Effect Of Resilient Modulus on Permanent Deformations Using VESYS 5W Program

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Abstract

Due to high temperatures and increased traffic loads, most of Iraq's streets suffer from permanent distortion problems, especially in streets where there are checkpoints, therefore, there are needs for reports and researches specialized in improving the pavement layers and increasing their resistance to temperatures and high traffic loads to reduce the rut depth. In this research, the VESYS 5W program was used to find a potential value for rut depth, where ordinary asphalt mixes and improved asphalt mixes were used using SBS polymer at 4% by weight of asphalt were it is evaluated according to different properties of these mixture and the resilient modulus one of these properties for it is importance. The results showed that when the value of the resilient modulus increases, the rut depth decreases, as the rut depth was reduced by 42.5% for the surface layer and 73% for the base layer.

1. INTRODUCTION

The asphalt binder, in general, it is a viscous-elastic substance with temperature & time characteristics that depend(1). Over the last few years, the pavements and road materials in Iraq have been exposed to multiple failures as a result of heavy traffic and severe climate changes. The failure of road pavement materials is one of the most serious issues that must be addressed in order to maintain the performance of road pavements(2). To minimize these effects, a variety of additives such as styrene-butadiene-styrene, lime, rubber, and waste powders have been added to change controlling asphalt and improving the performance of asphalt binder(3). Surface rutting occurs as a result of the paving material's plastic deformation, as well as the subgrade's and overlay asphalt layer's general subsidence. Permanent deformation of asphalt concrete materials has been the subject of much research. The majority of research were carried out on a variety of materials and procedures(4). Historically, the concept "permanent deformation" was used to characterize any distortion of the pavement surface caused by mix instability, such as shoving and pushing. Today, this type of distress is defined as longitudinal depressions or "ruts" that form along wheel paths as a result of "consolidation and/or lateral displacement in one or more of the component pavement layers due to repetitive, transient load applications(5). In the paving industry, polymer-modified asphalt binders are widely and successfully utilized to improve pavement performance and durability. Pavement cracking caused by heat stresses and repetitive loads has been reported to be reduced by polymer modification reduce rutting as a result of plastic deformation(6). When material densification in the wheel pathways causes a depressed channel less than 5 mm in depth, rutting is seen in the road's wheel paths(7).
Plate 1. show the rutting in flexible pavement (8)

According to (9), Rutting is classified by the Federal Highway Administration into four levels of severity:

- Hydroplaning (0.2 to 0.25 in)
- Low (0.25 to 0.5 in)
- Moderate (0.5 to 1.0 in)
- Extremely high (1.0 in)

Many experts believe that the only appropriate criterion is one that is consistent with hydroplaning; for conventional cross slope values, a rut depth of 12.5 mm (0.5 in) is commonly agreed upon as the maximum allowed rut depth (10). SBS is a thermoplastic polymer that improves the overall performance of asphalt pavement by lowering water sensitivity and potential rutting in the summer and cracking in the winter by boosting asphalt binder stability, elasticity, and stiffness (11). The strength of polymer-modified mixtures. When compared to the unmodified mix, the SBS modified mixes had 1.2–1.9 times higher modulus values (12)

2. Materials and experimental works:

2.1. Asphalt cement

The virgin asphalt binder used in this project was asphalt cement with a penetration grade of 40-50, which was provided by the Al-Dura refinery in Baghdad's south. The results of the asphalt cement tests show that its properties fulfill the State Corporation of Roads and Bridges (SCRB) specifications (13). The physical properties of asphalt cement are shown in Table 1.

| Properties                      | ASTM Designation | Results |
|---------------------------------|------------------|---------|
| Penetration at 25°C, 100gm, 5sec. (0.1 mm) 40-50 | D5                | 45      |
| Ductility at 25 °C, 5 cm/min. (cm) >100 | D113              | 142     |
| Flashpoint (Cleveland open cup), (°C) Min 232 | D92               | 322     |
| Softening point, (°C)          | D36              | 52      |
Viscosity @ 135 °C, C.s  
Min 400  
Viscosity @ 165 °C, C.s  
D4402  
Specific gravity at 25 °C  
D70  

2.2. Aggregate  
Crushed quartz aggregate from the Al-Nabai quarry was utilized in this study. The aggregates utilized meet the fine and coarse graduation requirements needed by requirements for Type IIIA surface course gradation and Type I base course gradation. (13), as shown on Table (2). Table 3 for properties of course and fine aggregate.

Table 2 selected aggregate gradation for the surface course and base course according to SCRB (R9/2003).

| Sieve size | Base course type I (midpoint gradation) | Surface coarse IIIA (midpoint gradation) |
|------------|----------------------------------------|----------------------------------------|
|            | Passing% Limits specification           | Passing% Limits specification           |
| 1 ½”       | 100                                    | 100                                    |
| 1”         | 95                                     | 90-100                                 |
| 3/4”       | 83                                     | 76-90                                  |
| 1/2”       | 68                                     | 56-80                                  |
| 3/8”       | 61                                     | 48-74                                  |
| No.4       | 44                                     | 29-59                                  |
| No.8       | 32                                     | 19-45                                  |
| No.50      | 11                                     | 5-17                                   |

Table 3. Coarse and fine aggregate properties utilized.

| Properties                  | ASTM Certification | Coarse aggregate | Fine aggregate |
|-----------------------------|--------------------|------------------|----------------|
| Bulk Specific Gravity       | (C12-C128)         | (2.612)          | 2.567          |
| Apparent Specific Gravity   | (C127-C128)        | (2.656)          | 2.629          |
| Percent Water Absorption    | (C127-C128)        | (0.94)           | 0.91           |
Angularity (D5821) (0.97) Minimum 95%
Toughness - (Los Angeles Abrasion) (C535) (20.8 %) Maximum 30%
Soundness (C88) (4.1 %) Maximum 12%
Clay Content (D2419) 86.5 % Minimum 45%

Fig 1. Curves showing an aggregate's gradation for use in a wearing course

Fig 2. Curves of aggregate gradation for base course

2.3. Mineral Filler
Portland cement was chosen as a filler in this study; table 4 illustrates the physical characteristics of (Portland cement)

| property                  | result  |
|---------------------------|---------|
| Bulk specific gravity     | 3.1500  |
| Passing Sieve (No.200)- (0.075 mm) | 97.00%  |
2.4. Additive
According to researcher (6), a styrene-butadiene styrene was used in this study at a rate of 4% of the weight of asphalt and was mixed by an electric mixer at a temperature of 180-190 °C for 120 min (the physical properties of SBS are described in the Table 5). The Table 6 also shows the influence of SBS on the physical properties of asphalt cement.

Table 5. The physical and chemical properties of SBS

| property                           | Test Method       | Units        | Typical Value | note |
|------------------------------------|-------------------|--------------|---------------|------|
| hardness, Shore A (15 sec)         | ASTM D2240        | Hardness, Shore A (15 sec) | 70.00 | A    |
| bulk Density                       | ASTM D1895 method B | g/cm³       | 0.400         |      |
| specific Gravity                   | ISO2781           |              | 0.9400        |      |
| melt Flow Rate, 200°C/5kg          | ISO 1133          | g/10min      | 1.00          |      |
| 300% Modulus                       | ISO 37            | Mpa          | 4.800         |      |
| elongation at Break                | ISO 37            | %            | 1000.00       |      |
| tensile Strength                   | ISO 37            | Mpa          | 33.00         | A    |

A Measured on compression molded slabs

Table 6. Test results for modified binder 40-50 were taken for design of asphalt mixture from the laboratory

| Properties            | Test standard | Bitumen 40/50 +4 % SBS | Required by ASTM D6373 for PG 76-10 |
|-----------------------|---------------|------------------------|-------------------------------------|
| Penetration           | ASTM D 5      | 30                     | ---------                           |
| at 25°C, mm           |               |                        |                                    |
| Property                        | ASTM Standard | Value   |
|--------------------------------|---------------|---------|
| Softening point, °C            | D36           | 58.5    |
| Flash point (Cleveland open cup), °C | D92          | >330 min 230 °C |
| Viscosity (Brookfield) at 135 °C, cP | D4402        | 1482 max 3000 |
| Ductility at 25°C              | D113          | >132cm min 100 cm |
| RTFOT mass change, %           | D2872         | 0.28 Max 1 % |

Plate 2. Show SBS polymer  
Plate 3. Show electric mixer for mixing asphalt and SBS polymer

3. Preparation of Asphalt Mixtures samples

This search pay attention to using the Marshall Mix method to construct the surface and base layers for each of the standard asphalt mixture and the asphalt mixture modified with SBS polymer added. There were various stages to this research. The first stage is to choose fine and coarse aggregates for the surface and base layers, with physical properties and gradations determined in accordance with the specifications. There have been three stages in the second stage. First, typical asphalt mixtures were made by mixing five percentages of preheated asphalt (4, 4.5, 5, 5.5, 6%) into the aggregate for the surface layer and six other proportions (3, 3.5, 4, 4.5, 5, 5.5) % into the aggregate for the base layer. The aim of this phase is to determine the optimal asphalt percentage that creates a good balance of laboratory components (flow value, Marshall Stability, bulk density, and total air voids), and the optimal binder percentage for the surface layer was 5% and 4.2 percent for the base layer. The second phase involves heating the asphalt and mixing it with the heated aggregate for two minutes manually to ensure the titration process is complete, as well as preparing six samples (3 samples for the surface layer with an optimal asphalt ratio of 5 percent and 3 samples for the base layer with an optimal asphalt ratio of 4.2
percent) These samples are ready for testing in the laboratory. The procedure of adding the SBS polymer to the asphalt content was the third phase of the second stage, which involved heating the asphalt and then adding the SBS polymer at 4% of the weight of the asphalt and mixing it with an electric mixer while keeping a temperature around (180 - 190 ° C). Following that, an addition was made. Optimum asphalt mixture content to heated aggregate, as well as the preparation of 6 samples for the surface and base layers. These samples are ready for laboratory tests.

Plate4. Shows how to make a mix with SBS polymer and asphalt.

The test was carried out with a single deviator stress of 20 Psi (138 kpa). A 10,000-repetition Compressive loading with a loading cycle of 60 cycles per minute and a 0.1-second rectangular wave load followed by a 0.9-second rest period (The 0.1-second load duration was chosen to imitate the loading of a truck traveling at 50 km/h on a highway).[15, 16]

The permanent axial deformation of the pre-prepared Marshall samples is calculated by Dial gauge with a precision of 0.0005in composite with a thin cylindrical piece of iron and the result is recorded by a high-resolution camera and the results are calibrated with a final reading based on the data The permanent strain, resilient strain, and resilient modulus are calculated according to the following equations (1, 2 and 3) during the examination period, when the recorded readings of the permanent axial deformation are at blow.

\[
\varepsilon_p = \frac{pd \times 1000000}{h}
\]  

(1)

\(\varepsilon_p\) = permanent micro strain

\(pd\) = permanent deformation (axial deformation)

Table7. Indicates the number of blows that are calculated for the sample.

| Number of blow | 1   | 2   | 10  | 50  | 100 |
|----------------|-----|-----|-----|-----|-----|
| 500            | 5000| 6000| 7000| 8000| 9000|
The resilient deformation is determined at the load repetition of 50 to 100 because it depends only on the recoverable elastic part (within the elastic limit)

$$\varepsilon_r = \frac{\Delta r}{h}$$  \hspace{1cm} (2)

$$\varepsilon_r = \text{axial resilient strain (micro strain)}$$

$$M_r = \frac{\sigma}{\varepsilon_r}$$  \hspace{1cm} (3)

$$M_r = \text{Resilient modulus (psi)}$$

$$\sigma = \text{repeated axial stress (psi)}$$

$$\varepsilon_r = \text{axial resilient strain (in/in)}$$

$$\Delta r = \Delta r_{\text{high}} - \Delta r_{\text{low}}$$  \hspace{1cm} (4)

$$\Delta r = \text{axial resilient deformation}$$

$$\Delta r_{\text{high}} = \text{high deformation reading for the dial gauge reading and}$$

$$\Delta r_{\text{low}} = \text{low deformation reading for the dial gauge reading}$$

Also the permanent deformation coefficients (ALPHA & GNU) showed in figure below are one of the most important data that must be entered in the program and can be calculated using the following equations:

$$\text{ALPHA (}\alpha\text{)} = 1 - S$$  \hspace{1cm} (5)

$$\text{GNU (}\mu\text{)} = \frac{IS}{\varepsilon}$$  \hspace{1cm} (6)

where

$$S: \text{slope of the straight line of the log permanent strain versus number of load repetition}$$

$$I: \text{the intercept occurs at } N = 1$$

$$\varepsilon: \text{elastic strain}$$

The specifics of the factorial variables utilized in the Permanent deformation test's experimental design are summarized in Table 8. And the result of equation (5&6) summarized in table9.

Table 8. the specifications of the variables used in permanent deformation test

| parameter             | Selected value       |
|-----------------------|----------------------|
| Temperature           | 20 °C                |
|                       | 40 °C                |
|                       | 60 °C                |
| Applied stress        | 20.00 Psi            |
| Resilient strain      | at 50 to 100th       |
| Maximum loading       | 10,000               |
| repetitions           |                      |
Conditioning time 2 hours
Load cycle time 0.1 second haversine load
0.9 second rest period

Table 9. The result of ALPHA and GNU.

| layer | Temperature °C | Without SBS | With SBS |
|-------|----------------|-------------|----------|
|       |                | ALPHA       | GNU      | ALPHA    | GNU      |
| surface | 20              | 0.865138994 | 0.63633 | 0.852870357 | 0.441387 |
| surface | 40              | 0.667708153 | 0.79238 | 0.739705046 | 0.99777 |
| surface | 60              | 0.58003763  | 0.94947 | 0.772442373 | 0.786   |
| base   | 20              | 0.879808348 | 0.92461 | 0.862407332 | 0.30712 |
| base   | 40              | 0.622300277 | 0.92326 | 0.824178074 | 0.8986  |
| base   | 60              | 0.597946734 | 0.9046  | 0.603155449 | 0.52912 |

Figure (3): log-log figure of permanent strain versus number of load repetition (14).

VESYS 5W program It is a program provided by Federal Highway Administration (FHWA) that is used to analyze and evaluate paving layers in terms of performance prediction, ruts and fatigue crack.

In this study, the use of the program is limited to finding the Rut values for each layer by entering the data as shown in the table (10).
### Table10. Data input in VESYS 5W program.

| data            | unit | value                      |
|-----------------|------|----------------------------|
| thickness       | in   | Surface = 4.7              |
|                 |      | Base = 4                   |
|                 |      | Subbase = 15.7             |
|                 |      | Subgrade = infinite        |
| temperature     | °C   | Season 1 = 20              |
|                 |      | Season 2 = 40              |
|                 |      | Season 3 = 60              |
|                 |      | Season 4 = 40              |
| Poisson ratio   |      | Surface = 0.35             |
|                 |      | Base = 0.4                 |
|                 |      | Subbase = 0.45             |
|                 |      | Subgrade = 0.5             |
| Resilient modulus | Psi | from Table 11              |
| alpha (α) & GNU (μ) | | From Table 9               |
| ESAL            |      | 15*10^6                    |

Plate5. Front page of VESYS 5W program.
4. Results and discussions.

The results showed that the resilient modulus has a direct effect on the permanent deformations that occur in the layers of the paving, as the process of improving the resilient modulus (increasing its value) reduces the effect of the rut layers. The addition of SBS polymer to asphalt mixtures led to a clear increase in the resilient modulus for the surface and base layers as showed in Table 11.

Figure (4) shows that when the value of the resilient modulus of the surface layer is increased, it reduces the effect of high temperatures and traffic loads, which decreases the rut depth values due to the addition of SBS polymer to asphalt mixtures, which increases the bonding of the bituminous material and increases the hardness of the asphalt mixture and thus increases the resilient modulus. While Figure (5) indicates a decrease in the effect of permanent deformations (Rut Depth) for the base layer due to the addition of SBS polymer to the asphalt mixture, which increases the hardness of the layer and increases the resilient modulus.

Table 11. The result of Mr and rut depth.

| Layer | Temperature | Resilient modulus (PSI) | Total rut depth (mm) |
|-------|-------------|-------------------------|----------------------|
|       |             | Without SBS | With SBS | Without SBS | With SBS |
| Surface | 20°C | 58181.82 | 72727.27 | 3.048 | 1.7526 |
|        | 40°C | 33684.2105 | 53333.34 |  |
|        | 60°C | 25600 | 29090.9 |  |
| Base   | 20°C | 53333.34 | 80000 | 3.9624 | 1.0668 |
|        | 40°C | 32000 | 58181.818 |  |
|        | 60°C | 21333.34 | 29090.9 |  |

![Fig4](image)

**Fig4.** Relationship of the rut depth with MR for the surface layer
5. Conclusion

The process of improving the resilient modulus of the asphalt layers includes adding SBS polymer by 4% of the weight of the asphalt. Depending on the results of the research, we conclude, Increasing the resilient of elasticity reduces the rate of rut depth of the surface and base layers. When adding SBS polymer to asphalt mixtures, it increases the MR of the base layer more than it increases the MR of the surface layer. The decrease in the rate of rut depth of the base layer is more than the decrease in the rate of rut depth of the surface layer when improving MR. Reducing the rate of rut depth helps to reduce the economic cost of creating paving layers by reducing the thickness of these layers.

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