Effects of polyvinyl chloride (PVC), styrene butadiene styrene (SBS) and aggregate gradation on permanent deformation of asphalt concrete pavement

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Abstract. Rutting, stripping and fatigue represent serious distresses which lead to complete failure of the pavement. These distresses could minimize the performance of asphalt pavements. In Iraq, under the influence of repeated vehicle loading, high temperature at summer days and water damage, specific requirements are needed to control the quality of highway materials especially asphalt binder since some of the distresses are related with asphalt binder and can be controlled by modifying asphalt with several modifiers in order to increase the durability of the pavement and to reduce the effect of rutting and moisture damage. The main objective of this research is to study the effects of using hybrid elastomer and plastomer polymers modifiers and aggregate gradation on the asphalt mixture resistance to rutting. In this study, different types and concentration of polymers are used. 1% and 3% of Polyvinyl Chloride (PVC) were added for both control asphalt binder and asphalt modified with 3% Styrene Butadiene Styrene (SBS). To evaluate rutting depth, roller compactor and wheel-track devices test were used in this paper.

1. Introduction

The structure of the pavement consists of several layers for the essential purpose of transferring and distributing loads of traffic to the subgrade [1]. Increasing of traffic loads combined with variation of weather conditions will reduce the performance of asphalt binder. In addition, sensitivity of bitumen to temperature intensifies deterioration of asphalt concrete pavements [2]. High climate temperature can develop a negative effect on the hot mix asphalt (HMA) pavement's performance that lead to deformation such as rutting which represents one of the main distresses that influence the pavement performance especially in hot weather countries like Iraq. Rutting is resulted from the accumulation of permanent deformation in pavement layers under the effects of repeated traffic loads. It appears only on flexible pavement as longitudinal depression along the wheel paths of the highways. The depth and width of the rut are mainly affected by layer thickness, quality of materials, traffic loading and climate conditions [3]. The service life of the pavement could be reduced if permanent deformation happens, and this will create serious dangers to the user of the highway by affecting vehicle handling characteristics [4].

Arabani and Taleghani [5] studied the influence of using powder PVC on the properties of both asphalt binder and mixture. The results obtained from dynamic shear rheometer (DSR) and rotational viscosity (RV) revealed that an increasing in the amount of PVC powder leads to proportional increase in penetration resistance and rutting parameter (complex modulus/ sin phase angle) (G*/sinδ). Thus, the
authors deduced that mixtures containing PVC powder are more resistant to rutting. Results obtained from Alkaissi [6] demonstrated that there is a great influence of both thermal and traffic loading conditions on rutting of flexible pavement and higher temperatures will produce high rut depth by 2.29, 3.1 and 4.3 times for Asphalt surface layer, base layer and subgrade layer respectively. Oudah [7] studied the effect of using of styrene butadiene styrene (SBS), nano-silica (N-SiO$_2$) and nano high density polyethylene (NHDPE) on the rheological properties of local asphalt binder. A 3% and 5% of each modifier were mixed with the binder. The results showed that all the modifiers had improved the performance grad of the local binder PG64-16 as well as the rutting parameter and fatigue parameter of N-SiO$_2$, NHDPE and SBS were generally enhanced as compared with the control asphalt binder. Some researchers have reached to various conclusions with respect to the effect of aggregate gradation on resistance of asphalt mixtures to rutting. Wang [8] stated that fine gradation mixture is more resistance to permanent deformation than coarse gradation mixtures while Qasim et al. [9] concluded that coarse gradation had higher resistance to permanent deformation than fine gradation mixtures for control asphalt mixtures.

2. Objectives
The main objective of this research is to study the effects of using hybrid elastomer and plastomer polymers modifiers and aggregate gradation on asphalt mixture resistance to permanent deformation.

3. Materials Properties
The materials used in this work are locally available and currently used in road construction in Iraq. They include asphalt binder, aggregate and mineral filler in addition to additives.

3.1 Asphalt Binder
Asphalt binder with penetration grade (40-50) was used. It was brought from AL Daurah refinery in Baghdad. The physical properties of the asphalt binder are depicted in Table1.

3.2 Aggregate
To prepare the specimens, crushed quartz aggregates source are brought from Al-Nibaie quarry which is widely used for asphalt mixes in Baghdad city. The results of the physical properties of used aggregate are presented in Table 2. In this study, two aggregate blends with nominal maximum size of 12.5 mm are selected to design aggregate structure: a coarse blend and a fine blend so as to investigate the effect of gradation on the performance properties of the mixtures. The gradation of aggregate meets the range of gradations limits as specified by the State Commission of Roads and Bridges (SCRB) for dense graded paving mixtures of wearing course [10]. The used gradations with specification limits are demonstrated in Table 3 and Figure 1.

3.3 Mineral Filler
The filler used in this study are limestone dust with specific gravity of 2.74 and it was brought from the lime factory in Karbala governorate.

3.4 Additives
Two types of polymers were used in this study. The first is plastomer polymer, polyvinyl chloride (PVC), which was purchased from the local markets and produced by SABIC Company. Figure 2 shows polyvinyl chloride, while Figure3 shows scanning electron microscopy (SEM) of PVC which showed that its particles size is in the range of 0.08 - 0.22-mm. SEM test was conducted at the Ministry of Science and Technology / Directorate of Materials Research. Table 4 depicts the typical properties of PVC. The second additive is elastomer polymer, Styrene Butadiene Styrene (SBS). The chemical chain of SBS is made up of three parts: - Styrene provides durability and performance for asphalt at high temperatures, while butadiene contributes to give the flexibility for asphalt at low temperatures. Figure 4 illustrates the SBS used in this study while Table 5 demonstrates the properties of SBS.
### Table 1. Properties of asphalt cement, according to ASTM requirement and Iraqi specifications.

| Test                      | Test condition                        | ASTM Designation | Penetration grade (40-50) |
|---------------------------|---------------------------------------|-----------------|--------------------------|
| Penetration               | 100 gm, 25°C, 5sec., (0.1mm)          | D-5             | 45                       |
|                           |                                       |                 | 40-50                    |
| Rotational Viscosity      | 135 °C                                | D-4402          | 0.60                     |
| Ductility, cm             | 165 °C                                |                 | 0.144                    |
| Flash Point, °C           | 25°C, 5 cm/min                        | D-113           | 120                      |
|                          |                                       |                 | >100                     |
| Softening Point, °C       | (4±1) °C/min                          | D-36            | 49                       |
|                           |                                       |                 |                         |

### Table 2. Physical properties of aggregate.

| Type of aggregate      | ASTM Designation | Bulk specific gravity | Apparent specific gravity |
|------------------------|------------------|-----------------------|---------------------------|
| Coarse aggregates      | C-127            | 2.641                 | 2.672                     |
| Fine aggregates        | C-128            | 2.662                 | 2.685                     |
| Los Angeles abrasion, % | C-131            | 12.3                  |                           |
| Flat and elongated particles (%) | D-4791 | 1.5                  |                           |

### Table 3. Percent Passing by Weight of Used Aggregate Gradations (12.5 mm Nominal Maximum Size, Wearing Course).

| Sieve Size | Gradation % Passing | Iraqi Specification [10] |
|------------|----------------------|--------------------------|
| Standard Sieves (mm) | English Sieves | Coarse gradation | Fine gradation | Min. | Max. |
| 19 | 3/4" | 100 | 100 | 100 | 100 |
| 12.5 | 1/2" | 96 | 97 | 90 | 100 |
| 9.5 | 3/8" | 85 | 86 | 76 | 90 |
| 4.75 | #4 | 64 | 66 | 44 | 74 |
| 2.36 | #8 | 36 | 43 | 28 | 58 |
| 1.18 | #16 | 24 | 33 | ----- | ----- |
| 0.6 | #30 | 17 | 24 | ----- |----- |
| 0.3 | #50 | 12 | 17 | 5 | 21 |
| 0.075 | #200 | 5 | 6 | 4 | 10 |
**Figure 1.** Gradation blends with Iraqi and superpave requirements.

**Figure 2.** Polyvinyl Chloride Appearance.

**Figure 3.** SEM Image for Polyvinyl Chloride.

**Figure 4.** Styrene Butadiene Styrene.

**Table 4.** Typical properties of PVC.

| Apparent bulk density Kg/m³ | Density g/cm³ | Passing through mesh 200 | Tensile Strength N/mm² | K-value | Color          |
|-----------------------------|---------------|--------------------------|-----------------------|--------|----------------|
| 570                         | 1.38          | Max 4%                   | 2.6                   | 67     | White powder  |

**Table 5.** Mechanical and Physical Properties for SBS.

| Bulk density Kg/m³ | Elongation % | Specific gravity | Tensile Strength MPa | Melting point ºC | Color |
|--------------------|--------------|------------------|----------------------|------------------|-------|
| 0.4                | 88           | 0.94             | 32 min.              | 180              | White |
4. Preparation of Hybrid Elastomer and Plastomer Modified Bitumen
The process of preparation the hybrid modified bitumen is conducted in two stages. The first stage, included mixing pure asphalt with 3% Styrene Butadiene Styrene (SBS) together by mixer device shown in Figure 5 at 2220 rpm, for 3.5-4.0 hours, while keeping the temperature at 180 °C to ensure compatibility and homogeneity. At the second stage, mixing of the modified asphalt with PVC to form hybrid modified asphalt mixtures is performed. The hybrid mixture was mixed by mixer device at 2220 rpm. Also, the rotation was maintained for two hours, while keeping the temperature at 165 °C. It is important to mention that the PVC was added to the modified asphalt at concentration of 1% and 3% by the weight of asphalt binder. Scanning Electron Microscopy (SEM) was used to depict how PVC and SBS particles spread in the asphalt binder as shown in Figure 6 while Figure 7 shows SEM image for control asphalt binder. The percentages of additives were chosen after many trails.

![Figure 5. Mixing device](image)

![Figure 6. SEM Image for PVC and SBS Modified Asphalt](image)

![Figure 7. SEM Image for Control Asphalt Binder](image)

5. Mix Design
The optimum asphalt binder content of the surface layer is determined according to superpave method. Superpave Gyratory Compactor (SGC) was used to prepare cylindrical specimens of asphalt concrete to determine the volumetric design according to Superpave system (AASHTO Designation: T 312-2010). Specimens were prepared by mixing and compacting at the appropriate temperature which was obtained from the relationship between viscosity and temperature as depicted in Figures 8 to 13. In this study mixture designed as $N_{\text{init.}}$, $N_{\text{des.}}$, and $N_{\text{max.}}$ were 8, 100, and 160 gyrations, respectively to which a specimen must be compacted within the Superpave Gyratory compactor. To prepare test specimens, about 4700 grams of the mix are used and the height of the specimen is recorded for each gyration. Also, short term aging of (2 hours) is used to simulate what is happening in the hot mix plant during the mixing and compaction operation. It is worthwhile to mention that compaction of the specimens within SGC was conducted at Al-Nahrain University, Civil engineering laboratory.

6. Roller Compacter Slabs Preparation
Compaction is conducted by using the roller compactor machine in accordance with (EN 12697-33:2003). In order to compact the slab in the roller compactor machine; firstly, the aggregate and the binder are mixed in mixing bowel. Secondly, the asphalt- aggregate mixture is short term oven aged for 4 hours at 135 °C for compaction [11]. At the end of short term aging time, the compaction mould with dimension of (400mm by 300 mm by 50mm) is charged with the mixture after leveling. When compaction is completed, the slab is left to cool at room temperature for 24 hours before removing the mould. Figure 14 shows the roller compactor machine with compacted slab. It is worthwhile to mention that 24 slabs were prepared to be tested. This test was performed at Al- Nahrain University, Civil engineering laboratory.
Figure 8. Relationship between temperature and viscosity for control asphalt binder.

Figure 9. Relationship between temperature and viscosity for 3% SBS modified asphalt binder.

Figure 10. Relationship between temperature and viscosity for 1% PVC modified asphalt binder.

Figure 11. Relationship between temperature and viscosity for 3% PVC modified asphalt binder.

Figure 12. Relationship between temperature and viscosity for 1% PVC+3% SBS modified asphalt binder.

Figure 13. Relationship between temperature and viscosity for 3% PVC+3%SBS modified asphalt binder.

Figure 14. Roller compactor machine with compacted slab.
7. Wheel Tracking Test
Wheel tracking machine is generally used to provide information about the rate of permanent deformation (rutting) from a moving, concentrated load. After preparation of asphalt concrete slab, it placed up on the plate which will move backwards and forwards under the loaded wheel which applies about 700 N of load at a contact points and passes repetitively over the slab for up to 10000 cycles with a constant load frequency of 26 load cycle per minute. Measuring the rut depth of each group of passes is done by recording the reading from the dial gauge. The test is stopped either when the passes are reached to 10000 load cycles or when 25 mm maximum allowed deformation is reached. Figure 15 shows slabs testing by using locally manufactured Wheel Tracking Device by the author and Ph.D. student Mohammed Assi. Wheel Tracking Test was conducted at Al- Nahrain University, civil engineering laboratory.

8. Results
8.1 Effect of Aggregate Gradation
The major portion in the asphalt pavement is aggregate. In this study two gradations of aggregate are used to produce hot mix asphalt in Iraq. They are: coarse gradation which is near to the lower limit of specification and fine gradation which is near to the upper limit of specification. From Figure 16, it is clear that fine gradation is more resistance to rutting than coarse gradation by 87% at 10000 cycles. Also, from Figure 17, it is found that at a temperature of 60 °C, the coarse gradation failed at 2500 cycles whereas the fine gradation failed at 3000 cycles. This gives an indication that fine gradation is failed at number of cycles more than the coarse gradation by 17% at 60 °C. Fine gradation mixture provides more resistance to permanent deformation and this can be attributed to the proper interlock among fine crushed aggregate and hence, the percentage of air voids will be reduced in the asphalt pavement mixture. As a result the permanent deformation is minimized and the resistance to rutting will be increased, while coarse gradation is subjected to segregation within the sample of coarse mixture; therefore, mixtures showed higher deformation. It can be concluded that fine gradation mixture is more resistance to permanent deformation. These results and conclusion confirm with the results and conclusions which were obtained by Golalipour et al. [12]. They concluded that the mixture which is near to the lower limit of specification revealed lower resistance to rutting.

![Figure 15. Manufactured wheel tracking test device and tested sample.](image)

![Figure 16. Effect of aggregate gradation on rutting at 40 °C.](image)

![Figure 17. Effect of aggregate gradation on load cycles at 60 °C.](image)
8.2 Effect of Hybrid Elastomer and Plastomer Polymer Modifiers

Figure 18 shows the effect of using different percentages and types of polymers on permanent deformation for fine and coarse gradation mixtures. It can be observed that the rut depth decreases by 73.97% and 51.6% when 3% SBS polymer is used for fine and coarse gradation mixtures respectively, while using 1% and 3% PVC can reduce rut depth by 61.64% and 70.03% for fine gradation mixtures respectively, and by 39.07% and 47.85% for coarse gradation mixtures respectively. Moreover, from Figure 18 it is found that using of 1% and 3% PVC with 3% SBS (hybrid modified asphalt) can decrease rut depth by 88.01% and 96.58% for fine gradation mixtures respectively, and by 59.38% and 69.17% for coarse gradation mixtures respectively. The reduction in the rut depth that occurred by using 3% SBS can be attributed to the fact that when SBS is mixed with bitumen, the elastomeric phase of the SBS absorbs the oil fractions from the bitumen and swells up to nine times as much as its initial volume and install a physical network between the asphalt binder and the polymer. This instillation will lead to increase the complex modulus and participate to the adhesion ability of the aggregate in the hot mix asphalt, as a result, increase resistance to permanent deformation [13]. From Figure 18, It can be seen that the reduction in rut depth is increased as the percentage of PVC is increased from 1% to 3%, this can be due to the installation of a polymer network and the spatial location of the atoms around the C-Cl and C-H chains in the chemical structure of PVC as shown in Figure 19 and as a result, increases the resistance of the asphalt mixture to rutting [14, 15]. Also, PVC tends to reduce the percentage of air voids in the mix by filling the voids that are not filled with fine materials or mineral fillers; therefore pavement becomes more stable under the effect of the applied loads. Consequently, the pavement having better resistance to permanent deformation than unmodified pavement [16]. Because of blending both elastomer (SBS) and plastomer polymers (PVC) together, therefore, the properties of the mixtures are strongly related to the properties of these two polymers. So, the best resistance to permanent deformation is provided when using hybrid elastomer and plastomer polymers which can be attributed to the properties of SBS and PVC. Firstly, by formation of a polymer network and secondly, by reduction the percentage of air voids in a mix which is achieved when using PVC. While when mixing SBS with bitumen, it absorbs the oily fractions from the bitumen and then it swells up to nine times higher than its initial volume and constructs a strong network between the asphalt binder and the polymer. This construction will lead to increase the complex modulus and hence increase resistance to permanent deformation by reducing the rut depth. Therefore, modifying asphalt binder with hybrid elastomer and plastomer polymers gives the pavement the best enhancement to rutting compared with the other polymers as demonstrated in Figure 18. Generally, reduction of the rut depth will lead to the reduction in the aggregation of water on the pavement surface which is leading to drive safety, in addition to the reduction in the costs of maintenance during the service life of the pavement by reducing the percentage of damage that is resulted from moisture. From the above results, it can be concluded that by mixing elastomer and plastomer polymers together i.e. (PVC+SBS) the mixture become stiffer due to the properties of both PVC and SBS as compared with control mix and with mix modified with 1% or 3% PVC only.

![Figure 18](image)

**Figure 18.** Effect of hybrid elastomer and plastomer polymer modifiers on rutting for fine and coarse gradation mixtures at 10000 cycles.
8.3 Effect of Temperature

For fine gradation mixtures, it is found from Figure 20 that modifying asphalt with 3% SBS can decrease rut depth by 90.04% as compared with the rut depth that occurs in the control asphalt binder mixtures at temperature of 60 °C and at 3000 cycles where the maximum allowable failure (25 mm) for the control asphalt is reached, while modifying asphalt with 1% and 3% PVC reduces rut depth by 64.8% and 89.52% respectively. Furthermore, for hybrid elastomer and plastomer modified asphalt it is obvious from Figure 20 that modifying asphalt with 1% PVC plus 3% SBS can decrease rut depth by 92.6%, while modifying asphalt with 3% PVC plus 3% SBS causes a significant pronounced reduction in the rut depth by 98.08%.

For coarse gradation mixtures, it is evident from Figure 21 that modifying asphalt with 3% SBS can reduce rut depth by 89.68% as compared with the rut depth that occurs in the control asphalt binder mixtures at a temperature of 60 °C and at 2500 cycles where the maximum allowable failure (25 mm) for the control asphalt is reached, whereas modifying asphalt with 1% and 3% PVC decreases rut depth by 60.2% and 86% respectively. Furthermore, for hybrid modified asphalt it is obvious from Figure 21 that there is a great effect when modifying asphalt with 1% PVC plus 3% SBS where the rut depth is decreased by 91.88%, while modifying asphalt with 3% PVC plus 3% SBS decreases rut depth by 96.84%.
Based on results above, it is concluded that using a hybrid elastomer and plastomer polymer of 3% PVC plus 3% SBS followed by 1% PVC plus 3% SBS are more suitable percentages to be used as modifiers in hot climate country where it is anticipated that the temperature may reach 60 °C. The higher reduction in the percentage of rut depth that is achieved by using hybrid elastomer and plastomer polymers is attributed to the properties of PVC and SBS. PVC has high softening temperature which is around (100-260°C), so, PVC increases the softening point of the asphalt binder [17]. Also, the increase in softening point is due to the arrangement of particles and their interconnection with each other strongly, especially when increasing the temperature which leads to increase cohesion between the chains linked to each other and thus give better resistance to permanent deformation [18]. Moreover, adding of PVC increases the viscosity of the binder. Increasing viscosity means that cohesion will increase and thus stability is increased and as a result, the asphalt pavement is higher resistant to rutting as compared with unmodified asphalt mixtures in hot climate [19]. From Table 6, it is found that the viscosity of asphalt binder increased about 198% when modifying asphalt with 3% SBS while there is no significant effect on viscosity when modifying asphalt with 1% and 3% PVC where viscosity increased by 58% and 73% respectively, therefore; it is not required to increase the temperature of mixing and compaction. So, these values may be suitable for good workability and pump-ability according to superpave specifications. From other side, the presence of SBS plays an important role in the enhancement of hot mix asphalt to permanent deformation where, SBS provides a rubber-elastic network between the polymer and the bitumen. This network increases the complex modulus which gives an indication about resistance to rutting and provision good elastic characteristics of the modified bitumen. The magnitude of complex modulus is obtained from DSR test.

### Table 6. Viscosity at 135 °C for control and modified asphalt binder

| Type of modifier | control | 3% SBS | 1% PVC | 3% PVC | 1% PVC + 3% SBS | 3% PVC + 3% SBS |
|------------------|---------|--------|--------|--------|----------------|----------------|
| Viscosity Pasec at 135 °C | 0.6     | 1.788  | 0.95   | 1.038  | 2.133          | 2.588          |

9. Conclusions

In this research, asphalt binder is modified by using elastomer and plastomer polymers and asphalt mixtures resistance to rutting made by the modified binder are assessed. The main conclusions drawn from laboratory test results are presented as follow:

1. From wheel-tracking test, it is concluded that resistance of asphalt pavement to permanent deformation affected by the gradation of aggregate. Fine gradation mixture is more resistance to rutting than coarse gradation mixture by 87%.
2. Fine gradation mixture is failed at number of cycles more than the coarse gradation mixture by 17% at 60 °C.
3. Using hybrid elastomer and plasteromer polymers of 3% PVC plus 3%SBS followed by 1%PVC plus 3%SBS can significantly reduce rut depth at 60 °C by 98.08% and 92.6% respectively. Therefore, it is recommended to use these percentages which are more suitable to be used as modifiers in hot climate country which is anticipated that the temperature may be reached to 60 °C.

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