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RESEARCH ARTICLE

Influences of polymer modifiers on Porous Hot Asphalt Mixture Property and Durability

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ABSTRACT

Fundamentally, sustainability and cost-effectiveness in infrastructure development have received widespread attention. Permeable pavement is such a concept that it is sustainable in the field of transportation and is being tested. Fully permeable pavement is a modern design method in which each layer is porous and can store water, avoiding the impact of stormwater on the pavement to avoid stormwater, skidding, floods, and water splash on the road and parking area which decrease safety rate. Porous asphalt (PA) is an asphalt mixture with a little or no fine aggregate. Due to open structures and advantages are used as a drainage layer in highway pavements in reducing noise and decreasing safety hazards during rainfall. Besides, it reduces splash and spray effects and thus increases the visibility. The main aim of this study is to analyze the influence of two asphalt modifier types: Styrene butadiene styrene (SBS) and propylene modifier polypropylene (PP), on porous hot asphalt mixture performance. The PA evaluation influence findings are based on permeability, durability, and Marshall stability-flow for hot asphalt mixture. The test results emphasize the modifier usage in reducing the abrasion loss and increasing the stability with enhancing the durability of PA. PA mixture binder prepared with 4% SBS and 4% PP modifier was the most polymer binder in modifying the abrasion resistance and stability of mixture in pavements.

Keywords: Durability; Mechanical properties; Permeability; Polymer modifiers; Porous asphalt

INTRODUCTION

In the past two decades, traffic volume and loads have been increased, along with rising temperature gradients have been experienced in some places, and the flooding has given rise to early pavement deterioration (Alvarez et al., 2006). Therefore, porous asphalt (PA) becomes a trustworthy solution for pavement. PA is an asphalt mixture with a little or no fine aggregate. The redaction of the amount fine aggregate creates open gaps, which lets water pass through the mixture with a proper inhalation PA pavement that allows runoff volume rate annually reached up to 80% for infiltration (Sasana et al., 2003).

The main advantage of PA applications is to provide skid resistance, which is remarkably better than regular asphalt as well as increase the design speed (Moore et al., 2001), also reduce noise and glare (Casey et al., 2008). Furthermore, PA is the most widely used technique for controlling the drainage system to mitigate flooding due to their large amount of interconnected voids. Compared with typical asphalt pavement, PA has a high percentage of void content up to %20, which is decreasing the structural stability (Hagos, 2008). Therefore, Asphalt binder is called aggregate holder, which responses to the strength of PA to enhance stability and durability that pavement polymer modifiers (PMs) will be used. PM mainly contains plastic materials which are used as additive materials to improve asphalt binders (Al-Jumaili, 2016).

Researchers used polymers in two different ways, either in dry or in the wet process, which is mix with mixture and binder, respectively (Brasileiro et al., 2019). As a result of using PM in the wet process, it changes the physical properties of asphalt binders such as ductility, penetration, elasticity, and a softening point, which directly has an improvement on the stability and durability of the pavement (Casey et al., 2008).

This study investigated the effects of using polymers as PM for asphalt binders in a wet process to find their effect on the PA mixture property. Depending on laboratory works and test results, the aggregate gradation, maximum particle size, and AC% were selected to obtain a proper PA mixture that has suitable permeability, stability, and air void %.

MATERIALS AND METHODOLOGY

Materials

Asphalt binder

In this research, one source of local asphalt is used, with (40–50) grades from the Lanaz refinery, which is located in Erbil-Kurdistan Region, Iraq. Table 1 shows the test result of asphalt binder properties.

Aggregates

The crushed coarse aggregate and fine natural aggregate are used from the Aski Kalak quarry in Erbil, and the physical properties of aggregates are shown in Table 2.

Polypropylene

Polypropylene (PP) SABIK PP-575P is a thermoplastic material used in most applications and produced from oil refinery and also called polypropene, which is partially crystalline and non-polar (SABIC, 2019). Table 3 shows the property of polypropylene polymer and Figure 1 shows the chemical component formula of PP and the material has used.

Styrene butadiene styrene (SBS)

SBS D1192 is a linear porous pellets copolymer composed of styrene and butadiene with a 30% mass of bound styrene (Kraton, 2019). Figure 2 shows the chemical component formula of SBS that contains the high vinyl in the midblock. Furthermore, Table 4 contains the physical properties of SBS-D1192.

Table 1: Properties of the regular asphalt binder (40–50) grades

Test method		Regular asphalt
Penetration at 25°C	ASTM D5	48
Flash point	ASTM D92	296°C
Fire point	ASTM D92	345°C
Softening point	ASTM D36	48°C
Ductility at 25°C	ASTM D113	150 CM
Elastic recovery at 25°C	ASTM D6084	16.66%
Sp. Gr. at 25°C	ASTM D70	1.05

Table 2: The physical properties of aggregates

Test method		Crushed coarse aggregate	
		Result	Test specification
Water absorption	ASTM C127	0.6%	≤3%
Abrasion	ASTM C131	23%	≤40%
Bulk SG.	ASTM C127-04	2.714	
Apparent SG.	ASTM C127-04	2.759	
Test Method		**Regular fine aggregate**	
Bulk SG.	ASTM C128	2.75	
Apparent SG.	ASTM C128-15	2.81	

Table 3: Physical properties of PP (Adapted from [SABIC, 2019])

Test method		SBS-D1192
Melting flow rate, 230°C/2.16 kg	ASTM D 1238	10.5 g/10 min
Density	ASTM D792	0.905 g/cm³
Vicat softening point	ASTM D1525	153°C
Melting point	ASTM D7138-16	160–170°C

Methodology

The selection of aggregate gradation

The selection of aggregate gradation for PA varied from a country or agency to another with different ranges of gradation, which i illustrated in Figure 3. In this study with considering different agencies (National Asphalt Pavement Association [NAPA] and FHWA), the gradation was selected based on many trials with different asphalt contents. Table 5 shows the aggregate gradation details for this study.

Experimental works

Asphalt binder was prepared by mixing the original asphalt (40–50 grades) with three different percentages of PP and

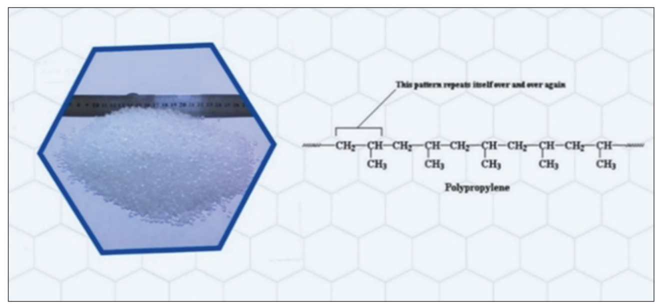

Figure 1: Chemical formula and sample of polypropylene (SABIK PP-575P)

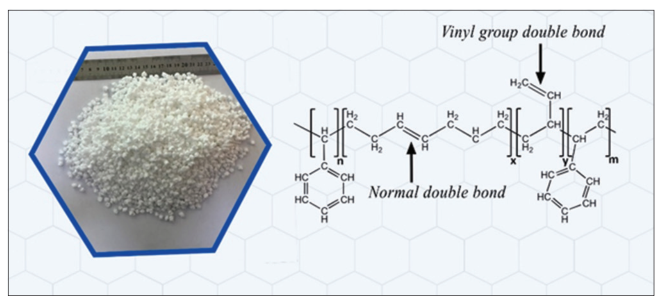

Figure 2: Chemical formula and sample of SBS (D1192)

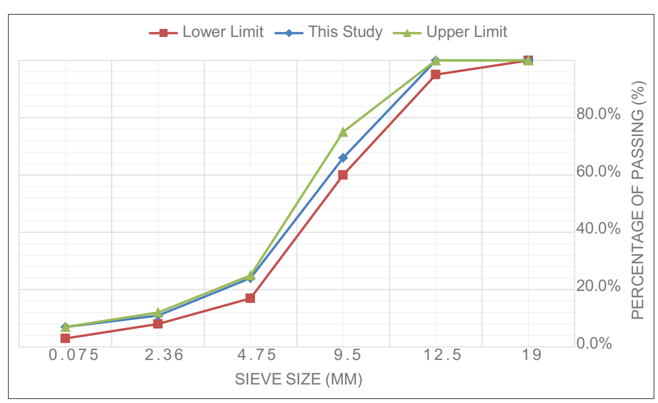

Figure 3: Aggregate gradations for porous asphalt mixtures

SBS (2, 4, and 6% by weight of the asphalt) based on the previous studies (Brasileiro et al., 2019; Al-Jumaili, 2016; Dalhat and Al-Abdul, 2017; Zhu et al., 2014). The mixing process begins with heating the asphalt up to 170°C; then the required polymer will be adding in the rate of 10 g/min, while the mixer is continuing mixing in the speed of 145 rpm for PP and 5000 rpm for SBS modifiers and mixes continually for 1 h (Brasileiro et al., 2019).

Selecting an asphalt modifiers content that has the best result by standard tests to continue and investigate the role of PM in PA using permeability, Marshall Stability-Flow, and abrasion tests. Figure 4 illustrates the flow chart of the experimental work step by step for each test. Thus, in this study, three samples were taken for each test: Total (126) samples were tested.

Table 4: Physical properties of SBS (adapted from [Kraton, 2019])

Test method		SBS-D1192
SG.	ISO 2781	0.94
Melting flow rate, 200°C/5 kg	ISO 1133	<1 g/10 min
Bulk density	ASTM D1895-B	0.4 kg/dm3
Melting point	ASTM D7138-16	170-180°C

Table 5: Aggregate gradation evaluated in this study

Sieve size (mm)	12.5	9.5	4.75	2.36	1.7	0.075
Percentage of passing	100	66	24	11	9	7

Permeability test

The permeability coefficient (K Value) for the PA mixture was measured using the falling head procedure of the permeability test, and as the test case, it will simulate sight situation in regard the water head pressure and drainage (ASTM C1781) (Khowshnaw et al., 2013). The test begins with a warping sample tied with plastic wrap to force the water exit only through the bottom of the specimen. Then, duct tape is used to hold the specimen with the 4-inch standpipe and folded over. Once the specimen fixed with a standpipe, water cannot flow between the standpipe and the specimen, as shown in Figure 5 (Lyons and Putman, 2013). The measurement of time began when the level of water reaching the head one and ended by reaching the water level at head two, and then the permeability coefficient of each Marshall sample determined using Eq.1

$$K = \frac{aL}{At} \ln\left(\frac{h1}{h2}\right) \tag{1}$$

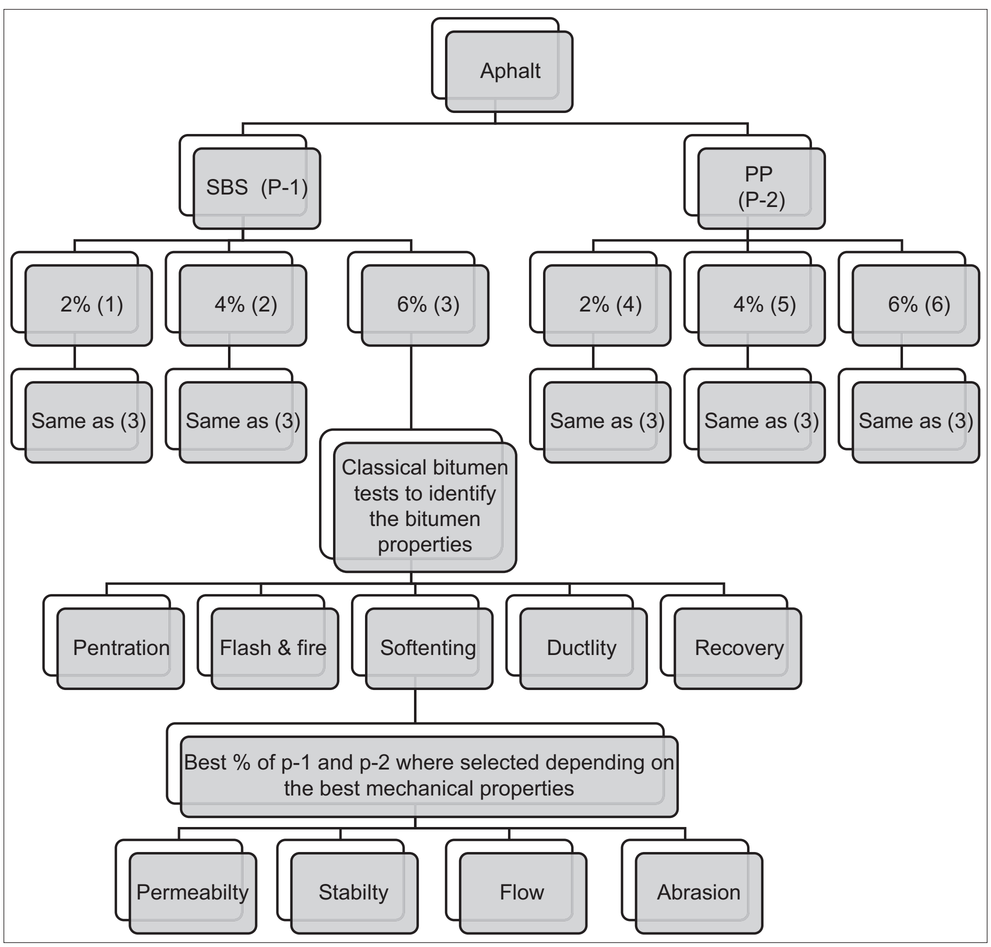

Figure 4: Experimental work procedure flow chart

Where: A is the cross-sectional area of the specimen in cm, a is the cross-sectional area of the standpipe, L is the height of the specimen, h1 is heading one (200 mm), and h2 is heading two (50 mm).

Marshall test

Marshall test is performed by the standard method, which is described by ASTM, D1559, to measure the resistance to plastic flow and stability for 101.6 mm diameter and 76.2 mm height specimen Marshall mixture through using 75 blows of 4.54 kg hummer for each face.

Abrasion test

The abrasion test means the resistance of any pavement surface to lose its particles due to skidding, sliding, from the breaking friction and movement of the vehicles, and also the weather intensity (Freezing and thawing) while, the lower value of abrasion means desirable and stiff pavement (Gesoğlu et al., 2014).

Therefore, the abrasion test shows a significant positive effect of polymers in the asphalt binder by creating more bonds between the surface particulars. The test specimen size is 71 × 71 × 71 ± 0.5 mm fixed on the abrasion testing machine (Bohme abrasive wheel) 40 rpm, according to DIN 52108 and IS 15658–2006 standards, Figure 6. After 352 as total cycling, 88 cycles in each direction of the contacted surface and using (crystalline AL_2O_3) dust; the calculation carries out from equation two below:

$$\Delta V = \frac{\Delta m}{D} \qquad (2)$$

Where:
ΔV: Loss in volume after 352 cycles, in cm^3
Δm: Loss in mass after 352 cycles, in gm and
D: Density of the specimen, in gm/cm^3.

RESULTS AND DISCUSSION

Mechanical Properties of PM

Form the standard tests carry out the mechanical properties of different percentages of polymers. Through analysis of the results of mechanical properties, the best percentages performance of SBS and PP polymers are chosen, as shown in Table 6.

Effect of PM on Permeability

The comparison results of the permeability test with different PMs and the control mixtures are shown in Figure 7. The two PMs did not show a significant change in the coefficient of permeability (K).

Figure 5: Permeability test schematic

Figure 6: Bohme abrasive wheel abrasion test machine

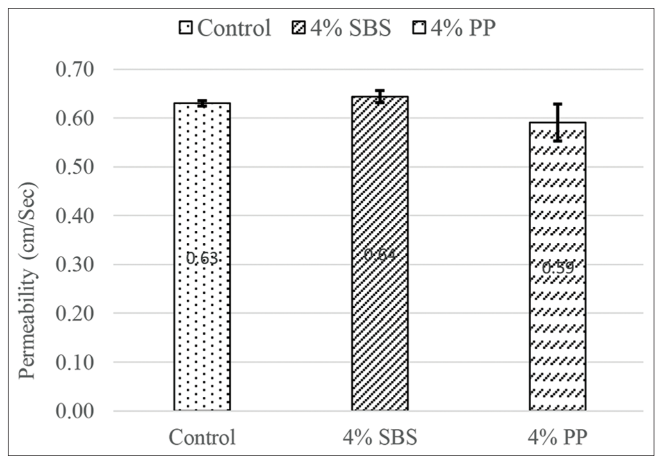

Figure 7: Effect of polymer modifiers on permeability

Effect of PM on Stability (Marshall Test)

Figure 8 illustrates the influence of PM on stability, adding (4% SBS and 4% PP) to the asphalt mixes, stability is poorly modified, where SBS effected better than PP polymers.

Effect of PM on Flow (Marshall Test)

It is shown in Figure 9 that Marshall flow is more similar to control by adding PM. Therefore, the flow rate is within the range (2–6 mm) of the NAPA (2003) standard specification, as recommended for PA pavements.

Effect of PM on Air Voids Content

The NAPA 2003 and The National Center for Asphalt Technology recommend that optimum asphalt content for PA be determined by asphalt content that air voids not less than 18%. To accomplish with this required rate of air voids, no fine aggregate and no filler were used in the

Table 6: Mechanical properties of different polymers

Tests	Normal bitumen	2% PP	4% PP	6% PP	2% SBS	4% SBS	6% SBS
Penetration (1/10 mm)	47	32	23	22	43	31	25
Softening (°C)	48.20	52.95	57.8	61.2	55.2	59.2	73.45
Penetration index	–1.80	–1.46	–1.06	–0.49	–0.32	–0.20	1.71
Flash point (°C)	296	304	322	330	305	300	297
Fire point (°C)	345	346	348	373	340	328	324
Ductility (cm)	150	44	23	13	150	82	72
Elastic recovery (%)	16.67	22.67	19.33	18.80	61.76	67.00	83.00

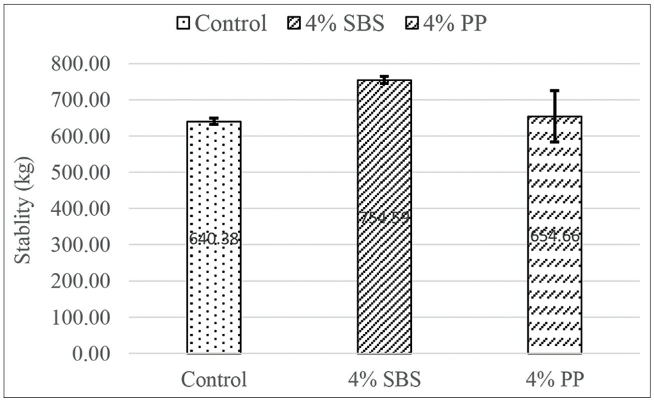

Figure 8: Effect of polymer modifier on stability

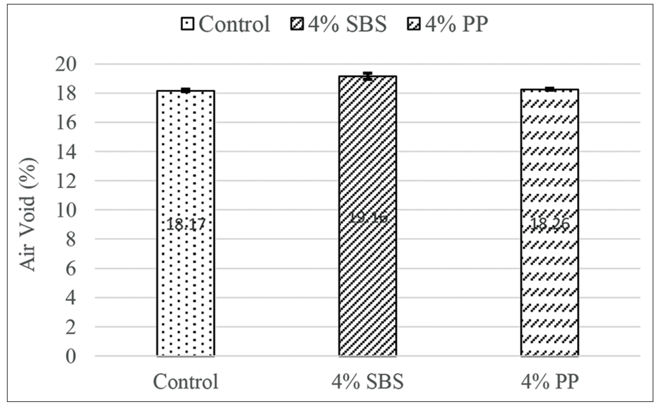

Figure 10: Effect of polymer modifier on air voids content

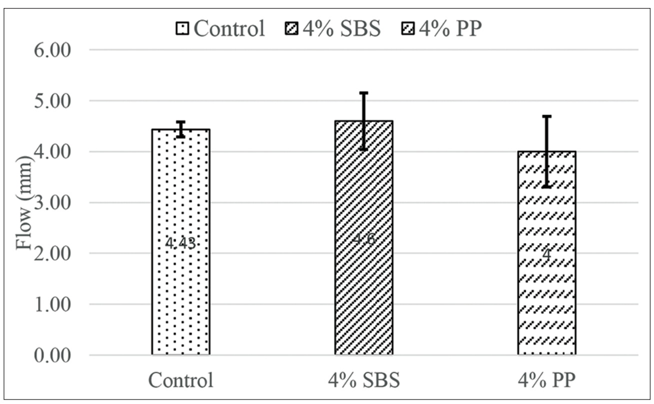

Figure 9: Effect of polymer modifiers on flow

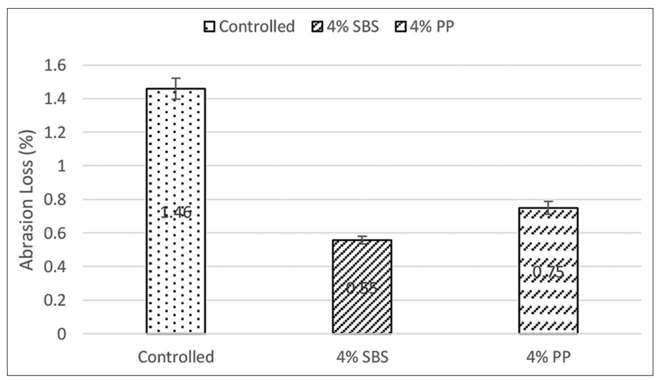

Figure 11: Effect of polymer modifiers on abrasion

mixtures, and the specimen's compaction blows number was 75 blows. However, air voids of the controlled mixture have covered the requirements and enhanced through interconnected air void of the mixture specimens. The two modifiers did not significantly affect the air voids rate, as illustrated in Figure 10.

Effect of PM on Abrasion

From the test results for various mixtures containing polymers Figure 11, the abrasion loss (%) was improved and decreased in comparison with the control mixture. The abrasion loss reduced by around 62% by adding 4% SBS polymer and about 49% when 4% PP was added. These grantees for better and longer service life of the pavement.

CONCLUSION

An investigation of polymers influences in PA as PM in hot asphalt mixture through using two deferent polymers (SBS and PP) in the wet process. The work concluded that:

1. Mixing 4% SBS polymers with bitumen binder caused the increment in mixture stability, which is about 18% of the controlled mixture
2. Replacing 4% bitumen by its weight with PP polymer keeps the PA mixture at the same level performance in terms of stability
3. Polymers of (4% of SBS and PP) amount in asphalt binder improve the porous mixtures abrasion property by 62% and 49%, respectively, which provide better durability and more interminable service life pavements

4. Adding 4% of SBS and PP polymers did not significantly affect the air voids, which are the essential aspect for permeability (the main PA pavement property)
5. According to the test results, when utilizing (PP and SBS) with bitumen binders, affected positively on the performance of the PA pavements as bitumen replacement. Therefore, they will serve the environment and saving economy aspects by providing better service life for the highway.

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