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EFFECT OF PG 76-10 POLYMER-MODIFIED ASPHALT ON CRACKING AND MOISTURE RESISTANCE IN PAVEMENT STRUCTURAL LAYERS

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ABSTRACT

Three kinds of asphalt were used in this study: conventional 40/50 asphalt, PG 76V-10, and PG 76E-10 modified asphalt to investigate the effect of modified asphalt on the performance of asphalt mixtures in binder and surface layers. The performance of the mixtures was assessed through tests measuring mixture stability, flow, moisture resistance, and crack resistance. The modified mixtures showed a decrease in optimal asphalt content (OAC), indicating improved aggregate coating and compaction. Mixtures containing polymer-modified asphalt—specifically PG 76E-10—achieved higher stability and density, lower flow and void ratio, and significantly improved resistance to moisture damage compared to conventional mixtures. Mixtures modified with PG 76E-10 also recorded the highest CT index (Crack Tolerance Index) values, indicating excellent resistance to cracking from repeated loading or thermal changes. The PG 76V-10 mixtures showed improved performance compared to conventional asphalt, but PG 76E-10 showed more pronounced improvements in most properties, especially in enhancing internal cohesion and reducing permeability. These results emphasize the importance of using polymer-modified asphalt in both layers to achieve better paving performance and emphasize the need for careful selection of the type of modified asphalt according to the function of the layer and the expected service conditions.

KEYWORDS

Modified asphalt, Marshall test, TSR, CT index, Pavement performance, Surface and binder layers.

1. INTRODUCTION

Asphalt paving mixes are subject to different types of damage through its service life. These stresses are produced by load (heavy traffic), poor asphalt characteristics, weathering (temperature, humidity, rain) and poor mix designs (Akinleye et al., 2021). Several of these serious disruptions comprise permanent deformation, erosion, fatigue cracking, and cracking that can eventually lead to complete failure of the roadway (Shaikh et al., 2022).In high-temperature regions such as Iraq, permanent deformation reduces driver comfort. It increases the potential for accidents, while fatigue cracking is exacerbated on roads with high traffic volumes, reducing the service life of the road and increasing the costs associated with regular maintenance.

From this point, the pavement design has undergone a series of improvements in the asphalt mixtures design, most notably the Performance Grade asphalt system, which is depend on the physical and thermal characteristics of asphalt instead of the conventional viscosity and penetration indexes. This system selects an asphalt type suitable for climatic conditions and frequent traffic loads to ensure long-term performance and minimize premature pavement failure(Budziński et al., 2023). The Performance-graded system considers the effective temperatures to which the pavement is exposed and addresses the main challenges pavements face, namely fatigue cracking, thermal cracking, and rutting. Some countries have started developing their special climate zones to select the appropriate PG for their specific conditions(Wahhab et al., 1997).

As environmental and traffic challenges have increased, additives have improved asphalt binder properties. polymers are one of the best shared techniques to increase performance of asphalt mixtures. SBS (styrene-butadiene-styrene) is one of the most popular polymers in asphalt modification, as it adds improved elastic properties to the asphalt binder and enhances its performance in harsh climatic and traffic conditions followed by reclaimed tire rubber (Becker, Mendez and Rodriguez, 2001). SBS-modified mixtures were shown to have lower moisture susceptibility than conventional mixtures and improved Marshall properties and temperature susceptibility(Awanti, Amarnath and Veeraragavan, 2008). Polymers' physical and chemical characteristics based on the nature of the individual molecular units, their number in every polymer chain, and their composition with other molecular kinds(Mark, 2009).

Although polymer-modified asphalt binders are widely used around the world, their adoption in Iraq is still limited. Most of the local research has relied on modifying conventional asphalt in the laboratory by adding different polymers to improve its properties.

A study by (Abbas and Al Mosawe, 2021)showed that the usage of SBS-modified binder reduces the effect of aggregate gradation deviation and maintains the mixture's stability, indicating the polymer's ability to enhance the mixture's structural cohesion. (Al-Nawasir and Al-Humeidawi, 2023) also provided a qualitative evaluation of the SBS-modified binder using penetration, softening point, and rotational viscosity tests. The findings indicated that penetration had reduced and softening point and viscosity had increased, which indicated improved thermal and mechanical properties of the binder. According to another study(Hussien, Eweed and Ibrahim, 2025), when 4% of the binder is added, the hardness of the binder is enhanced, and the performance of the mix is also improved in terms of Marshall and indirect tensile tests, which enhance the resistance of the pavement to heavy traffic and hot temperatures. In addition, the use of SBS polymer with recycled asphalt mixtures has proven effective in improving moisture resistance and reducing rutting depth(Joni, Hussein and Yawar, 2019).

This is of particular significance in the case of Iraq, as the pavements are subjected to very high temperatures, which may go up to 70-80°C in the summer. The fact that there are many heavy trucks that have the high axle loads makes the situation more demanding. Besides this, there are additional thermal stresses, which can induce premature cracking due to the drastic day-to-night variation in temperature. In this combination of factors, it is necessary to utilize modified asphalt binders to obtain a higher level of pavement work and increased service life. However, modification is not without disadvantages, as gaps during storage or application, or if not handled properly, can lead to poor pavement performance(Yildirim, 2007).

In this study, two performance-graded asphalt modified with SBS polymer, PG76V-10 and PG76E-10, were used in addition to conventional asphalt graded at 40/50 penetration. The number (76) refers to the maximum temperature that asphalt binder is designed to resist without losing its structural properties. In contrast, the number (-10) refers to the lowest temperature asphalt can withstand without cracking(AASHTO M320). The performance system also includes additional symbols that indicate the expected level of traffic that the pavement will be subjected to during its design service life. For example, the V Symbol indicates high-traffic roads. The E Symbol is used when the pavement is subjected to repeated heavy loads at low speeds, such as in parking lots or port entrances(ASTM D8239).

Accordingly, the present study aims to investigate the impact of three asphalt types on the mechanical performance of asphalt mixture through Marshall, the Tensile Strength Ratio (TSR) and the Indirect Tensile Cracking (ITCT) tests, with focus on the performance across both pavement layers (binder and surface) and recommend optimal asphalt selection under high temperatures and heavy traffic conditions.

2. METHODOLOGY

2.1. Materials Used

2.1.1. Asphalt Binder

Conventional asphalt (40/50): Supplied from Al-Doura refinery in Baghdad. This type is commonly used in standard road construction due to its medium penetration grade, making it suitable for binder courses under moderate climatic conditions. Tables 1 present the physical characteristics of the 40/50 asphalt.

Polymer Modified Asphalt (PG 76-10): Two types of high-performance polymer-modified asphalt obtained from Al-Suhool Company:

- PG 76V-10: Designed to resist deformation and creep under high traffic loads.
- PG 76E-10: Optimized to resist deformation due to loads and moisture damage due to its superior flexibility. Tables 2 present the physical characteristics of the PG 76V-10 and PG76E-10 asphalt.

Table .1 The properties of the 40/50 Asphalt

Property	Test Method	Specification Limit	Result
Penetration (25°C, 100g, 5s)(0.1mm)	ASTM D5	40-50	49
Softening Point (Ring & Ball) °C	ASTM D36	52-62	54
Kinematic Viscosity (135°C) cSt	ASTM D2170	≥ 400	480

Table .2 The properties of the PG 76V-10 and PG76E-10 Asphalt

Property	Test Method	PG76V-10		PG76E-10	
		Specification Limit	Result	Specification Limit	Result
Penetration (25°C, 100g, 5s)(0.1mm)	ASTM D5	25-55	36	25-55	31
Softening Point (Ring & Ball) °C	ASTM D36	65 min	71.9	Limit not specified	82.8
Viscosity Rotational at 135°C,Pa.s		3.0 max	1.816	3.0 max	2.713
Dynamic shear, G*/ sinδ at 10 rad/s, at76°C., kPa	ASTM D7175	1.0 min	3.16	1.0	3.64

The amount of the SBS polymer content is considered to be proprietary information and not disclosed, but it plays a important part in enhancing performance of pavements, particularly in situations of high traffic and adverse environmental factors. The supplier provided the physical properties of each type of asphalt and confirmed their conformity to the requirements of the Iraqi General Specifications for Roads and Bridges (SORB/R9, 2003).

2.1.2. Aggregate

This was obtained from a local source and divided into coarse aggregate, fine aggregate, and filler (standard Portland cement was utilized as filler). The gradation of aggregates was designed according to (SORB/R9, 2003) specifications for both binder and surface layers. The gradation for the mixes is shown in Table 3. All aggregate characteristics were evaluated to ensure suitability for use in hot mix asphalt.

Table 3 The Gradation for the mixtures

Sieve size	mm	Binder Layer		Surface Layer	
		(%Passing by Weight of Total Aggregate + Filler)			
		Sp. limits	Gradation	Sp. limits	Gradation
1	25.0	100			
3/4	19.0	90 - 100	100	100	
1/2	12.5	70 - 90	80	90 - 100	95
3/8	9.5	56 - 80	68	76 - 90	83
No. 4	4.75	35 - 65	50	44 - 74	59
No. 8	2.36	23 - 49	36	28 - 58	43
No. 50	300 µm	5 - 19	12	5 - 21	13
No. 200	75 µm	3 - 9	5	4 - 10	5

2.2. EXPERIMENAL WORK:

2.2.1. Asphalt concrete mix design:

Asphalt concrete mix design using Marshall Technique, which is the standard technique used in the design of hot mix asphalt, and is used during road construction to check the quality(Ali and Ismael, 2021). The Asphalt Mixture was designed according to (ASTM D1559)by mixing the components (aggregate, filler, and asphalt cement) and determining the optimum asphalt content, different asphalt percentages ranging from 4.3% to 5.5% were used, with regular increments of 0.3% for each type of asphalt for both the binder and surface layers. Three samples were prepared for each percentage of asphalt in accordance with the standard preparation procedures.

Upon evaluation of every experimental mix, volumetric and mechanical properties, the optimum asphalt ratio was established depending on the highest stability values, acceptable flow values, necessary air void ratio, and suitable VMA and VFA values Fig. 1.

Fig. 1. Marshall specimen preparation and testing process

2.2.2. Indirect Tensile Strength Ratio Test:

The moisture susceptibility of asphalt mixtures was evaluated through the Indirect Tensile Strength Ratio (TSR) test performed by (AASHTO T283). Where moisture is one of the most common causes of damage to asphalt mixtures, the presence of water weakens the adhesion between the asphalt binder and the aggregate at the contact surface, causing separation between the asphalt and the aggregate and reducing the mixture's strength(Eltwati et al., 2024). Three sets of samples were prepared at the optimum asphalt content for each binder type, for two different layers with 7% air voids. Each set contained six samples that were divided into:

- Three samples from the unconditional group (dry) were left at room temperature for 24 hours before testing and then at 25°C.

-Three samples from the conditional group (wet) were saturated with water using a vacuum device, then wrapped in plastic bags and placed in the freezer at -18°C for 16 hours. Then, they were placed in a water bath at 60°C for 24 hours and tested at 25°C.

The TSR value is calculated as a percentage of the average tensile strength of wet and dry samples. The minimum acceptable TSR value is 80% and is obtained according to the following equations:

Tensile Strength Ratio (TSR) = $\frac{\mathrm{ITSw}}{\mathrm{ITSd}}$

Where:

ITSw : indirect tensile strength of wet specimens .

ITSd : indirect tensile strength of dry specimens .

$ITS = \frac{2000\ \mathrm{P}}{\pi\ \mathrm{t}\ \mathrm{D}}$

Where:

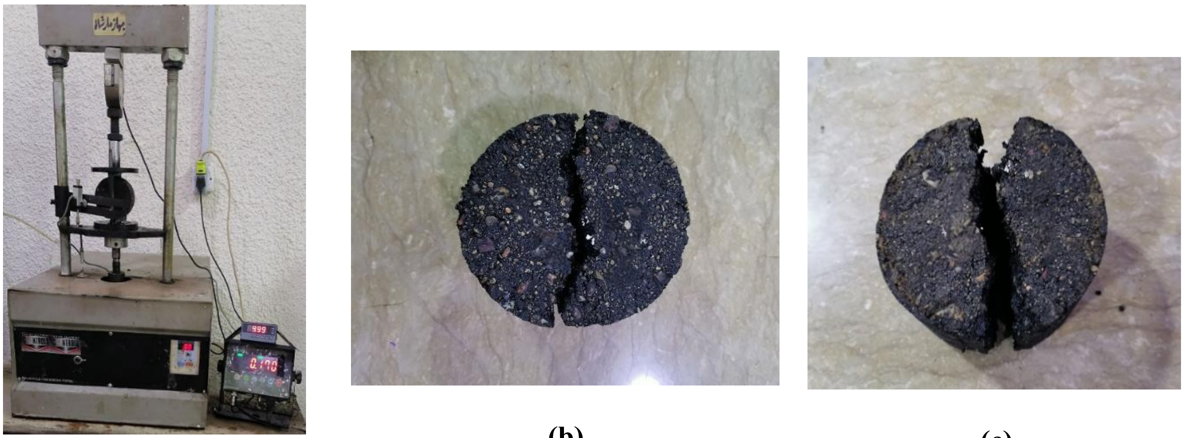
ITS = indirect tensile strength, kPa

P = maximum load, N t = specimen height immediately before test, mm

$D = specimen\ diameter$, mm

2.2.3. Indirect Tensile Cracking Test (ITCT):

ITCT is one of the modern tests used to evaluate the resistance of asphalt mixtures to cracks resulting from repeated stress and fatigue by (ASTM D8225).This test is characterized by its simplicity and ease of execution and its ability to give accurate indicators of cracking resistance in the mixture, making it an effective tool in the evaluation and design of asphalt mixtures. Samples are prepared using the optimum asphalt content; after mixing (aggregate-asphalt binder), the mixture is placed in the oven at (130-135) °C for two hours to simulate short-term aging according to (AASHTO R30)recommendations. The specimens were prepared similarly to Marshall specimens and compacted to achieve 7% air voids; the specimens were left for 24 hours at room temperature; before testing, the specimens were placed in a water bath at 25°C for two hours Fig. 2.



(a) (b) (c)

Fig. 2. Indirect Tensile Cracking Test: (a)testing machine, (b-c) specimen after testing

During the test, video recording was used. After completing the test, the recording was reviewed in slow motion to ensure the accuracy of the data. The crack tolerance index (CT index), which expresses the ability of the mixture to withstand cracks, is calculated by analyzing the load-displacement curve data Fig. 3 according to the following equation:

$$CT_{Index} = \frac{t}{62} \times \frac{I_{75}}{D} \times \frac{G_f}{|m_{75}|} \times 10^6 \qquad (1)$$

Where:

CT_{Index} = Cracking Tolerance Index

G_f = Fracture energy $(J/m^2) = \dfrac{W_f}{D \times t} \times 10^6$

I_{75} = Displacement at 75% the peak load after the peak (mm)

t = Specimen thickness (mm)

D = Specimen diameter (mm)

$|m_{75}|$ = Absolute value of the post − peak slope at 75% of the peak load (N/mm) Calculated as $\left|\frac{P_{85}-P_{65}}{I_{85}-I_{65}}\right|$

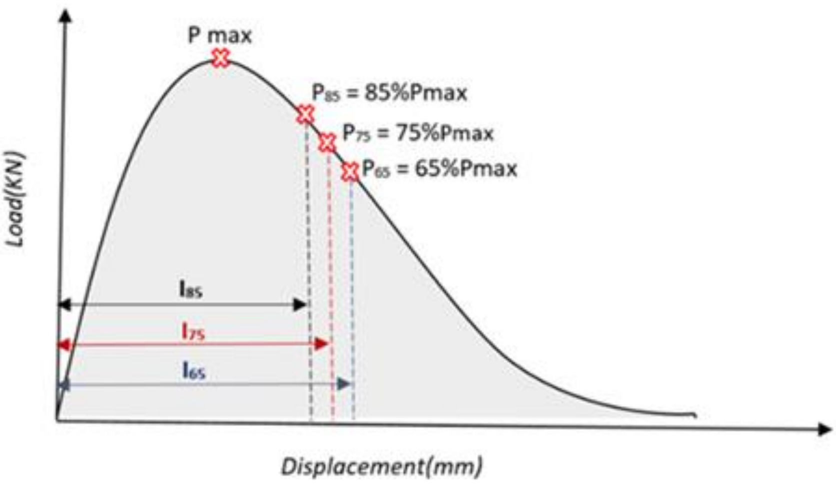


Fig. 3 Load-line displacement

This equation is an exact analytical tool for measuring the ability of a mixture to withstand cracks after being subjected to repeated loads. The area under the curve (energy), the speed of resistance degradation after the peak, and the correction factor for the specimen dimensions are the main factors influencing the calculation of the CT Index. A higher CT Index value indicates a better performance of the mix regarding crack resistance, making this index an important reference in the design and evaluation of modern asphalt overlays.

3. RESULTS ANALYSIS AND DISCUSSION:

3.1. Marshall Properties Result:

According to the data in Tables 4 and 5, the following points illustrate the effect of modified asphalt on Marshall properties:

1- Conventional asphalt mixes (40/50) require a higher binder content (4.75%) than modified asphalt (PG 76V-10 and PG 76E-10) ،which registered 4.3%. The decrease may be attributed to the higher rheology and viscosity properties of the modified asphalt, which enhance aggregate coating ,according to a previous study (Guo et al., 2022). Furthermore, the polymer modification increases the film thickness uniformity around aggregates, allowing better coating efficiency even at lower binder contents, which typically leads to improved durability and reduced susceptibility to bleeding. The higher asphalt content in some PG 76E-10 mixes is due to enhanced crack resistance, tolerance to harsh climatic conditions, and additive components that may increase cohesion requirements.

2- Modified asphalt achieves the highest stability values. PG 76V-10 recorded 19.24 kN in the binder layer compared to 13.2 kN for conventional asphalt. In the surface layer, PG 76E-10 recorded 19 kN vs. 12 kN for conventional. The reason is due to the improved deformation resistance and high elasticity of the modified asphalt, which increases the ability of the mixture to withstand loads according to the Iraqi SCRB specifications. This is closely associated with an improved complex modulus (G*) of polymer-modified binders that offers it excellent resistance to rutting and permanent deformation when subjected to repeated load cycles.(Gong et al., 2021; Al-Nawasir and Al-Humeidawi, 2023)

3- Use of modified asphalt decreased the flow values of the binder layer, where both forms gave 2.6 mm versus 3.4 mm compared to normal asphalt, showing more resistance to elastic deformation. In the surface layer, the values were comparable between the modified asphalt with PG76E-10 and the traditional 40/50 asphalt, with the two having values of 2.5 mm. Meanwhile, the flow value of 1.6 mm indicated a high degree of internal cohesion and better resistance to permanent deformation of PG76V-10. Such low values are good in hot conditions and high traffic. Such actions affirm the successful work of added polymers when it comes to the attainment of a balance between viscous and elastic properties within the mixture, which allows us to deform the mixture safely without failure.

4- Modified asphalt mixtures are denser than the conventional mixtures. The increase is attributed to the high enhancement in the filling of voids and minimizing porosity, which improves the distribution of loads on the pavement and decreases the layer permeability. This increase in density is also due to greater efficiency in aggregate bonding and reduced air voids during compaction, which helps to form a pavement layer with higher cohesion.

5- A decrease in air voids (AV%) and an increase in voids for asphalt (VFA) for modified asphalt, with a slight decrease in aggregate voids (VMA). These improvements indicate higher efficiency in the internal distribution of the binder, which enhances moisture resistance and reduces stripping and cracking problems. Additionally, the improved VFA and reduced AV% are well correlated with higher film durability and enhanced resistance against moisture-induced damage, as the polymer-modified binder forms stronger adhesive bonds with aggregate surfaces, limiting water infiltration and stripping.

6- The Marshall stiffness (MS) parameter was included in the analysis to evaluate the effect of asphalt type on the mixture's stiffness and rutting resistance. This parameter is calculated by dividing the Marshall stability by the flow. Higher MS values indicate stiffer mixtures that are more resistant to rutting(Arabani, Tahami and Taghipoor, 2017; Al-Mohammed and Al-Hadidy, 2023). The results showed that the modified mixtures in both layers had higher MS values than the conventional mixtures, indicating a clear improvement in rutting resistance.

Table 4. Properties of Asphalt mixtures for Binder layer

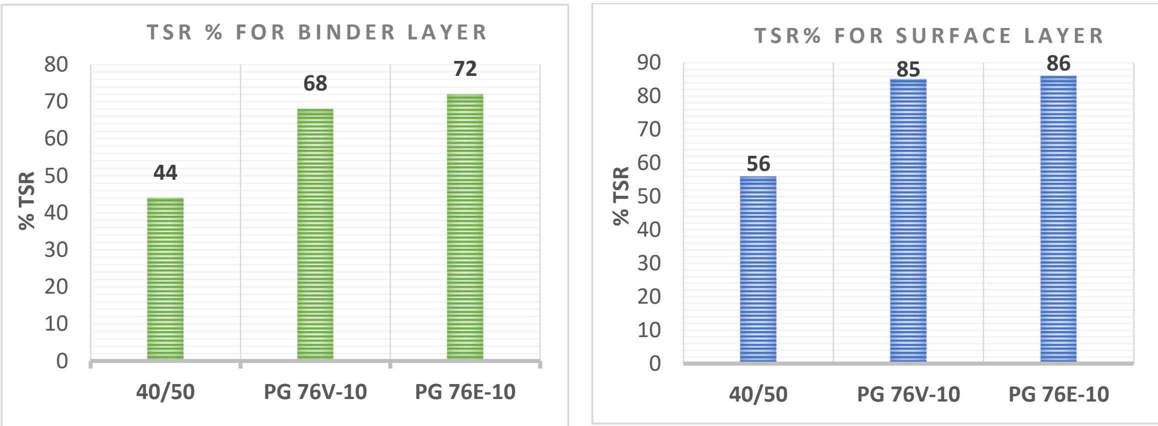
Asphalt Binder Type	**Property**							
	OAC %	Stability (KN)	Flow (mm)	Bulk Density (Gmb)	AV%	VMA %	VFA %	MS (KN/mm)
40/50	4.75	13.2	3.4	2.33	4.5	14.5	69	3.88
PG 76V-10	4.3	19.24	2.6	2.349	4.4	13.7	67.8	7.4
PG 76E-10	4.3	17.4	2.6	2.349	4.4	13.7	67.8	6.69

Table5. Properties of asphalt mixtures for Surface layer

Asphalt Binder Type	**Property**							
	OAC %	Stability (KN)	Flow (mm)	Bulk Density (Gmb)	AV %	VMA %	VFA %	MS (KN/mm)
40/50	4.8	12	2.5	2.356	3.8	14	72.8	4.8
PG 76V-10	4.5	16	1.6	2.35	4.5	14	68	10
PG 76E-10	4.8	19	2.5	2.363	3.5	13.8	74.6	7.6

3.2. Indirect Tensile Strength Ratio Test

The test results, shown in Fig. 4, showed that the modified mixtures had significantly higher TSR values than the mixtures prepared with conventional 40/50 asphalt. The surface layer modified with PG 76E-10 had the best TSR value of 86%, while the lowest value of 44% was in the binder layer using conventional asphalt. The relatively low TSR values in mixtures using 40/50 asphalt, especially in the binder, indicate potential moisture susceptibility and the need to reinforce the binder when long-term durability is necessary. in the surface layer exceeded the recommended TSR value of 80%. Although they did not reach this level in the binder layer, they showed a noticeable improvement compared to conventional asphalt. The enhancement is attributable to the heightened cohesion and diminished permeability of the resultant asphalt binder due to the elastic nature, leading to the minimal occurrence of disintegration and harm to the asphalt as a result of the exposure to the moisture, in addition to the improve adhesion between the modified asphalt binder and aggregate surfaces, particularly in surface layers that were directly subjected to the traffic and environmental factors. The same findings have been demonstrated in a past study, where SBS polymer-modified asphalt has had a significant effect on increasing the TSR value, thus increasing the ability of the mixture to withstand moisture damage as compared to the unmodified binders.(Mahmood and Kattan, 2023). Furthermore, another study confirmed that polymer-modified mixtures revealed better retention of mechanical properties under moisture exposure compared to conventional mixtures(Lv et al., 2022).



(a) (b)

Fig. 4. The Results of (TSR) test for (a)Binder and (b)Surface Layers

3.3. Indirect Tensile Cracking Test (ITCT) result:

The values of the Cracking Tolerance Index (CTindex) are used to assess the cracking resistance of asphalt mixtures, as illustrated in Fig. 5, by examining the data of load-displacement curves in Fig. 6. The outcome revealed a considerable difference in values of the CT index:

For conventional (40/50) asphalt for the binder layer, where the maximum load of the sample reached (pmax=11.25 KN) and the displacement at 75% of the maximum load after the peak was (I_{75}=2.45mm). The absolute value of the post-peak slope (m_{75}= 5.11N/mm) was calculated based on the difference between the load values at 85% and 65% of the maximum load divided by the difference between the corresponding displacements. The fracture energy reached a value of (G_f=4746 J/m^2) and was calculated by dividing the area under the load-displacement curve up to the point of failure (W_f=30.85 J) by the cross-sectional area of the sample.

Using these values in addition to the sample dimension, the crack index equation was applied to obtain the CT index value for conventional (40/50) asphalt for the binder layer, which was 24, and this means it has low crack resistance. It was better on the performance of the PG 76V-10 asphalt, of which the index (37) was attained because of higher viscosity and medium polymeric modification. The highest index value of 81 was obtained with PG 76E-10 asphalt, which proves its efficiency in enhancing flexibility and crack resistance. On the surface layer, index values of conventional asphalt and PG 76V-10 dropped to 19 and 21, respectively, because of the environmental factors and the various distributions of air voids to different spots. Nevertheless, the performance of PG 76E-10 asphalt was high (52), which indicates its high performance even when subjected to thermal loads and direct loads.

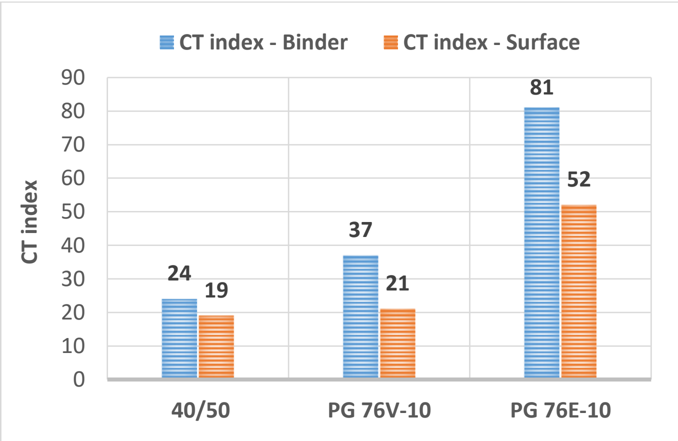
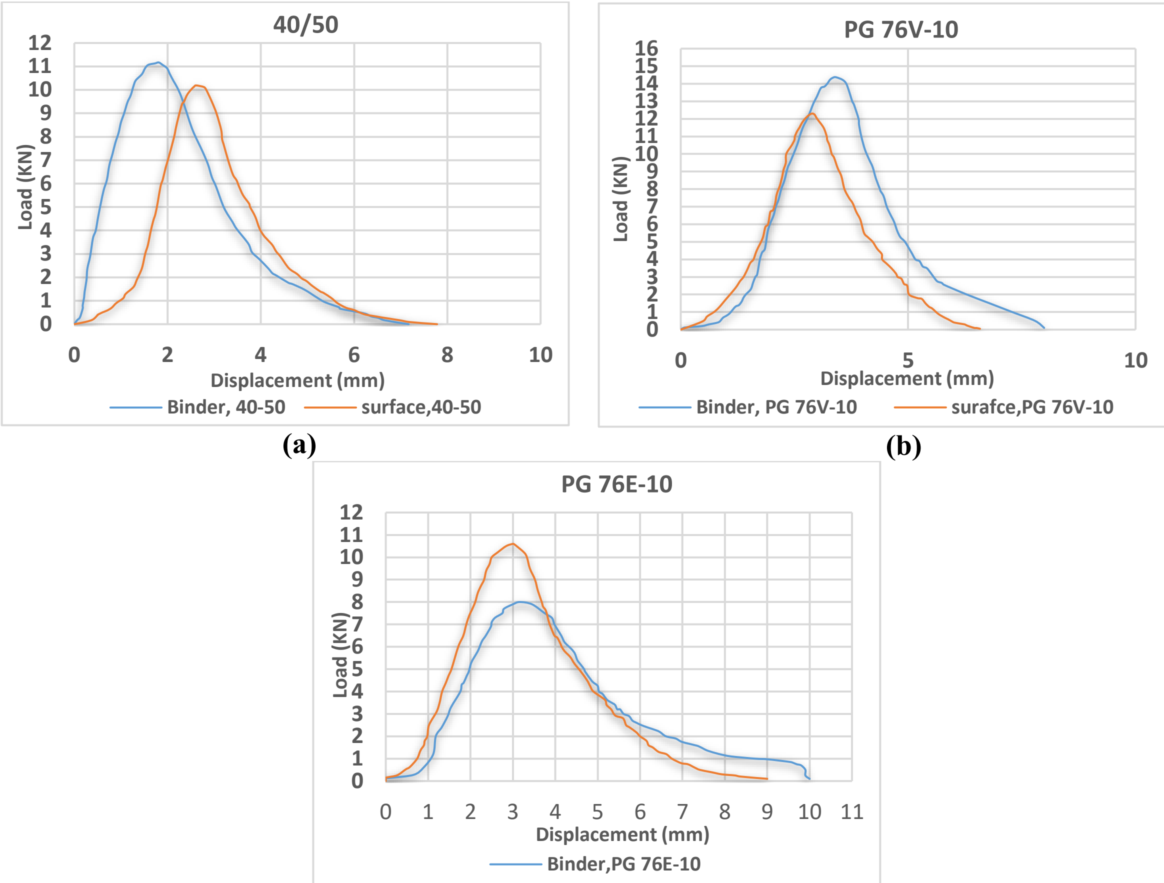


Fig. 5. the Cracking Tolerance Index (CTindex) values

The difference in the behavior of the mixtures is evident in the load-displacement curves. The 40/50 mixture soon attained its full load and then plummeted. This represents brittle behavior and an inability to resist cracking. Conversely, the modified versions of the PG 76 V-10 and the PG 76 E-10 mixtures were more flexible in behavior and had a higher resistance to deformation up to failure. These mixtures were defined as having a delay to peak values and increased displacement that is associated with a higher resistance to deformation.

The modified mixtures were not able to get higher Pmax values; however, their post-failure behavior is what makes them stand out, given that cracks are formed gradually and that more displacement is needed to reach ultimate failure due to the enhanced properties of the polymer binders, which contribute to the distribution of stresses and dissipation of energy even after cracking has started.



(a) (b)

(c)

Fig. 6. The load-displacement curves (a) (40/50), (b)PG 76V-10, and (c) PG 76E-10

4. CONCLUSIONS:

Modified asphalt is highly beneficial to the mechanical performance of the mixture, and the resistance to deformation when repeated loads are applied increases, as well as the properties of the mixture, which contribute to the increase in pavement life and stability.

The modified mixes require less asphalt than conventional mixes. This is due to the improved efficiency of coating the aggregate with the modified binder, which enhanced the internal structure of the mix.

The modified mixtures had high moisture resistance, particularly on the surface layer, compared to the conventional mixtures, which had very poor performances. This is because the modified mixtures have higher internal cohesion and lower permeability.

It is the modified mixtures that possess maximum crack resistance and therefore are ideal when the layer is exposed to direct and repeated loads. This minimizes the possibilities of premature layer failure and enhances stress distribution on the pavement.

Surfaces with modified asphalt have been reported to be denser and more stable with respect to mechanical strength, and also more resistant to moisture content and cracking, and are therefore the best surfaces to be used in surface layers that directly experience traffic and environmental conditions. In the case of sub-surfaces that have a comparatively low load, standard asphalt mixes can be employed, and at the same time, the pavements remain stable in terms of durability and performance under the design conditions.

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