexural strength	MPa	11.5
Active solids content	%	45.0

Table 8: Some mechanical properties for SBS (Anonymous, 2010)

Property or characteristic	Unit	Requirement or value
Density	g/m^3	1.242
Specific gravity	-	0.94
Modulus 300 (%)	MPa	2.08
Tensile strength	MPa	32
Elongation	%	880
Apparent	-	White kraton particles
Melting point	°C	180

Styrene Butadiene Styrene (SBS): Is an elastomer with molecules in different length and arrangement. That may influence modification degree introduced for the asphalt cement binder. As well as the ease of blending and the stage stability (Airey, 2004). Some mechanical properties for SBS is revealed in Table 8.

Preparation of specimen: Proper compaction play a major role in permeability of HMA. That the presence of moisture and traffic action affect damage of the layer. As the reduction of the connected air voids within dense graded HMA will also reduce the permeability of the layer.

To assess the influence of compaction, a series of modified and control mixture was produced and compacted at: 7% (6-8)% field experience for permeability. The examined HMA were prepared in accordance with standard Marshall design method with different number of blows for adopting the required percent air voice (about 7%).

Permeability test: Density of permeability measurement will give better durability indication then density alone (Harris, 2007).

For laboratory test procedures, the general method that is used was developed by the Florida Department of Transportation (FDOT). This test method has been adopted as the standard lab test and the procedure is outlined in ASTM PS 129-01, Permeability of Bituminous Materials. The lab permeability apparatus is shown in Fig. 2.

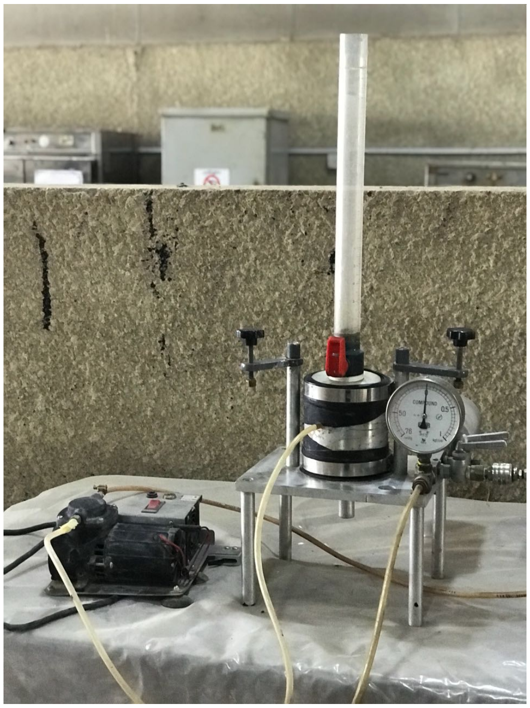

Fig. 2: Setup of lab permeability device

After the test specimen has been prepared, it is saturated in a de-aeration chamber. Next the sample is placed in the chamber where the latex membrane is pressurized to prevent water passing through the sides of the sample. The standpipe is then filled with water and the valve is released. The time is then recorded for the water level to move from the initial head value to the final head value.

The information from test and dimensions of the sample are entered into Darcy's law to obtain the coefficient of permeability. This equipment used the falling have device. In this Research the specimens for lab permeability testing were prepared with dimensions 4 inch diameter ×2.5 inch height with air voids percent in total mix about 7%. Permeability coefficient, k is find as the following:

$$K = \frac{aL}{At}\ln\left(h_1 / h_2\right) \quad (1)$$

Where:

K	=	Permeability coefficient (cm/sec)
A	=	Inside cross-sectional area of the buret (cm^2)
L	=	Average thickness of the test specimen (cm)
A	=	Average cross-sectional area of the test specimen (cm^2)
T	=	Elapsed time between h_1 and h_2 (sec)
h_1 and h_2	=	Initial and final head across the test specimen, respectively (cm)

RESULTS AND DISCUSSION

Almost, polymer addition increase the viscosity at moderate and high temperature that result in improvement of ratting and fatigue resistance and long term durability due to thicker film produced on the aggregate particles. While the soft asphalt base with polymer improve low temperature cracking resistance (Terrel and Epps, 1989).

Two basic types of polymer utilized in modifying asphalt for road applications which are elastomers and plastomers. In general choosing of the right polymer for the application in the asphalt mixtures is highly dependent upon the concentration, the molecular weight, the chemical composition, physical properties and the molecular orientation of a particular polymer as well as the crude source, the refining process and the grade of the base asphalt used.

Thermoplastic elastomers derive their strength and elasticity from a physical cross-linking of the molecules in to a three dimension network (Crossley, 1999).

As with most polymer-asphaltsystems, there must be compatibility between the base asphalt and the plastomer to ensure optimum properties are achieved (Terrel and Epps, 1989).

An air void in the mixture is an important factor because it permits performance of the mixture to be predicted for the service life of the layer.

The intrusion of water and air in asphalt pavement can lead to long-term durability problems due to rapid moisture damage and oxidation. In local specification, the air void limitations is assumed to cover the requirements of hydraulic conductivity for paving mixtures. In general, the following model has been formulated to predict the hydraulic conductivity of local dense paving mixtures (Hammody, 2011).

Polymer combination (plastomer with elastomer) were utilized for HMA modification against moisture damage which was indicated by permeability values.

The results of air voids and permeability test are shown in Table 9 and 10 with different modifiers combination.

The adopted air voids varied according to nominal maximum size and modifiers combination. Almost permeability value decreased with range (1.34 reach to 2.04) for HMA with nominal maximum size (9.5 mm) and with range (1.07 reach to 1.49) for HMA with nominal maximum size (12.5 mm) for modified mix when compared with control ones. The best combination for PE and SBR is 4% PE and 1% SBR which results in lowest permeability value for both nominal maximum size 12.5 and 9.5 mm.

Table 9: Results of air voids and permeability tests of surface asphaltic course type IIIA (HMA with nominal maximum size 12.5 mm)

Type of mixture	Air void (%)	Permeability value (cm/sec) $k\times10^{-5}$
Control	7.1	90.1
2% PE and 1% SBR	7.2	99.5
2% PE and 3% SBR	7.0	84.7
4% PE and 1% SBR	6.9	75.4
1% PP and 3% SBS	6.8	68.5
2% PP and 3% SBS	6.5	60.5
2% PP and 1% SBS	7.3	94.5

Table 10: Results of air voids and permeability tests of surface asphaltic course type IIIB (HMA with nominal maximum size 9.5 mm)

Type of mixture	Air void (%)	Permeability value (cm/sec) $k\times10^{-5}$
Control	6.9	72.5
2% PE and 1% SBR	6.5	49.7
2% PE and 3% SBR	6.3	43.0
4% PE and 1% SBR	6.6	37.4
1% PP and 3% SBS	6.4	38.4
2% PP and 3% SBS	6.2	35.9
2% PP and 1% SBS	6.7	54.1

Elastomer (SBS and SBR) behave as asphalt softener which leads to modified asphalt mechanism throw air voids of mixture easily and efficiently which cause a decrease in the permeability while the plastomer (PP and PE) behave as matrix former which close the moisture path throw the mix and reduce the permeability.

According to the Florida Department of Transportation (FDOT) the critical permeability value for the falling head permeameter method is 125×10^{-5} cm/sec (Hammody, 2011).

According to the results data presented, mixtures with both NMS (12.5-9.5) mm agrees adopted requirements. For all mixes, there is an increase in permeability values noted with increase in the MMS. This may be return to increment of coarse particles quantity as well as decrement of fine particle ones. That reflected on inter connections of air voids that cause more flow throw paths (Hammody, 2011).

CONCLUSION

Within the limitation of test methods and materials used in this research, the following facts can be concluded: NMAS plays a significant role in permeability of local HMA

Almost, there is a clear compatibility between air voids and permeability variation with mixture type when using polymer combination HMA modification, permeability value has a decrement reach to 2.04 times for HMA with NMS 9.5 mm (surface course IIIB) and to 1.49 times for HMA with NMS 12.5 mm (surface course IIIA) when compared with control HMA.

According to, the FDOT requirements and for all mixture types the permeability values did not exceed the critical value. The best polymer combinations where 4% PE-1% SBR and 2% PP-3% SBS which resulted in lowest permeability values for both surface courses.

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