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Effect of PolyPhosphoric Acid on Rutting Resistance of Asphalt Concrete Mixture

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Abstract

The action of high repeated trucks load associated with dramatically elevated ambient temperatures leads to the most harmful distress in asphalt pavements occurred in Iraq known as rutting. Essentially, it is produced from the accumulation of irrecoverable strains, which mainly occurred in the asphalt layers. That visually demonstrated as a longitudinal depression in the wheel paths as well as small upheavals to the sides. Poly Phosphoric Acid (PPA) has been used as a means of producing modified asphalt binders and the interest to use it has increased in recent years. The PPA provides modified asphalt binder, which is relatively cheaply produced compared to polymer-modified asphalt. In this paper, PPA was used by three-percentages 1, 2 and 3 % of the weight of asphalt binder. Two asphalt binder grades were used in this study, 40-50 and 60 -70. The evaluation process based on conducting Marshall Test, Compressive strength test and the Wheel Tracking test. The optimum asphalt content was determined for eight asphalt mixture. The results of the index of retained strength of modified asphalt were slightly increased compared with conventional mixtures. The rut depth was determined by using wheel tracking device at different temperature (45 and 55 ˚C) for each asphalt mixture under 10000 cycles and the results showed that modified asphalt with PPA produced mixtures with more rutting resistance than conventional asphalt mixture. Moreover, the effect of PPA on rutting resistance for asphalt grade 60-70 was higher than asphalt grade 40-50.

Keywords: Asphalt, Rutting, Poly Phosphoric Acid, Modified Asphalt, Wheel Tracking Test.

1. Introduction

Asphalt pavement is a durable surface material laid down on the ground surface meant to sustain vehicular traffic loading. Flexible pavements are immensely adopted in Iraq as it provides ease in construction, operating and maintenance, the summer in Iraq is very hot where temperature raised to more than 50 ˚C. It persists for a long time, nearly for five to six months. Therefore, all roads situated in this area suffer from the phenomenon of rutting, and absence of control of the higher axial loads in preceding years. Overloading and high pavement temperatures are most widely on many roads in the Iraq. Modified binders have been used for construction of top surface courses of the flexible pavement for quite some time to achieve improved pavement performance. To improve the quality of the binder, it is essential to identify the proper parameter of the asphalt that controls the rutting in the flexible pavement [1].

Several attempts to develop pavement materials that assisted to earn longer serviceability. Most of these attempts were pointing to improving the design of asphalt binder mix through modified asphalt binders [2]. Asphalt mixture has been modified by adding a different type of additives, the addition of additives typically excesses the stiffness of the

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asphalt binder and improves temperature susceptibility. Increase stiffness lead to improve the permanent deformation resistance of the asphalt mixture in the hot weather [3]. Several researchers have studied the effect of the PPA modification on asphalt. It became an accepted practice to mix the PPA with asphalt binder available to researchers to improve asphalt properties. Many alternative procedures have been developed by various researchers by modifying conventional asphalt binder with various admixes. Few of the contributions are summarized as follows:

According to studies Al-Shaybani (2018) [3], Zhang et al. (2018) [4] and Jafari and Babazadeh (2016) [5], PPA improves the high temperature performance grade (PG) of asphalt binders with only minor effects on their properties at low temperatures, while Jafari et al. (2017) use a PPA to modify a performance graded binder (PG 58-22) and the experimental program included use of three PPA contents (0.5, 1, and 1.5%) by weight of the binder and use of ants tripping limestone aggregates, and the results showed that PPA significantly improved rutting resistance of asphalt mixture [6].

Studying was done on the low-temperature and high-temperature performance of PPA through utilizes dissimilar percentage dosage of PPA. The result demonstrations that the effect of PPA modifier on bitumen asphalt types. The PPA could meaningfully improve the elastic recovery rate of bitumen, decrease the cumulative strain and creep stiffness of the viscosity part, improve the high-temperature performance, and decrease the permanent deformation of the bitumen under repeated load which analyzed through utilize the creep elastic recovery rate, accumulating strain and creep modulus tests [7]. Previous studies showed that PPA may increase or decrease the potential of moisture damage dependent on the aggregate type. The potential of moisture damage with the use of the PPA can be overcome by using an anti-strip additive or using limestone aggregates in the asphalt mixture [4].

Ismael et al. (2014) studied the effect of four types of polymers (SBR, EPDM, PEW and EVA) to resist the permanent deformation. The results showed that the SBR and EPDM polymers are sharing approximately the same value of permanent deformation reduction by 30.20 % and 30.46 % respectively, and at the same polymer content of 15 % by weight of asphalt binder. On the other hand, the PEW and EVA polymers reduce the permanent deformation by 13.24 % and 17.35 % respectively at the 6 % polymer content [8].

2. Materials and Methods

The first phase of the laboratory work is represented by asphalt binder conventional test for virgin and modified asphalt cements. The prepared asphalt concrete mixtures formed to determine the optimum asphalt by conducting Marshall Test. Furthermore, the stability and flow values in addition to the volumetric properties determined to satisfy the requirement of Iraqi specifications. The compressive test has been carried out in order to determine the Index of Retained Strength (IRS). The mixture variables are including two asphalt grades brought from locally refinery, one aggregate gradation with a maximum size of 3/4" which is specified for wearing course. The magnitude of added PPA is 1, 2 and 3 percentages by weight of asphalt binder. In order to measure the rut depth, slab specimens are prepared by roller compactor. The wheel tracking test has been performed at two test temperature (45 and 55 C°) to simulate the local high ambient climate. Figure 1 is the flowchart of the methodology opted for the present study.

2.1. Asphalt Cement

The Asphalt grade (40-50) and (60-70) were obtained from Al-Dura Refinery and used in hot mix asphalt mixtures. Table 1 and Table 2 shows the physical properties of asphalt cement.

Table 1. Physical properties of asphalt cement grade (40-50)

Test	Result	SCRB Specification [9]	ASTM Specification [10]
Penetration (25 ^{0}C, 100 g, 5 sec)	43	40 - 50	D-5
Ductility (25 ^{0}C, 5cm/min)	147	≥ 100	D-113
Softening point (ring & ball)	51	—	D-36
Flash Point (Cleveland Open Cup)	295	232 min	D-92
Specific gravity at 25 ºC	1.039	—	D-70

Table 2. Physical properties of asphalt cement grade (60-70)

Test	Result	SCRB Specification [9]	ASTM Specification [10]
Penetration (25 ^{0}C, 100 g, 5 sec)	64	40 - 50	D-5
Ductility (25 ^{0}C, 5cm/min)	167	⩾ 100	D-113
Softening point (Ring & Ball)	42	—	D-36
Flash Point (Cleveland Open Cup)	244	232 min	D-92
Specific gravity at 25 ºC	1.048	—	D-70

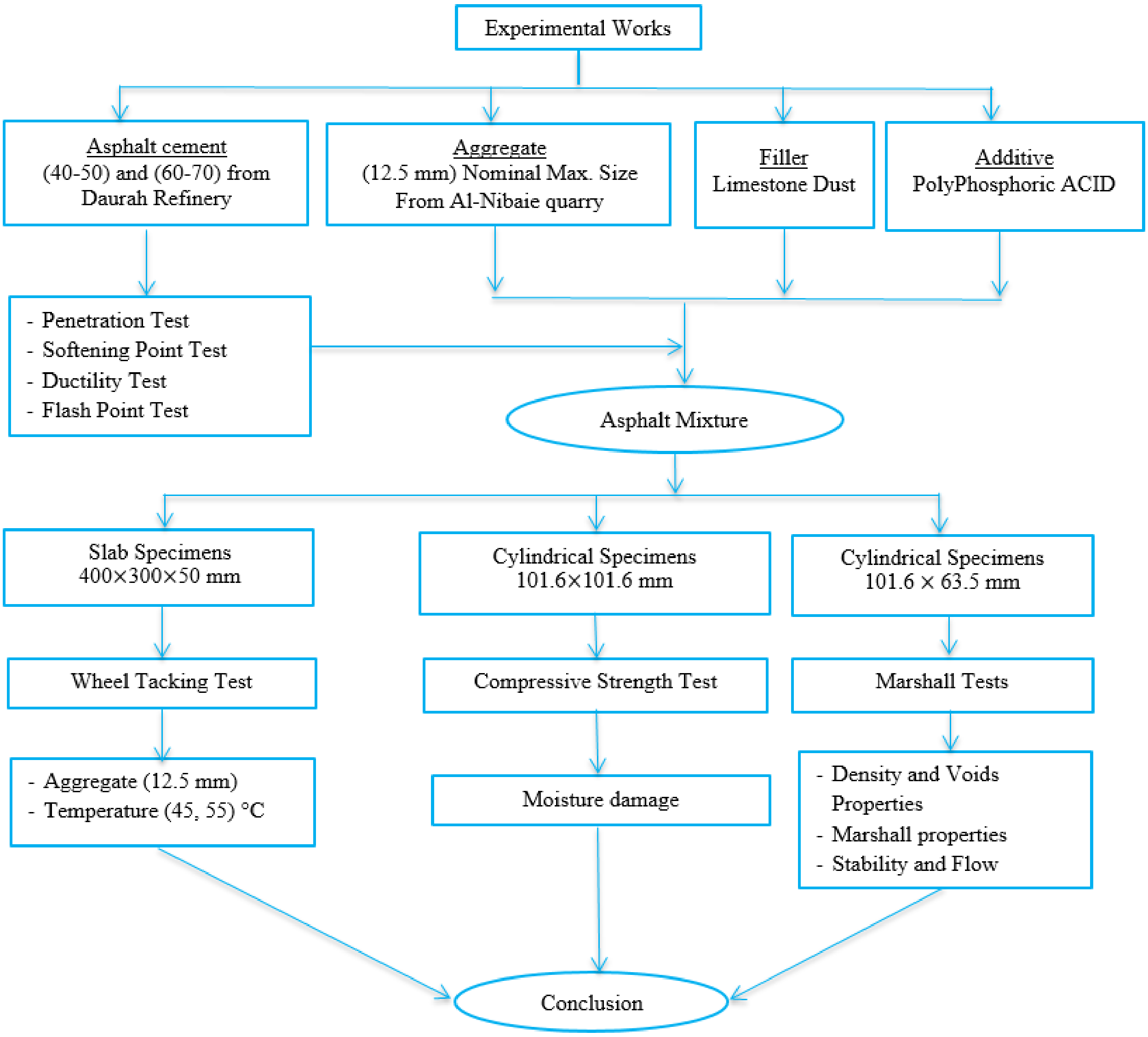

Figure 1. The Work Program Flow Chart

3.2. Coarse and Fine Aggregate

Coarse crushed aggregate was used in this research and obtained from Al - Nibaie quarries. It is most commonly used in local pavement construction. It retains on sieve No. 4. The fine aggregate was bought from local source (particle size between No.4 and No. 200). Laboratory evaluation was conducted to set the basic aggregate properties. The physical properties of aggregates are shown in the Table 3.

Table 3. The physical properties of aggregates

Property	ASTM Specification [10]	Test Results
Coarse aggregate		
Bulk Specific Gravity	C-127	2.610
Apparent Specific Gravity	C-127	2.684
Percent Water Absorption	C-127	0.439
Percent Wear	C-131	19.19
Fine aggregate		
Bulk Specific Gravity	C-128	2.629
Apparent Specific Gravity	C-128	2.682
Percent Water Absorption	C-128	0.552

3.3. Mineral Filler

Limestone dust was used for preparing asphalt concrete mixture. Filler is non-plastic material that is passing sieve No 200 (0.075 mm). It was bought from lime factory in Karbala governorate. The physical properties of mineral filler are illustrated in Table 4.

Table 4. The physical properties of mineral filler (Limestone Dust)

Property	Result
% Passing No. 200	95
Specific gravity	2.71

3.4. Additive (PolyPhosphoric Acid)

The PPA is an inorganic polymer. It is obtained by condensation of monophosphoric acid or by hydration of P_2O_5. The PPA is a liquid mineral polymer and one of several additives which is used to modify and improve grade of bitumen. In this work the food PPA was used and it was bought from local a company in Baghdad. The physical and chemical properties are shown in Table 5 and, Figure 2 shows the PPA used in this study.

Table 5. Properties of PolyPhosphoric Acid

Property	PPA
Physical state	liquid
Appearance	Clear, colourless liquid.
Colour	Colorless
Odor	Odorless
Boiling point	158 °C
Vapor pressure	2.2 hPa (20 °C)
Relative density	1.7
Specific gravity / density	1685 kg/m³
Molecular mass	98 g/mol
Solubility	Soluble in ethanol. Water: Complete

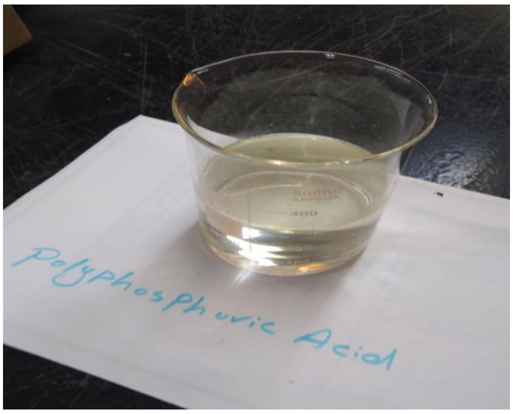

Figure 2. Poly Phosphoric Acid used in the study

3.5. Selection of Aggregates Gradation

The selection of the aggregates in this study was following the specifications recommended by the State Commission of Roads and Bridges (SCRB), [9] for wearing course with the nominal maximum size of aggregate of 12.5 (mm). Figure 3 shows the selected aggregates grade for the wearing course.

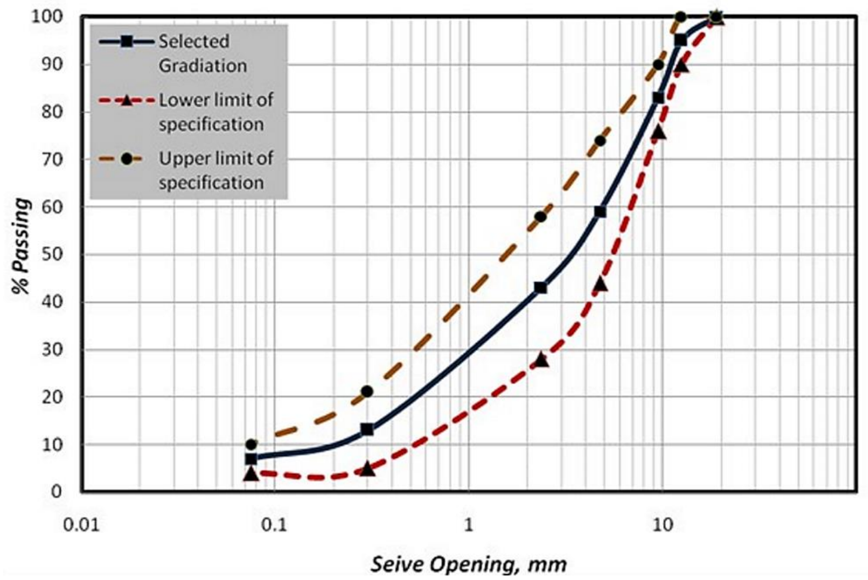

Figure 3. Gradation of the aggregates for wearing course layer according to [9]

3. Marshall Test

The bulk specific gravity and density were conducted according to (ASTM D2726-08), theoretical (maximum) specific gravity according to (ASTM D2041-03) and the percent of air voids (ASTM D3203-05) were determined for each specimen. Marshall Stability and flow values were performed on each specimen according to procedure (ASTM D6927-04 [10]. The percent of air voids have been calculated from the Equation 1:

$$\%\,\text{Air Voids} = \left[1 - \frac{\text{Bulk sp. gr.}}{\text{Max. Theo. sp. gr.}}\right] \times 100 \tag{1}$$

Where:

Bulk sp. gr. = Bulk Specific Gravity.

Max. Theo. sp. gr = Maximum Theoretical Specific Gravity of the Mixture.

4.1. Preparation of Conventional and Modified Mixture

The aggregate was sieved for each single size, then combined with filler to meet the desirable gradation according to the Ismael (2018) [11] for wearing course. The combined aggregate heated to temperature 155 °C at the same time asphalt was being heated to temperature that produce a kinematic viscosity of (170±20) centistokes. Then a specified amount of asphalt was added to the heated combined aggregate to achieve the desired asphalt content. Finally mixed about two minutes until the combined aggregate are coated with asphalt.

The preparation of a modified mixture differs from preparation a virgin mixture by the amount of asphalt and PPA, which, added by the weight of asphalt binder by three percentages: 1, 2 and 3 %.

PPA was added to the asphalt cement at a temperature of 140 °C and stirring (on hot plate) to achieve a homogenous blend, the mixing and stirring was continued for 30 minutes by high shear mixer. Figure 4 shows a group of Marshall Specimens.

Figure 4. Prepared Marshall Specimens

4. Compressive Strength

The test is conducted according to (ASTM D1074-02) [10]. The compressive strength is the capacity of pavement materials to withstand axially directed compressive forces. The compressive strength is one of the most important factors determining its suitability for use under the given load and environmental conditions as a highway paving material. A diameter of cylindrical specimens of 4 inches (101.6 mm) and 4 inches (101.6 mm) in height, they were compacted using compressive device. Figure 5 shows some of the prepared specimens.

Figure 5. Group of Compressive Strength Specimens.

5. Index of Retained Strength Test

This parameter followed the procedure described by [12] and well explained by (ASTM D1075-07) [10]. This test covers measurement of the loss of cohesion resulting from the action of water on compacted asphalt concrete mixtures. A set of six specimens was prepared for this purpose for each eight mixtures. Three specimens were stored in air bath for 4 hours at 25ºC, and then tested for compressive strength and the average value was recorded (S1). The other three specimens were stored in a water bath at 60 ºC for 24 hours, then they were stored in another water bath at 25 ºC for 2 hours, and the compressive strength test was performed on these specimens as shown in Figure 6, the (IRS) calculated from Equation 2:

$$\text{Index of Retained Strength, \%} \ = \left[\frac{S2}{S1}\right] \times 100 \qquad (2)$$

Where $S1$: compressive strength of dry specimens (Group 1); $S2$: compressive strength of immersed specimens (Group 2).

Figure 6. Procedure of Mixing and Test of Compressive Strength

6. Wheel Tracking Test

The Wheel tracking device was used to predict the rut depths for asphalt mixtures [13]. This test measures the rut depth at a stress level of 102 psi applied to rectangular slabs of dimensions (400×300×50) mm at a different test temperature (45 ˚C, 55 ˚C) for 10000 cycles, as shown in Figure 7.

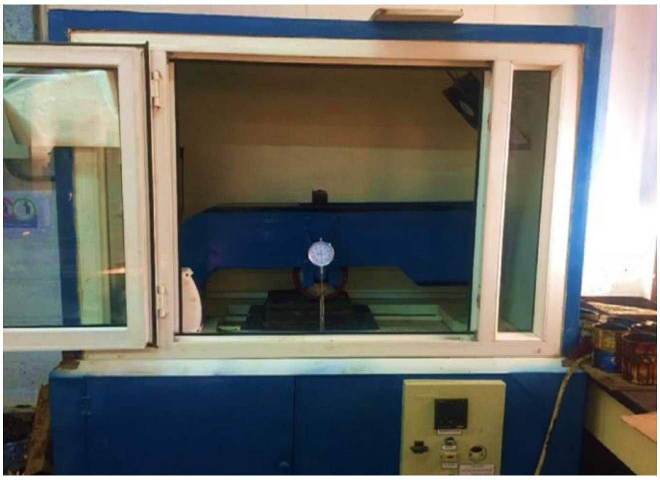

Figure 7. Wheel Tracking Machine at University of Baghdad [13]

6.1. Preparation specimens using Roller compactor

The preparation of slabs began from heating asphalt mixture to (150˚C) then papers were placed inside the mold after covering the internal surfaces of the mold with a layer of oil. At the same time, the mold of Roller Compactor was heated for casting the mixture in, the spatula was used for leveling the mixture. There are two options for compacting the slab specimen either compacting to a target density or to target height. Slabs specimens were compacted, and left to cool for (24) hours in the mold and them extraction from molds. Figure 8 presents a group of wheel tracking slabs and roller compacted used in this study.

A. presents group of wheel tracking slabs

B. Dyna-Compact Roller compaction machine

Figure 8. Group of wheel tracking slabs and roller compacted.

7. Results and Discussions

7.1. Marshall Test

A series of tests of Marshall stability, flow, and density-voids analysis was carried out for selecting the optimum asphalt content (OAC) for mixtures by using aggregate (12.5 mm nominal maximum size gradation), seven percent limestone dust (by weight of the total aggregate), and five different asphalt contents for each (40-50) and (60-70) penetration grade ranging from 4 to 6 percent (by weight of total mix) with an increment of 0.5 percent. The three percentages of PPA 1, 2 and 3% added by weight of the binder. The OAC was (4.9) % for conventional AC (40-50) , (4.88) % for modified AC (40-50) with 1% PPA, (4.83) % for modified AC (40-50) with 2% PPA and (4.81) % for modified AC (40-50) with 3% PPA .The OAC for conventional AC 60-70 was (5.1) % , (5) % for modified AC 60-70 with 1% PPA, (4.96) % for modified AC 60-70 with 2% PPA and (4.93) % for modified AC 60-70 with 3% PPA. The results of the tests meet the Iraqi specification requirements of Ismael et al (2014) [8].

The results show that stability was increased by 4.82, 14.45 and 21.65 % compared with conventional mixture AC (40-50) when using modified asphalt AC (40-50) with 1, 2 and 3% PPA respectively. The stability was increased by 2.56, 6.45 and 32.1 % compared with conventional mixture AC (60-70) when using modified asphalt AC (60-70) with 1, 2, 3% PPA respectively with aggregate gradation of SCRB (2003) [9]. Figure 9 presents the effect of PPA on the Marshall Stability.

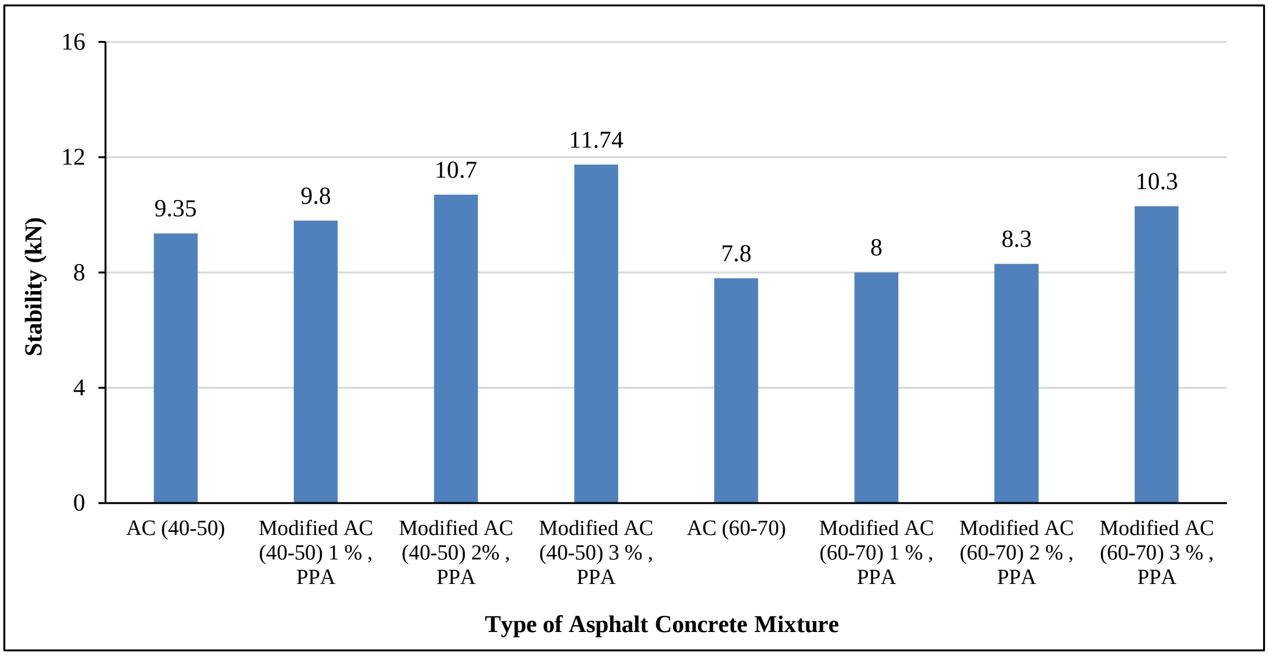

Figure 9. Effect PPA on the Marshall Stability

7.2. Compressive Strength Test

To assessment moisture damage susceptibility by using index of retaining strength according to ASTM D-1074 and D-1075 [10]. The SCRB in 2003 pointed to the acceptable value of the IRS is (70%) or above which obtained as the ratio of compressive strength for conditioned specimens to that of unconditioned specimens. The compressive strength test results revealed that modified asphalt with PPA less susceptible to moisture damage than conventional asphalt.

The results of the IRS at the OAC for modified AC (40-50) with 1, 2 and 3% PPA higher than conventional mixture AC (40-50) by 1.1, 1.45 and 1.75% respectively. The results of the IRS at the OAC for modified AC (60-70) with 1, 2 and 3% PPA higher than conventional mixture AC (60-70) by 1.7, 2.8 and 2.9% respectively. Figures 10 and 11 stated that. The reason attributed to influencing the asphalt-aggregate bond, as water infiltrate to the mixtures and consequently, permission the aggregate without a film of asphalt. Producing stripping to the aggregate and the better viscosity which gave better coating of aggregates may be explained by the hardened binder contained in modified mixtures which lead to more water resistance.

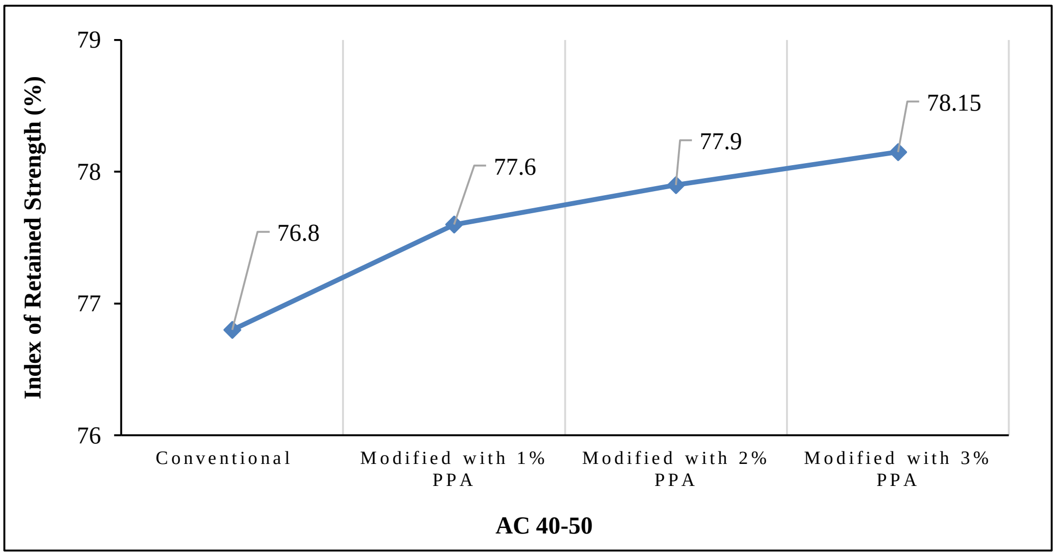

Figure 10. Index of Retained Strength Test Results for Conventional and Modified AC (40-50)

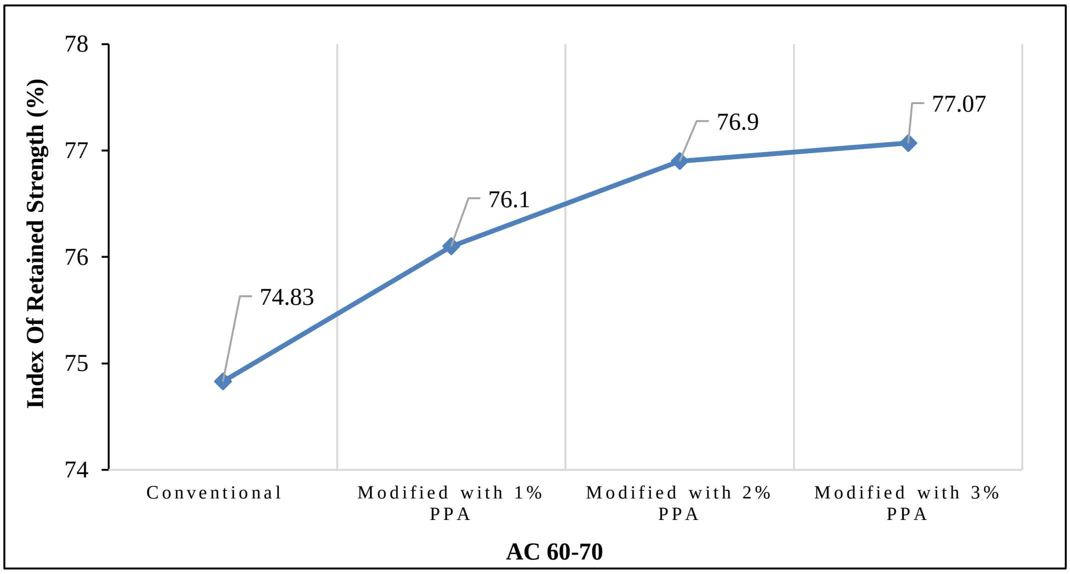

Figure 11. Index of Retained Strength Test Results for Conventional and Modified AC (60-70)

7.3. Wheel Tracking Test

Figure 12 shows that conventional mixture AC (40-50) failed to complete the10000 cycles and stop on level 6500 cycles recording rut depth of 22.12 mm while the modified mixtures AC (40-50) with 1,2 and 3 % PPA recorded rut depth (21.92, 22.01and 22.87) mm at (7000, 7500 and 8000) cycles at 55 ˚C .

Figure 13 shows the rut depth was decreased by 1.3.88, 12.85 and 25.65 % compared with conventional mixture AC (40-50) when using modified asphalt AC (40-50) with 1, 2 and 3% PPA respectively at level 10000 cycles at 45 ˚C.

At temperature 55 ˚C the conventional mixture of AC (60-70) does not exceed 4500 cycles and recorded rut depth 21.76 mm while the modified mixtures AC (60-70) with 1, 2 and 3 % PPA recorded rut depth (21.76, 22.12 and 23.1) mm at (5500, 6000 and 6500) cycles at 55 ˚C, on the other hand the modified asphalt needed more cycles than conventional mixtures to failure, figure 14 stated that.

Figure 15 shows the rut depth was decreased by 9.93, 24.65 and 33.9 % compared with conventional mixture AC (60-70) when using modified asphalt AC (60-70) with 1, 2 and 3% PPA respectively at 10000 cycles at 45 ˚C. This agree with [2] stated that modified mix with 3% PPA has rut depth less than conventional mixture.

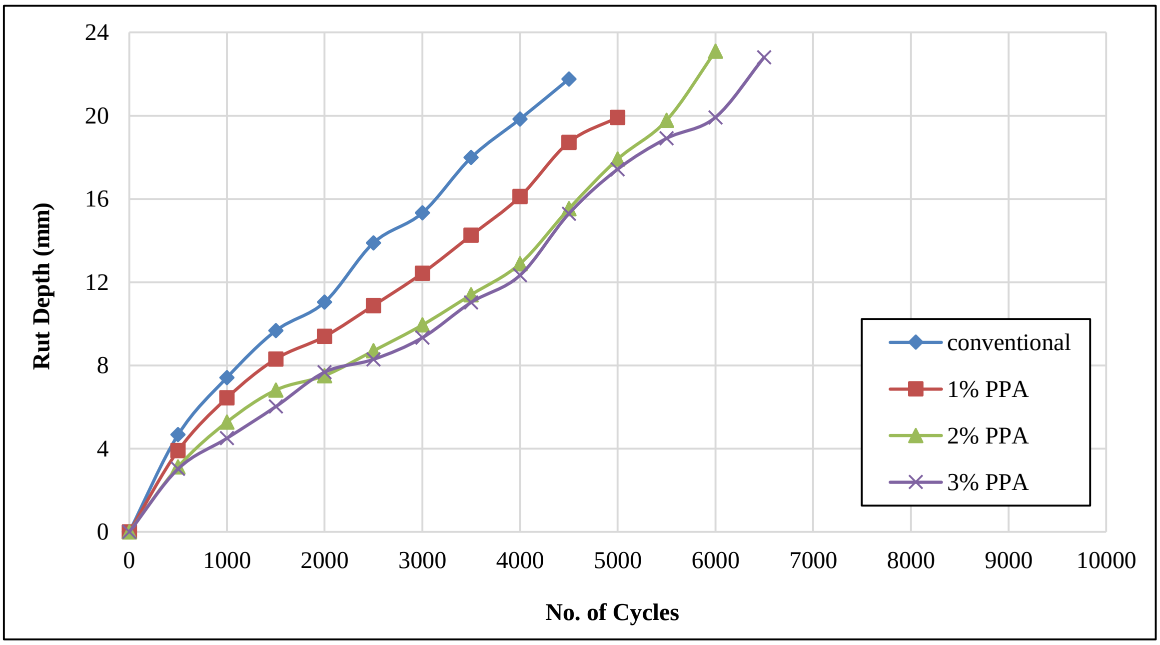

Figure 12. Effect of PPA on Rut Depth (AC 40-50, 55 ˚C)

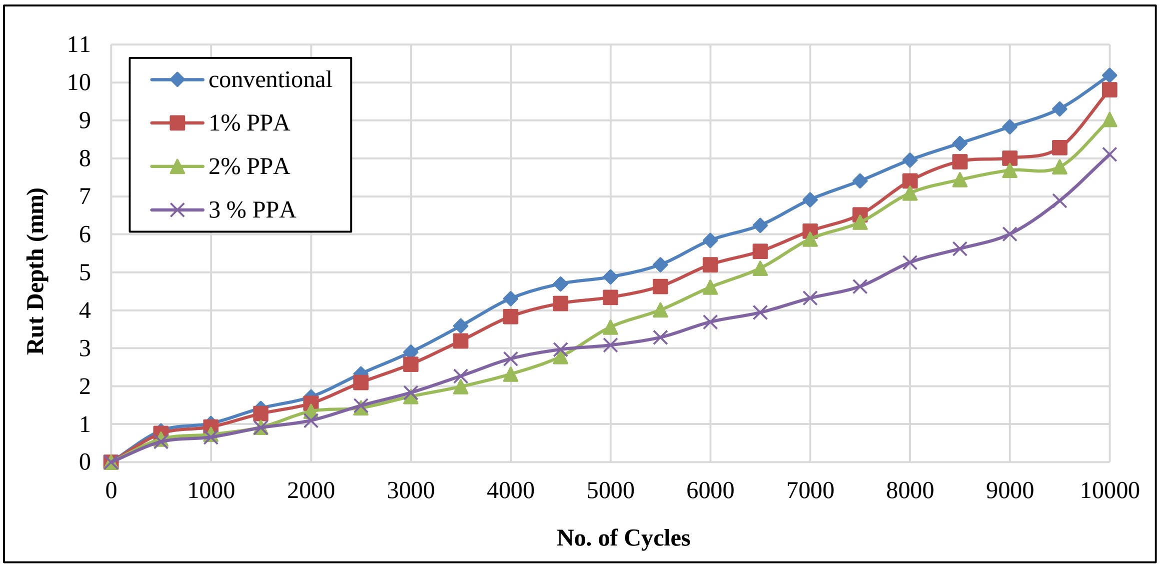

Figure 13. Effect of PPA on Rut Depth (AC 40-50, 45 ˚C)

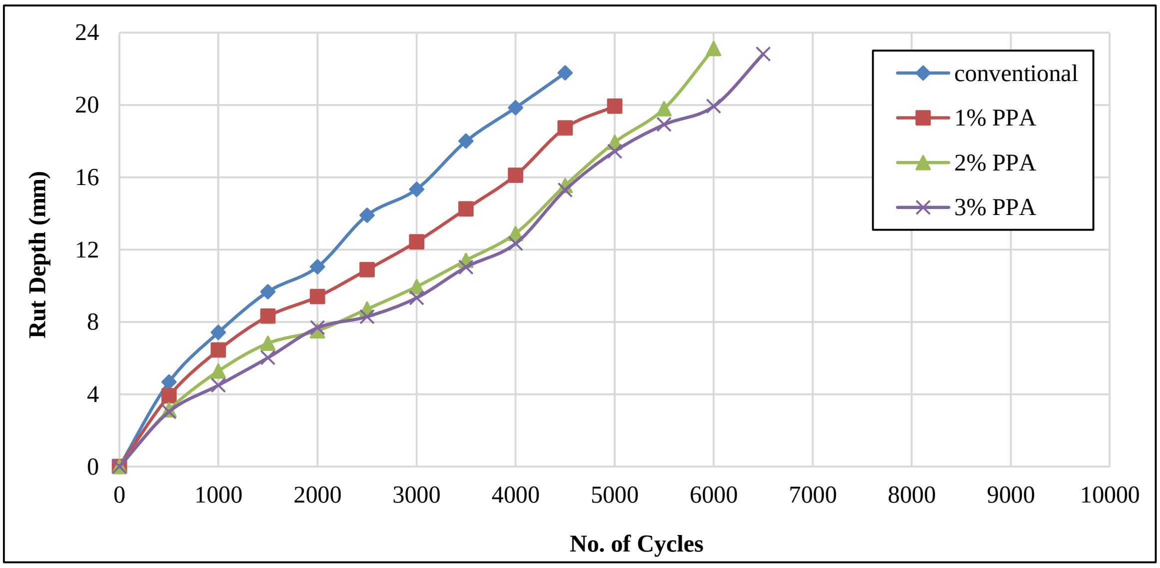

Figure 14. Effect of PPA on Rut Depth (AC 60-70, 55 ˚C)

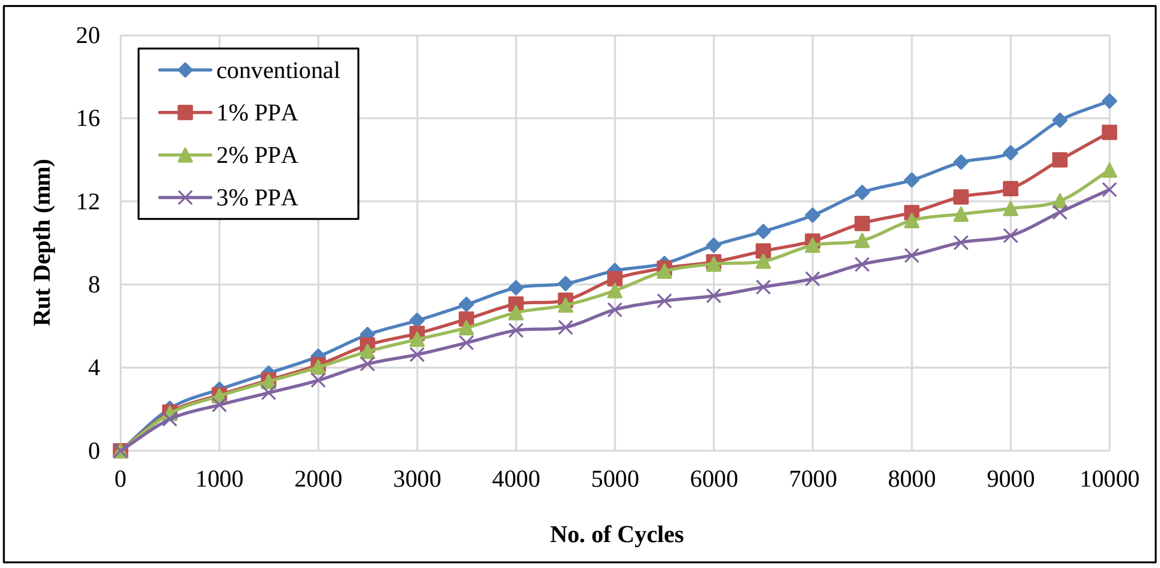

Figure 15. Effect of PPA on Rut Depth (AC 60-70, 45 ˚C)

8. Conclusions

- The Optimum Asphalt Content (OAC) for modified asphalt AC (40-50) with 1, 2 and 3% PPA decreased by 0.4, 1.45 and 1.87% compared with (OAC) of conventional asphalt AC (40-50) respectively. The OAC for modified asphalt AC (60-70) with 1, 2 and 3% PPA decreased by 2, 2.82 and 3.45% compared with (OAC) of conventional asphalt AC (60-70) respectively.
- The results of Marshall Stability increased by (4.82 %, 14.45 % and 21.65 %) of modified asphalt AC (40-50) with 1, 2 and 3 % PPA compared with conventional mixtures AC (40-50) respectively. The results of Marshall Stability increased by (2.56, 6.45 and 32.1 %) of modified asphalt AC (60-70) with 1, 2 and 3 % PPA compared with conventional mixtures AC (60-70) respectively.
- The mixture with modified asphalts (1, 2 and 3% PPA) for AC (40-50) have an index of retained strength higher than conventional mixtures at OAC by (1.1%, 1.45% and 1.75%) respectively. The mixture with modified asphalts (1, 2 and 3% PPA) for AC (60-70) have an index of retained strength higher than conventional mixtures at OAC by (1.7%, 2.8% and 2.9%) respectively.
- The results of rut depth of mixed with modified asphalt (1, 2 and 3% PPA) for AC (40-50) reduced by (1.3.88 %, 12.85 % and 25.65 %) compared with conventional mixture AC (40-50) respectively at 10000 cycles at 45 ^{o}C. The results of rut depth of mixed with modified asphalt (1, 2 and 3% PPA) for AC (60-70) reduced by (9.93 %, 24.65 % and 33.9 %) compared with conventional mixture AC (60-70) respectively at 10000 cycles at 45 ^{o}C.
- The results of rut depth of mixed with modified asphalt (1, 2 and 3% PPA) for AC (40-50) reduced by (by 9.89, 17.4 and 33.2 %) compared with conventional mixture AC (40-50) respectively at 4500 cycles at 55 ^{o}C. The results of rut depth of mixed with modified asphalt (1, 2 and 3% PPA) for AC (60-70) reduced by (16.3, 40.1 and 42.3 %) compared with conventional mixture AC (60-70) respectively at 4500 cycles at 55 ^{o}C.
- Effect of PPA on rutting resistance of AC (60-70) higher than AC (40-50).

9. Funding

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10. Conflicts of Interest

The authors declare no conflict of interest.

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