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Evaluating the Properties of Improved Asphalt Material and Hot Mixture Asphalt by Adopting Rotational Viscosity Test and Wheel Track Test

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ABSTRACT

Scientists and engineers are continually attempting to enhance the performance of asphalt pavements by altering the asphalt. Because of their natural compatibility with asphalt cement as well as their exceptional properties, polymers may offer an excellent opportunity for asphalt modification to extend service life and reduce early distress by enhancing the properties of hot-mix asphalt. This study aims to explain how the various polymers influence the properties of hot mix asphalt with a wet procedure using asphalt produced locally at the Al-Durah refinery and various polymers. Styrene-butadiene-styrene (SBS), polytetrafluoroethylene (PTFE), polyvinyl chloride (PVC), and (PVC+SBS) are examples of these polymers. Three and five per cent of the polymer are utilized for SBS, PTFE, and PVC, respectively. The asphalt cement ratio for (SBS+PVC) was 2.5% by weight at various blending times. The polymer asphalt mixtures are evaluated using Wheel Track tests and then compared to the conventional mixture. The modification of bitumen with polymers enhanced its conventional properties, such as viscosity. In addition, it was determined that the mechanical properties of HMA prepared with PMB samples, as measured by wheel track experiments, improved with increasing polymer contents.

Keywords: Asphalt, polymer, viscosity, wheel truck, SBS, PVC, PTEF

INTRODUCTION

A pavement aims to safely, efficiently, and cost-effectively transport vehicles between locations. However, various factors, including material properties, construction quality control, traffic, and the environment, diminish the pavement's initial smoothness over time. This reduced pavement smoothness or serviceability in flexible pavements will ultimately result in pavement failure or intolerable roughness. Permanent deformation (rutting) and fatigue cracking are the most frequent types of load-associated distresses that reduce the serviceability of flexible pavements. Typically, flexible pavement is designed according to axle capacity limits and climate conditions. Many nations, including Iraq, have imposed capacity limits for each kind of axle, which must not be overdone. However, several vehicles exceed these weight limits to reduce transportation costs. These overloaded vehicles cause severe pavement deterioration, shortening life (Salem 2008), (Syahirah et al. 2023).

The increase in road traffic over the past four decades (particularly the last one in Iraq), coupled with inadequate maintenance, has accelerated the deterioration of road structures in several nations. Special binders are urgently needed to improve the performance-related features of asphalt layers, such as resistance to permanent, low-temperature cracking, load-associated fatigue, wear, stripping, and ageing, in order to prevent deterioration and increase the long-term durability of flexible pavement (Lu & Isacsson 1997). Polymer-modified asphalt (PMA) has been used to improve pavement performance for a very long period. The enhanced functional properties are permanent deformation, fatigue, low-temperature fracture, stripping, and ageing (Raad et al. 1996).

The majority of the research shows that the qualities of PMA are affected by polymer features, polymer content, bitumen nature, and compounding technique. Despite the enormous number of polymeric goods available, there are only a few that are suitable for bitumen modification when utilized as bitumen modifiers. Selected polymers must be compatible with bitumen, processable with standard mixing and laying equipment, and retain their premium qualities during blending, storage, and service application. Furthermore, the usage of a modifier should be sparing. Polymers can be used to modify the asphalt cement's inherent viscoelasticity, thereby altering the optimal temperature range. Elastomers, which increase in strength and flexibility at high temperatures, and plasterers, which increase in strength without elasticity, are the two polymers used for this purpose. Typically, polymer-modified binders have a higher viscosity than unmodified bitumen and a greater adhesion to aggregate particles (Yetkin 2007), (Kurthan & Mustafa 2023).

Hot mix asphalt (HMA) is a mixture of aggregate uniformly combined with asphalt cement. "hot mix" originates from Asphalt cement and is crucial in holding hot mix asphalt pavement (Atkins 1997). When a wheel load is delivered to the pavement, two stresses are imparted to the HMA: vertical tension within the asphalt layer and horizontal stress at the bottom. The (HMA) should be strong to withstand compressive stresses and prevent pavement rutting. In addition, materials must have adequate strength to withstand base layer tensile stresses. In addition, the mixture must resist stresses caused by fluctuating temperatures (Estabraq 2020). Rutting is one of the most significant distresses that affect pavement performance. When permanent deformation occurs, the pavement's service life will be shortened, which may pose grave threats to highway users by changing vehicle handling characteristics. Two primary factors contribute to the deterioration of asphalt pavement: vehicle traffic and the slow impacts of weathering (Huang 2004), (Aioub & Gabriel 2023).

Abed and Al-Azzawi (2012) listed the most frequent errors made when designing HMA mixtures as follows: asphalt content, properties of filler material, the shape of coarse and fine aggregates, percentage of air voids, the texture of coarse aggregate, gradation of aggregate, asphalt performance grade, and finally aggregate size. Asphalt concentration in excess is possibly the most significant element contributing to irreversible deformation (Abed & Al-Azzawi 2012).

Zou et al. (2017) and Al-Humeidawi (2016) contend that pavement rutting is influenced by three primary factors: environmental conditions, traffic conditions, and pavement materials and design. In environmental conditions, the degree of temperature significantly impacts pavement deformation, as an increase in temperature increases the likelihood of pavement rutting. Increasing the number of wheels with a slow-moving vehicle may increase pavement deformation. The selection of a binder and aggregate is regarded as the most important factor (Zou et al. 2017), (Al-Humeidawi 2016).

The objective of this paper is to evaluate the properties of modified asphalt material and hot mixture asphalt which was used polymers materials as additives by adopting two types of tests. These tests are rotational viscosity test and wheel track test.

HOT MIXTURE ASPHALT MATERIALS

In this study, materials of hot mixture asphalt include coarse aggregates, fine aggregates, asphalt material, and filler. The gradation and properties of materials are same in reference No. 11 because of this study is complementary to the study of reference (Huda et al. 2023).

AGGREGATES

Coarse and fine aggregates were procured from neighboring quarries in Karbala for this study project. Section R9 of the General Specification for Roads and Bridges (SCRB 2003) and the graduation requirements for asphalt layer coarse (SCRB 2003) were used to sort, grade, and sieve the aggregates. Figure 1 depicts the density grade of aggregates with a reasonable size distribution. This investigation's coarse aggregate was angular, white-crushed limestone. Its characteristics were in accordance with the SCRB 2003. The physical parameters of coarse aggregate are shown in Table 1. These findings were obtained by laboratory experiments at the National Center for Laboratories and Research. Crushed sand and natural sand, both of which include less than 25% natural sand, were employed as fine aggregate in this investigation. Table 2 shows the physical properties of fine aggregate.

ASPHALT CEMENT MATERIAL

Asphalt cement with a penetration grade of (40-50) supplied from the Al-Durah oil refinery was employed in this study. The physical properties and tests of the asphalt cement used are outlined in Table 3, and they were compared to Iraqi highway and bridge specifications.

FILLER MATERIALS

Filler materials are utilized to impart certain properties, complete the skeleton of the mixture, and meet aggregate gradation criteria. Portland cement was used in this study, and its specifications are shown in Table 4. The laboratory evaluation was conducted out at the National Laboratories and Research Center. Filler materials must be free of water and contain no fine particles. They often refer to mineral units that pass sieve No.200.

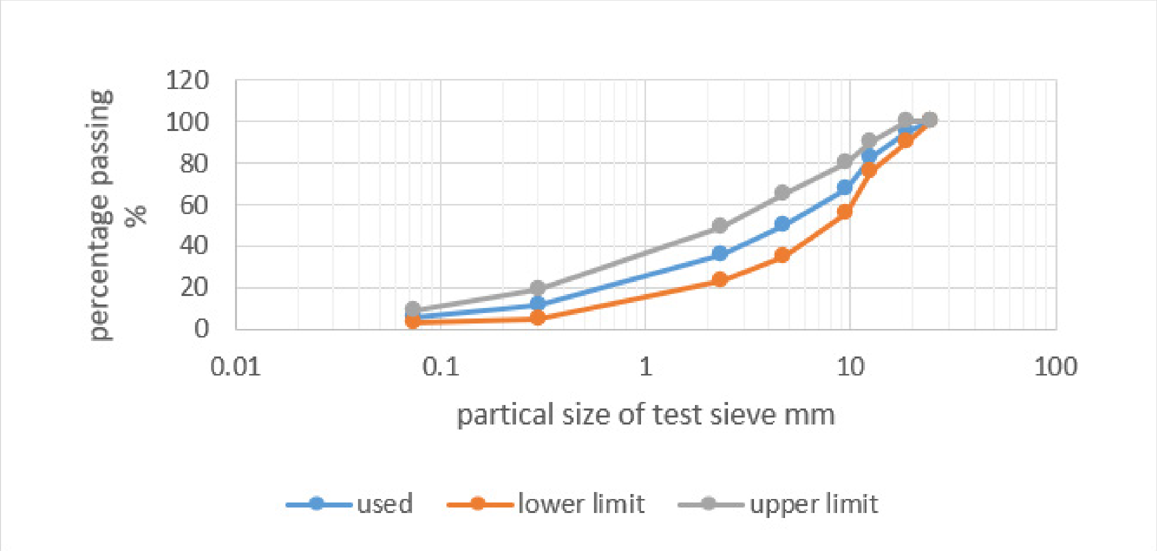


FIGURE 1. Practical size distribution of aggregates gradation

Source: Huda et al. (2023).

TABLE1. Physical properties of coarse aggregate (Huda et al. 2023).

Property	ASTM Designation	Crushed Coarse Aggregate	GSRB Specification, Bbinder Course(
Breakage ratio%	ASTM D 5821-2006	96	Min 90%
Thinning and elongation modulus	ASTM D4791-2005	-	Max 10%
Clay lumps, %	ASTM C142-10	0.069	3%
Mechanical corrosion%	ASTM C131-14	20	Max 35%
Covering and flaking	AASHTO T182-06	Max 95%	Min 95%
Chemical corrosion%	ASTM C88-2013	6	Min 12%
Bulk specific gravity, gm/cm3	C 128ASTM, 2015c	2.696	-

TABLE 2. Fine aggregates' physical characteristics

Property	ASTM	Passing percentage	GSRB Specification
Designation	Passing percentage	GSRB Specification	
Clay lumps, %	ASTM C142-10	1.89	Max 3%
Sand equivalent	ASTM D2419-02	69	Min 45%
Plasticity index	ASTM D4318-05	-	Mix 4%
Organic impurities	ASTM C40-11	-	-

Source: Huda et al. (2023)

TABLE 3. The physical characteristics and testing of the asphalt cement

Property	ASTM	Property	ASTM
Penetration 100 gm. ,25°C-5sec (1/10 mm)	ASTM D5, 2013	42	40-50
Ductility, 25℃, 5 cm/ min, (cm)	ASTM D113, 2018	125	>100
Kinematic viscosity at 135˚C	ASTM D2170, 2010	540	Min 400
Flashpoint, (°C)	ASTM D92, 2009	310	>232
Solubility in trichloroethylene, (%)	ASTM D2042 2015e	99.5	>99

Source: Huda et al. (2023)

TABLE 4. Fillers materials characteristics

Property	ASTM designation	Passing percentage	GSRB Specification
No.30	ASTM D546/2010	100	100
No.50	ASTM D546/2010	100	100-95
No.200	ASTM D546/2010	98	100-70
plasticity index	AASHTO T89-2010	-	Min 4

Source: Huda et al. (2023)

STYRENE-BUTADIENE-STYRENE (SBS) POLYMER

Kraton D1192 E is a clear linear block copolymer of styrene and butadiene with 30% bonded styrene.Two percent, three percent, and five percent by weight of asphalt (SBS) are used.

POLY-TETRA-FLUORO-ETHYLENE (PTFE) POLYMER

Zibo Bainaisi Chemical Co., Ltd. from China provides the polymer. Two percent, three percent, and five percent by weight of asphalt (PTFE) are used.

POLY VINYL CHLORIDE (PVC) POLYMER

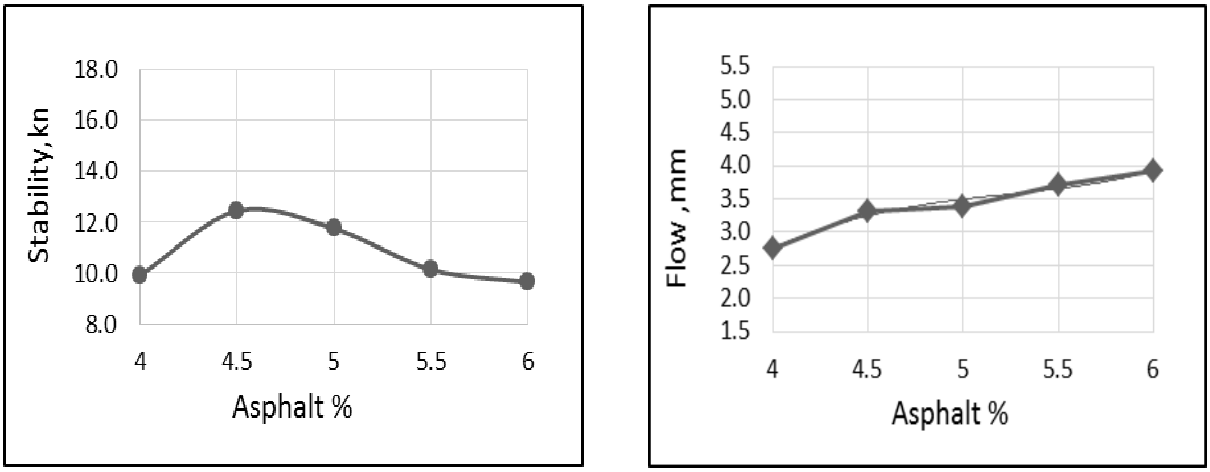
Poly vinyl chloride provided by the Petrochemical Arvand Company is utilized in concentrations of 3% and 5% by weight of asphalt (PVC).

PVC+SBS MIXTURE

The new material is produced by mixing the 2.5 % PVC polymer and 2.5 % SBS polymer.

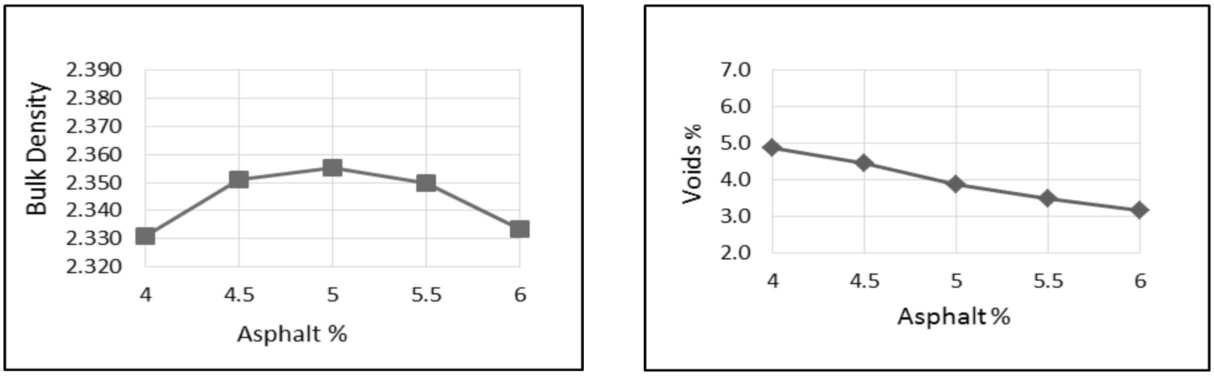
DESIGN AND SAMPLE PREPARATION OF CONTROL HOT MIXTURE ASPHALT

The blend of materials was created using the Marshall Mix design approach. Three samples were prepared for five different asphalt binder contents: 4%, 4.5%, 5%, 5.5%, and 6% by total weight of mixture in order to determine the optimal asphalt binder content (OAC). The Marshall sample preparation procedure begins with placing aggregates and asphalt in an oven until the mixing temperature (165 °C) is reached. After removing the aggregate from the oven and inserting it into the bowl of a mechanical mixer, the appropriate ratio of hot asphalt is applied to the aggregates. After fully blending the aggregate and asphalt, the mixture is placed in a steel mold and compacted using a Marshall hammer with 75 blows on each face or the number required by a specific specification. The specimen is taken from the mold when it has cooled. The ideal asphalt content (4.7%) has been found. The Marshal curves for stability, flow, density, voids, VFA, and VMA are shown in Figure 2.



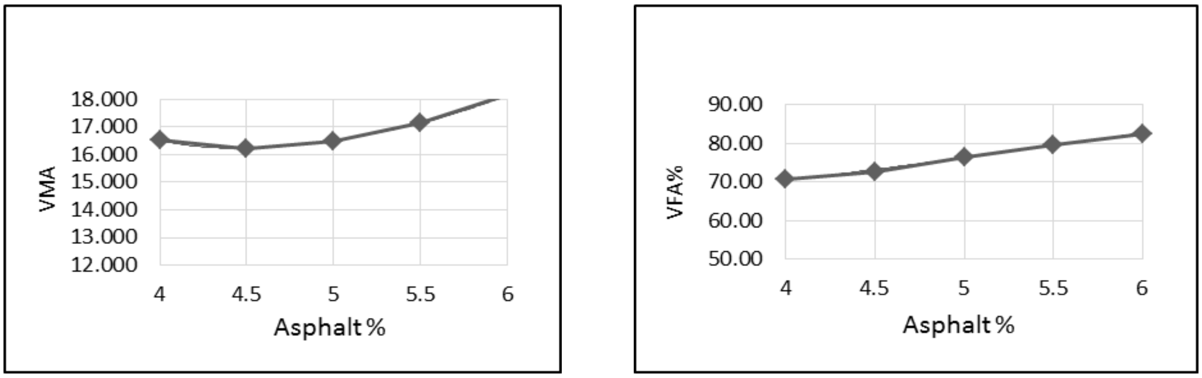
(a) Stability

(b) Flow



(c) Density

(d) Air voids



(e) VMA%

(f) VFA%

FIGURE 2. Marshal test results of control hot mixture asphalt

Source: Huda et al. (2023)

PREPARATION OF POLYMER MODIFIED ASPHALT

Figure 3 illustrates how asphalt was heated to 160 °C in an oven before being added to a mechanical shear mixer which was operated for 60 minutes at a speed of 2,500 rpm and a temperature of 180 °C to obtain the desired homogeneity (Ansar et al. 2022). SBS, PVC, PTFE and PVC+SBS polymers was added gradually to the hot asphalt to prepare the first set of modified binder. Two contents 3% and 5% of SBS, PVC, PTFE and (2.5 % PVC+2.5% SBS) polymers were used in terms of total asphalt binder weight. The finished product was taken from the flask and divided into little containers. The mixture was cooled to room temperature, wrapped in aluminum foil, and stored for future use. The results of asphalt tests were mentioned in reference (Huda et al. 2023). This study will concern on the test of rotational viscosity before and after adding polymers.

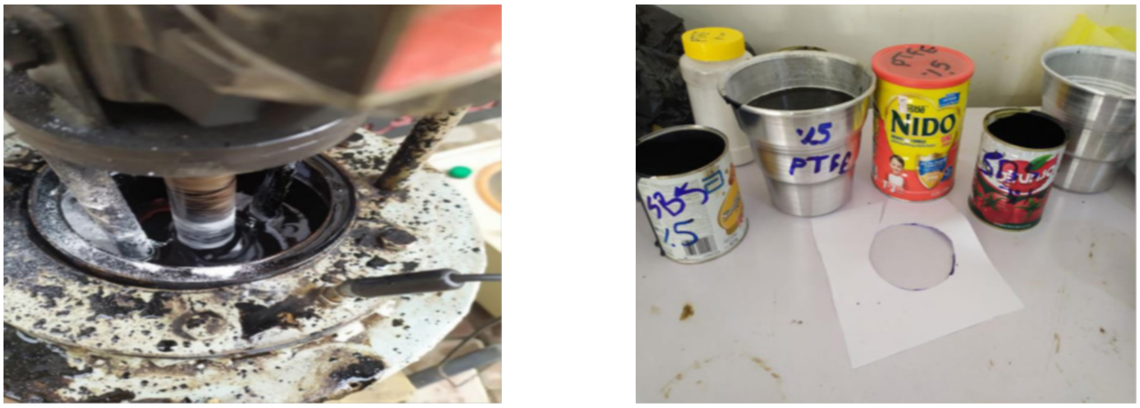


FIGURE 3. Mechanical shear mixer with sample

PREPARATION OF MODIFIED HOT MIXTURE ASPHALT

Marshall design method is used in the preparation of modified hot mixture asphalt to provide the samples of different types of test to evaluate the improved mechanical properties of hot mixture asphalt after mixing different types of polymers with asphalt materials. The results of modified hot mixture asphalt properties after and before mixing the different types of polymers were determined and evaluated in reference (Huda et al. 2023) and this study will concern on the wheel truck test for samples. Figure 4 shows the samples of modified hot mixture asphalt.

FIGURE 4. Some of modified hot mixture asphalt samples

LABORATORY TESTS

In this study, two types of tested will carry out on asphalt material before and after mixing the polymers with asphalt and hot mixture asphalt to evaluate the improving process of their properties. These tests are rotational viscosity test which is used for asphalt material and wheel truck test which is used for hot mixture asphalt.

TEST OF ROTATIONAL VISCOSITY

By following reference (ASTM D4402 2006), the viscosity of the asphalt binder was determined using the Brookfield DV-III rotational viscometer. The purpose of this test was to find the best mix and compaction temperatures for asphalt binders that had not been modified. The mixture viscosity should be 170 20 cP, and the compaction viscosity should be 280± 30 cP, according to reference (ASTM D 6926 2014) The temperature of blending and compaction for unmodified asphalt binder is depicted in Figure 5. Figure 6 shows the rotational viscometer.

This test is utilized to determine the bitumen's viscosity at application temperatures. Figures 7, 8 and 9 illustrate the relationship between viscosity and temperature for unmodified and modified bitumen. The viscosity values decreased with increasing test temperature, but asphalt modified with various ratios of modifiers has a higher viscosity than the viscosity of control asphalt. The numbers indicate viscosity decreases as temperature rises, and the chart parameters could indicate the impact of the modification. The rotational viscometer evaluates the pumping ability of asphalt binders during transport and plant operations by measuring their rheological properties. In addition, this test was used to calculate the optimal temperature varieties for selecting blending and compaction temperatures. Rotational viscosity measurements are more precise at higher torque readings of cylinder-shaped spindle No.27 immersed in bitumen and maintained at a constant temperature in a Temperature Controller.

The asphalt modified with various ratios of modifiers has a higher viscosity than the viscosity of control asphalt due to forming a polymer network; the bond between bitumen molecules is strengthened and increases asphalt stiffness and durability, and the asphalt's viscosity increases.

Figure 7 illustrates the impact of SBS on asphalt viscosity. The asphalt binders modified with 3% and 5% SBS polymer exhibit an increase in viscosity compared to the control; the result of viscosities demonstrates the effect of the used SBS polymer on the mixture. It increases the mixture's hardness and enhances pure bitumen's temperature change sensitivity. These outcomes are identical to the reference (Ahmedzade 2013).

Figure 8 displays the ratio of 3% to 5% for the rotary viscosity value of PVC. The addition of PVC will increase the mixture's rotational viscosity. The increase in viscosity also affects mixing and compaction temperatures, reducing workability (Köfteci et al 2014). This result is compatible with the reference (Nguyen wt al 2021). The same applies to the (SBS+PVC) mixture, where the viscosity increased compared to the control mixture. This result is compatible with the reference (Estabraq 2020).

A figure 9 displays the viscosity results of PTFE modification. The asphalt binders modified with 3% and 5% PTFE exhibit an increase in viscosity compared to the control mixture, particularly at high temperatures, which is desirable for resisting permanent deformation at high temperatures. This result is consistent with the reference No.19.

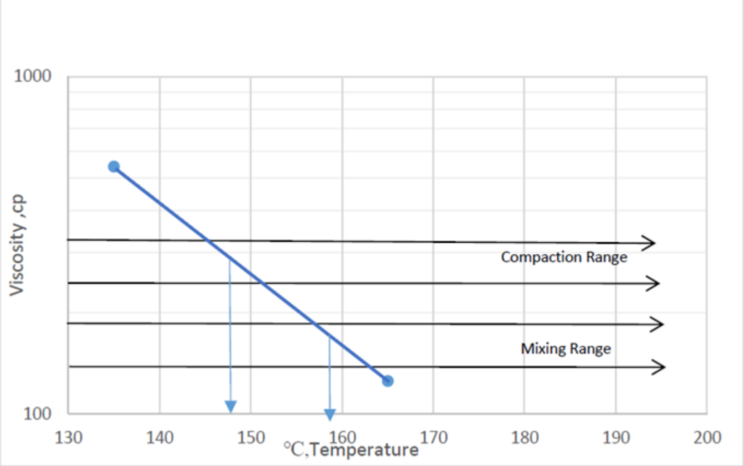


FIGURE 5. Temperature – viscosity Relationship for neat asphalt cement

FIGURE 6. Rotational viscometer

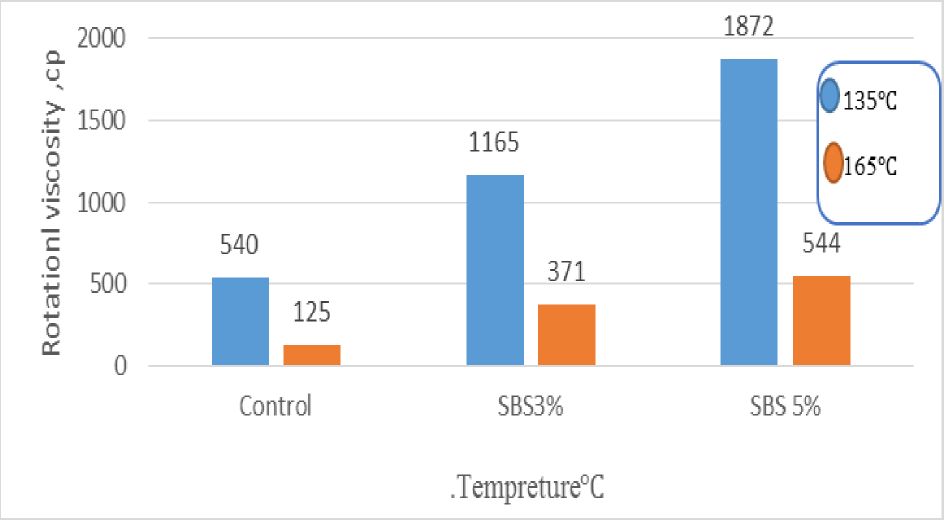


FIGURE 7. Rotational viscosities to temperature for unmodified and modified asphalt binder with SBS

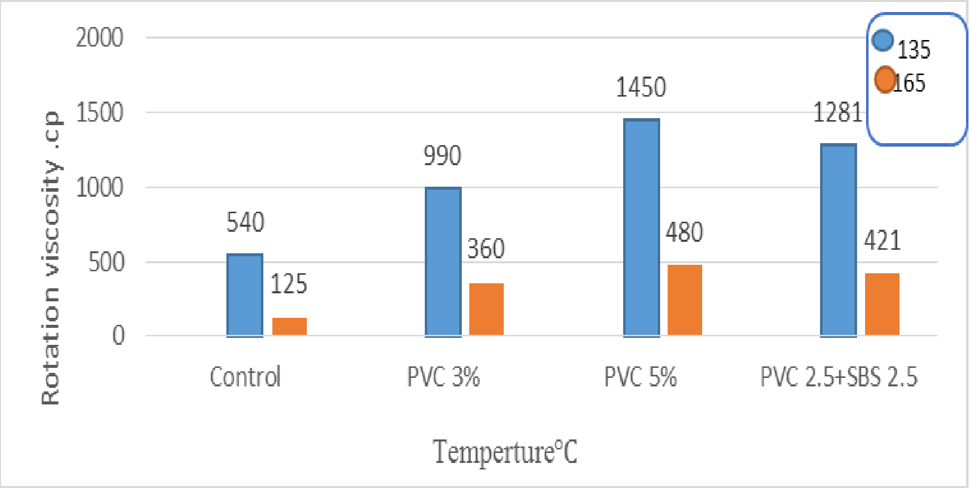


FIGURE 8. Rotational viscosity to temperature for unmodified and modified asphalt binder with PVC and (PVC+SBS) mixing

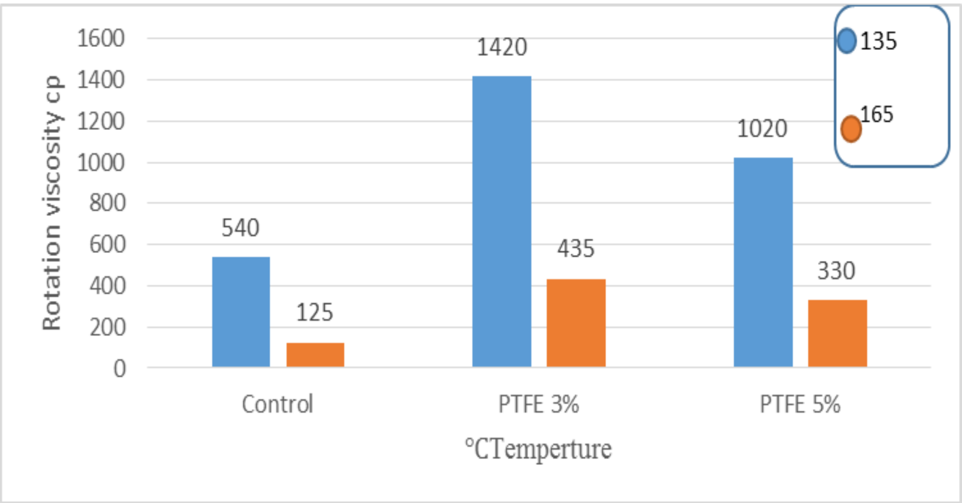


FIGURE 9. Rotational vviscosity to temperature for unmodified and modified asphalt binder with PTFE

WHEEL TRACK TEST

As previously stated, the asphalt binder has viscoelastic qualities, which means it will deform when traffic loads are applied to the pavement surface. After the load is removed, a portion of the deformation will be recovered, while a small portion will remain. This deformation accumulates over time to produce the rutting phenomenon. Before compacting the slab with the roller compactor machine, the mass of the bituminous mixture is heated to the requisite mixing temperature in an oven. Then, binder and aggregates are combined as rapidly and thoroughly as possible to create an asphalt mixture with a uniform binder distribution. The mixture is stirred every thirty minutes to ensure homogenous ageing. The 400 mm, 300 mm 60 mm mould is heated to a limited compaction temperature to ensure the mixture's temperature does not decrease. Compaction is performed at the National Laboratory Center - Baghdad in this research using a Matest asphalt roller compactor with reference (Ansar et al 2022)).

The bituminous mixture is pushed via a steel roller with a big enough diameter to run on the vertically mounted sliding plates on top of the mould. After compaction, the slab is allowed to cool at room temperature for twenty-four hours so that it does not deform during handling. Following the preparation of the asphalt concrete slab, it is put on a plate that moves back and forth under a load of 70 kg (700 N) applied by a load wheel at touch points and passes over the slab for up to 10,000 cycles at a load rate of (26.5 1 cycle per minute). Each group of passes' rut depth is measured by stopping the machine and documenting the dial gauge's reading. The test is terminated when 10,000 load cycles are completed, or the maximum allowable deformation of 25 millimeters is attained. Figure 10 shows the wheel track machine. Figure 11 shows the device used to compaction samples before the test.

Figures 12, 13, 14 show the rutting depth results. The graphs show the association between rut depth in millimeters and cycle count. When additives were used, the rut depth increased as the number of cycles grew and dropped as the number of cycles decreased. For the types of mixtures that provide a clear indication of the influence of polymers on the performance (rut depth) of mixtures, the modified asphalt mixtures had a higher permanent deformation resistance compared to the control mixtures. The kind, physical qualities, and concentration of the modifier all have an impact on the rutting resistance of improved mixes.

The increase in SBS concentration reduces rutting depth by 55.38 and 58.97 percent, respectively. SBS creates a rubber-elastic network between the polymer and the bitumen, considerably improving hot mix asphalt's resistance to permanent deformation. This network raises the complex modulus, which indicates rutting resistance and provides good elastic properties to the modified bitumen. The identical discovery was made by reference (Singh et al 2013).

In Figure 13, utilizing PTFE also improves permanent deformation resistance by 41.03 and 48.52. In addition, The adding of PTFE to the asphalt will improves its viscosity. As viscosity increases, so does cohesiveness and stability; as a result, asphalt pavement in hot areas is more resistant to rutting than unmodified asphalt mixtures.

Figures 15 show that the rutting depth is reduced by 33.39 and 39.47 percent, respectively. This is due to the incorporation of a polymer network and the spatial placement of the atoms surrounding the C-Cl and C-H chains in the chemical structure of PVC, which boosts the rutting resistance of the asphalt mixture. Furthermore, PVC reduces the quantity of air voids in the mixture, making the pavement more stable under the effect of applied loads. As a result, the changed pavement is more resistant to persistent deformation than the unmodified pavement.A similar discovery was reported in reference (Nguyen wt al 2021). The composition (PVC+SBS) revealed a lower rut depth reduction ratio of 13.57% as compared to other polymers. Reduced rut depth often results in less water aggregation on the pavement surface, enhancing highway safety and lowering maintenance costs during the pavement's service life by reducing the amount of damage caused by moisture.

FIGURE 10. Wheel track machine

FIGURE 11. The device used to compaction samples before the test

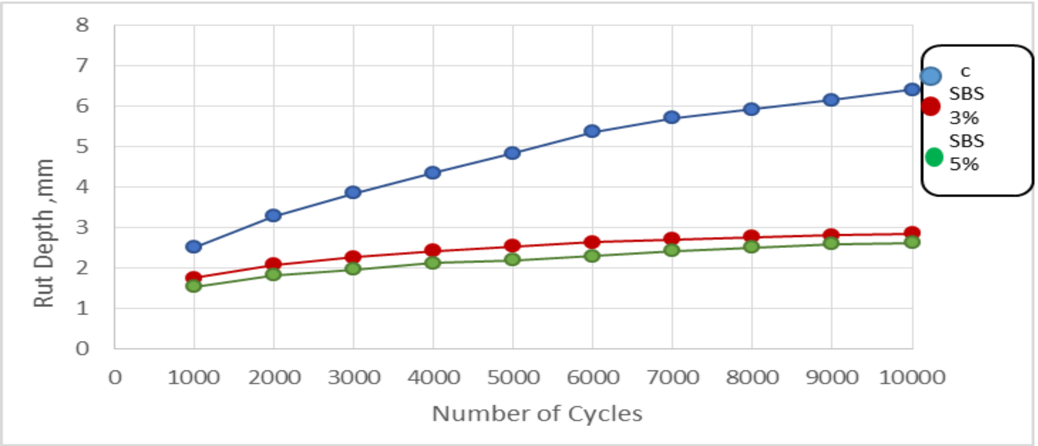


FIGURE 12. The influence of SBS on Rut Depth

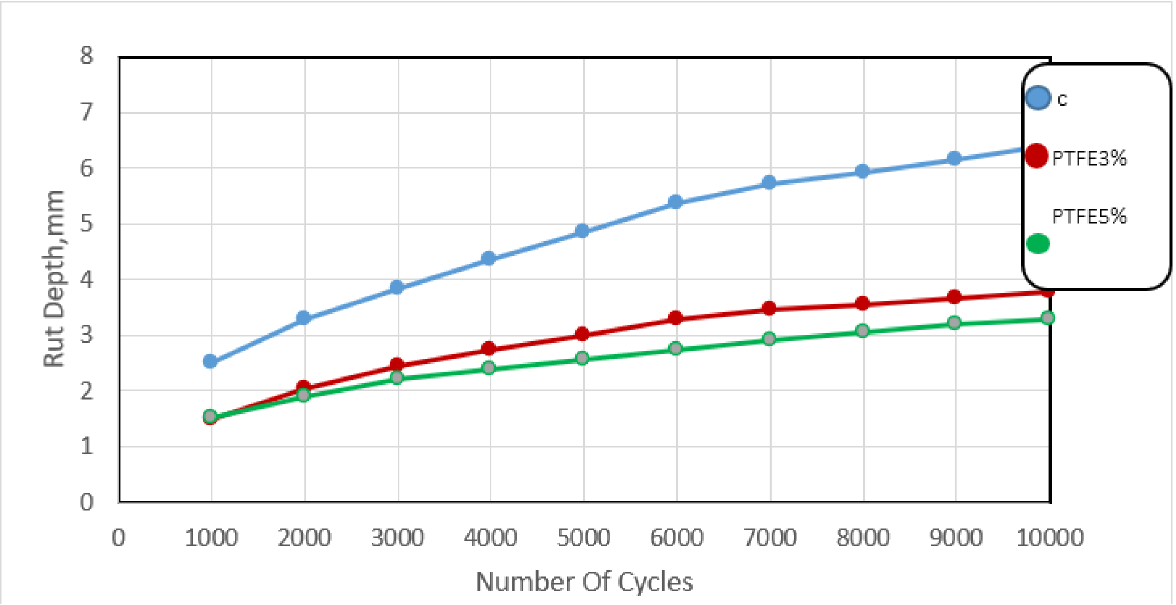


FIGURE 13. The influence of PTFE on rutting depth

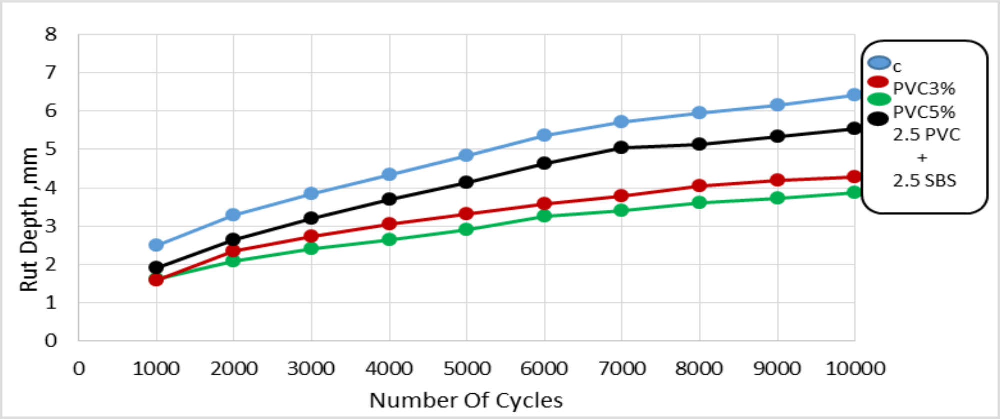


FIGURE 14. The influence of PVC and (PVC+SBS) on rutting depth

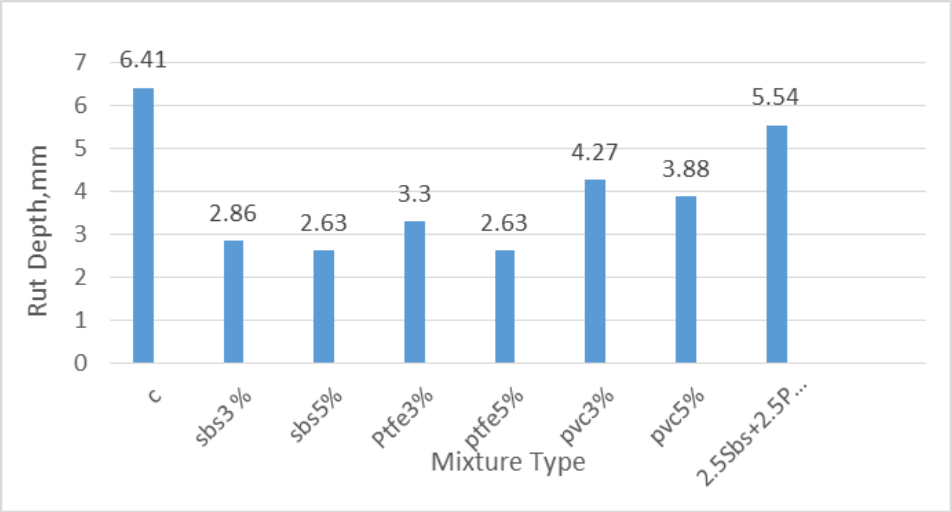


FIGURE 15. Effect of Polymer Modifiers on Rutting at 10000 Cycles

CONCLUSION

1. Adding SBS to the asphalt binder increasing viscosity. It increases the mixture's hardness and enhances pure bitumen's temperature change sensitivity.
2. Rut resistance increases as the percentage of SBS increases, as rut depth decreases by 55.38 and 58.97%.
3. The asphalt binders modified with 3% and 5% PTFE exhibit an increase in viscosity compared to the control mixture.
4. The resistance to permanent deformation is enhanced by 56.63 and 48.52 percent for mixtures containing 3 and 5 percent PTFE, respectively.
5. The addition of PVC will increase the mixture's rotational viscosity. The increase in viscosity also affects mixing and compaction temperatures, reducing workability.
6. The rutting depth is reduced by 33.39 and 39.49% for every percentage increase in PVC content.
7. The comprising of PVC and SBS collectively results in a slight change in the properties of the asphalt mixture indicated that the viscosity increased compared to the control mixture, and when collective modifiers are applied, the resistance to permanent deformation improves slightly as the rut depth decreases by 13.57 percent.

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DECLARATION OF COMPETING INTEREST

None

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