Reducing Rutting in Flexible Pavement Using Specified Polymers with HMA

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Abstract. Iraqi roads mainly suffer from rutting distresses which resulting from extremely axle loading and high difference in temperature between seasons and even in day and night for the same day. Different types of modifier polymer have been inserted into asphalt materials to enhance the characteristics of asphalt concrete mixture as a whole. Thus, this paper has generally been dedicated to investigate the effect of using two types of polymers; Styrene-Butadiene-Styrene (SBS) and High-Density Polyethylene (HDPE) on the rutting distress. Accordingly, five ratios (4%, 6%, 8% and 10%) of SBS and HDPE have been used as a percentage of total mix in order to get the optimum influence of each ratio. Hence, the best ratios for surface (Type III A) layer are 8% HDPE and 6% SBS; whereas these ratios for binder layer are 6% HDPE and 2% SBS. The results indicate that the reduction in rutting percent are (72% and 65%) for HDPE and SBS for each type of additives at 40ºC. Accordingly, this means these types of polymers have a significant role in reduction of rutting in surfacing and binder layers.

Keywords: Hot Mix Asphalt, High-Density Polyethylene, Styrene-Butadiene-Styrene, rutting distress.

1. Introduction

The reviewing of appropriate existing literature revealed that several detrimental types of distresses may influence on flexible pavement within its service life. Traffic load, weather and construction practices are one of the causes that lead to such distresses. Some of these distresses are rutting, shoving, fatigue and stripping; which may cause the functional failure and even the structural failure of the flexible pavement. The influence of these distresses may reflect uncomfortable ride to drivers (Hafeez et al., 2013; Sorum et al., 2014; White, 2018; and Bala et al., 2018).

In this era, using modified asphalt binders in constructing flexible pavement is widely spreading.
Modifiers, such as styrene-butadiene-rubber (SBR) and high density polyethylene (HDPE), can enhance the physical and rheological properties of asphalt materials (Lu and Isacsson, 2001). HDPE improves the elastic properties of asphalt cement at high temperature wherever permanent deformation influences the pavement. As the percentage of HDPE increases, the mechanical behavior improves (Perez-Lepe, et al., 2005 and Razak, 2015).

In fact, rutting decreases the beneficial service life of the pavement and generates severe risks for road operators by influencing car handling characteristics. In Iraq, rutting problems can be witnessed at some sites in the roads because of the heavy axle loading and high temperature at summer seasons (Yassoub, 2005). Utilizing recent technologies to enhance pavement effectiveness and increase its service life which is a significant measure of pavement designing and rehabilitating systems. Several technologies may offer benefits such as improving pavement effectiveness, one of these technologies is additives (Ai-Qadi and Appea, 2003). The stripping distresses are triggered by the weak bond of the bitumen binder to specific aggregates, particularly in the existence of water. Therefore, a serious need for recent or modified binders is required (Fernando and Gurguis, 1983). The usage of Polymer-Modified Asphalt (PMA) to attain improved flexible pavement performance has been noticed for a long term. The enhanced functional properties contain permanent deformation, fatigue, low temperature cracking, and aging (Raad et al., 1996). Recent studies indicated that the characteristics of PMA are mainly based on the polymer properties, polymer content and binder origin in addition to the mixing process. Regardless of the high polymeric products, there are somewhat few kinds which are appropriate to asphalt binder modification, when utilized as asphalt modifiers. Particular polymers have to be appropriate to asphalt binder, be able to be processed by conventional blending and laying apparatus, and be capable of maintaining their superior properties during blending and application in service. utilizing a modifier has to also be cost-effective (Al-Bana’a, 2010). Polymers can be categorized as elastomers and plastomers. Elastomers, at primary low strain level, can add just slight strength to the binder; whereas these polymers could be elongated out and become stronger at high strain and return as the applied load is left. Plastomers is a rigid three-dimensional network and indicates tensile strength under high load whereas crack at higher strains. The roads have indicated initial marks of distresses because of the severe weathering conditions and heavy traffic loads. The high temperature on the pavement surface may be 60°C in Iraq in summer which decreases the stiffness of paving mix and accordingly leads to pavement deformation (Al-Abdul Wahhab et al., 1996). Al-Khatheeb, et. al., (2011) used ABAQUS program to inspect the static repetitive load influence on rutting of asphalt pavement structure. They confirmed that the depth of rut rises with growing temperature and tire pressure and reducing subgrade strength. Hossain et al., (2019) used SBS, HDPE, polyphosphoric acid (PPA), polyethylene (PE) and crumb rubber (CR) to improve a neat bitumen binder (PG 64-22). They noticed a significant improvement in asphalt characteristics such as increase in SBS percentage rises the ductility and an increase in HDPE percentage reduces the ductility in the studied rates.

Ibrahim (2019) investigated the effect of 5% HDPE on dense-graded Hot Mix Asphalt (HMA) and stone mastic asphalt mixtures. These mixes were exposed to aging process at 100°C with different levels of aging for 48 and 96h. Then, these effects have been characterized by Marshall stability, indirect tensile strength, tensile strength ratio, and resilient modulus. Moreover, other characteristics, such as penetration, ductility, softening point, loss of heat and air (aging) have been evaluated, too. The results reveals that the 5%HDPE for dense-graded asphalt and stone mastic asphalt mixtures are higher 1.4 for indirect tensile strength under 48h and 96 h aging than the control mixes. Whereas, the same behavior has been observed for tensile strength ratio, and resilient modulus (Ibrahim, 2019). On the other hand, some studies found that using 5% of HDPE improved asphalt mix effectiveness (Al-Hadidy and Yi-qiu, 2009; Al-Hadidy, 2018a and 2018b; and Attaaelmanan et al., 2011). Moreover, even using reclaimed PE can improve the characteristics of HMA such as increasing the tensile strength of the asphalt mixtures at low temperatures (5°C) which may reduce the cracking potential of pavements at low temperatures (Punith and Veeraragavan, 2007). The authors found that the optimum PE content required for improving the performance of asphalt concrete mixtures is 5% by weight of asphalt for 80/100-grade asphalt cement.
Recently, Abed and Bahia (2020) found out the effect of using HDPE and SBS modifiers on the asphalt binder and asphalt concrete mixtures. The used asphalt was PG (64-16) with 3% and 5% of nano-HDPE and SBS, respectively, by weight of total asphalt binder. The results of their research indicated that HDPE could be utilized as a significant modifier with lower blending and compaction temperature in addition to equal or considerably better rutting and strength performance than traditional SBS Modifier.

The permanent deformation of flexible pavements has a main effect on the performance of pavement. The accumulation of plastic deformations within asphaltic layers has been recognized as one of the main reasons of rutting in asphaltic pavements. Rutting was the chief distress in Iraq resulting from the excess axle loads and high local summer temperature. The objective of this paper is to investigate the effect of using HDPE and SBS with five different ratios of both of these modifiers at 40ºC to reduce the rutting in asphalt mixture for both binder and wearing layers.

2. Research methodology
It is noteworthy to highlight that the current study has used two modifiers (i.e., HDPE and SBS) with five percentages (2%, 4%, 6%, 8% and 10%) for wearing and binder courses to reduce rutting failure. Then, wheel tracking test has been implemented to assess the rutting distress.

3. Materials and testing methods
The used materials in the current study are locally existing and commonly utilized for constructing the pavement in Iraq. The asphalt cement used here is (40-50) penetration grade gained from Al-Daurah refinery in Bagdad. Table 1 reveals the physical properties of the asphalt cement that have been tested in civil engineering department lab at university of kufa.

| Test                                | Unit | Tested results | SCRB  |
|-------------------------------------|------|----------------|-------|
| Penetration ((ASTM-D5))             | 0.1mm| 46             | 40-50 |
| Ductility ((ASTM-D113))             | cm   | 112            | >100  |
| Flash point ((ASTM-D92))            | °C   | 261            | >232  |
| Solubility ((ASTM-D2042))           | %    | 99.2           | >99   |
| Specific Gravity 25°C ((ASTM-D70)) |       | 1.01           | ---   |

As indicated in Table 1, all physical characteristics such as the penetration, ductility, flash point, solubility are satisfied with the Iraqi specifications. These tests have been implemented according to ASTM as shown in Table 1.

Two maximum sizes of 25mm and 19mm were used to aggregate gradation adopted by SCRB specifications for wearing and binder courses and two categories of additives (HDPE, SBS) as modifies to use in HMA. The selected gradation is in line with the mid-limits gradation of the SCRB specification (2003). Table 2 demonstrates the gradation for wearing layer and Table 3 indicates the gradation for binder layer. The gradation for both layers is fallen within the required limits.
Table 2. Gradation of aggregate for wearing layer.

| Sieve size | Sieve opening (mm) | Percentage passing by weight of total aggregate | Finer wearing course Type III A (%Passing by weight of total aggregate + Filler) |
|------------|--------------------|---------------------------------------------|---------------------------------------------------------------------------------|
|            |                    | Specification limits (SCRB, 2003) | Mid-point gradation |
| 3/4"       | 19.00              | 100.00                                   | 100.00                                                                          |
| 1/2"       | 12.50              | 90-100                                   | 95                                                                              |
| 3/8"       | 9.50               | 76-90                                    | 83.00                                                                           |
| No.4       | 4.75               | 44-74                                    | 59.00                                                                           |
| No.8       | 2.36               | 28-58                                    | 43.00                                                                           |
| No.50      | 0.30               | 5-21                                     | 13.00                                                                           |
| No.200     | 0.075              | 4-10                                     | 7.00                                                                            |
| Asphalt content (%) |                | 4-6                                      | ----                                                                           |

The HDPE is obtained from Iran, which is a white color with density greater than 0.941 and less than 0.965. It is a plastomers thermoplastic polymer material which consists of carbon and hydrogen atoms forming a product with a high molecular weight changing into ethylene. Subsequently, applying heat and pressure converts the HDPE into polyethylene. This material consists of 500,000 to 1,000,000 carbon units long. Consequently, the longer chain molecules have the large the number of atoms which has the heavier the molecular weight. This could be a measure of several mechanical and chemical properties of the resulted product.

The physical properties of optimum asphalt binder with the addition of polymers are indicated in Table 4. The results of tests indicate that adding 8% HDPE leads to reduction in some characteristics from the specifications such as penetration, ductility and ductility of residue. This could be attributed to its effect of HDPE on the asphalt nature.

The SBS is widely used as an asphalt polymer modifier. This modifier was obtained from Baghdad, Iraq. The modifier is used as an asphalt modification. The SBS can be found in various lengths with different arrangement of the molecules. These differences could mainly be due to the effect of modification produced by the SBS, in addition to the ease of mixing and the storage stability.

Table 3. Gradation of Aggregate to Level (binder) Course.

| Sieve size | Sieve Opening (mm) | Percentage passing by Weight of total Aggregate | Finer leveling (binder) Course Type II (%Passing by Weight of Total Aggregate + Filler) |
|------------|--------------------|---------------------------------------------|---------------------------------------------------------------------------------|
|            |                    | Specification Limits (SCRB, 2003) | Mid-point Gradation |
| 1"         | 25.00              | 100.00                                   | 100.00                                                                          |
| 3/4"       | 19.00              | 100.00                                   | 95                                                                              |
| 1/2"       | 12.50              | 90.00-100.00                            | 80.00                                                                           |
| 3/8"       | 9.50               | 76.00-90.00                             | 68.00                                                                           |
| No.4       | 4.75               | 44.00-74.00                             | 50.00                                                                           |
| No.8       | 2.36               | 28.00-58.00                             | 36.00                                                                           |
| No.50      | 0.30               | 5.00-21.00                              | 12.00                                                                           |
| No.200     | 0.075              | 4.00-10.00                              | 6.00                                                                            |
| Asphalt content (%) |                | 4.00-6.00                              | ----                                                                           |
Table 4. Some properties of modified asphalt with (8%) HDPE.

| Test                                | Unit | The results | SCRB |
|-------------------------------------|------|-------------|------|
| Penetration ((ASTM-D5))             | 0.1mm| 23.00       | 40.00-50.00 |
| Ductility (ASTM-D113)               | cm   | 35.00       | > 100.00   |
| Flash point ((ASTM-D92))            | °C   | 251.00      | ≥ 232.00   |
| Solubility ((ASTM-D2042))           | %    | 99.70       | > 99.00    |
| After Thin-Film Oven Test (ASTM-D1754) |       |             |        |
| Retained penetration ((ASTM-D5))    | %    | 84.00       | > 55.00%   |
| Ductility of residue ((ASTM-D113))  | cm   | 16.00       | > 25.00    |
| Loss in weight ((ASTM-D1754))       | %    | 0.35        | ≤ 0.75     |

A copolymer has two various kinds of repeating molecular units, the most widespread co-monomer utilized with styrene is butadiene. Block copolymers, such as SBS, have these repeating molecular units in a frequently happening block pattern. The SBS binders have the capability to withstand long-term deformation and to reduce fatigue and cracking due to low temperature. The physical properties of optimum asphalt cement when with the addition of polymers as indicated in Table 5. The addition of SBS, as indicated Table 5, has approximately the same behavior in reduction some of the physical characteristics (penetration and ductility) of the modified asphalt.

Table 5. Some properties of modified asphalt with (6%)SBS by weight of asphalt.

| Test                                | Unit | Tested results | SCRB |
|-------------------------------------|------|----------------|------|
| Penetration ((ASTM-D5))             | 0.1mm| 34.00          | 40.00-50.00 |
| Ductility (ASTM-D113)               | cm   | 53.00          | > 100.00   |
| Flash point ((ASTM-D92))            | °C   | 251.00         | ≥ 232.00   |
| Solubility ((ASTM-D2042))           | %    | 99.50          | > 99.00    |
| After Thin-Film Oven Test ASTM D 1754 |       |                |      |
| Retained penetration ((ASTM-D5))    | %    | 94.00          | > 55.00%   |
| Ductility of residue ((ASTM-D113))  | cm   | 38.00          | > 25.00    |
| Loss in weight ((ASTM-D1754))       | %    | 0.35           | ≤ 0.75     |

4. Permanent deformation test

There were two main categories of rutting: HMA rutting and subbase rutting. Asphalt mix rutting occurred as a lower layer did not rut until the pavement surface reveals wheel path distresses because of compaction and insufficient mixture design. Granular material/subgrade rutting happens as the layers displayed wheel path depressions because of extreme loading. The asphaltic slab specimens used for rutting test. The roller compactor device could compact asphaltic layers to a required density utilizing loads per unit roll width, which have been satisfied with those pavements rollers utilized in the road construction. The roller compactor gives a pneumatically powered means of compacting layers of bitumen material in the laboratory with conditions, which simulate in-situ compaction as demonstrated in Figure 1.

Figure 2 demonstrates the dimensions of samples (400 mm × 300 mm × 40 mm) for surface layer and (400 mm × 300 mm × 60 mm) which is assigned for binder layer. Rutting testing were achieved at 4% AV by roller compactor device at National Central of Construction Laboratories (NCCL) consistent with (EN12697, 2003). The mass of the asphaltic mix is a function of several factors as demonstrated in Eq. 1 (EN12697, 2003):
\[ M = 10^6 \times L \times I \times e \times \rho_{mx} \times \left( \frac{100-v}{100} \right) \]  

(1)

Where:

- \( M \): is the weight of slab (kg);
- \( L \): is the interior length of mold (mm);
- \( I \): is the interior width of mold (mm);
- \( e \): is the compacted thickness of slab, in millimeters (mm);
- \( \rho_{mx} \): is the max. theoretical density of an asphalt mix, (kg/m³);
- \( v \): is the air voids in slab (%);

**Figure 1.** Wheel Tracking Test for Compacting Slab for NCCLR in Baghdad.

The weight of sample to surface and binder layers as in Eq. (1) are 10.828 kg and 16.243 kg; respectively. Based on the test scale, the samples were loaded ranging from full size to small tries. The sample in wheel-tracking tests was loaded frequently by moving the wheel on the sample. Whereas, in the case of small scale wheel tracking tests, by moving the specimen under the load.

**Figure 2.** Steel Mold and Specimen.
The samples were usually loaded in one direction. Furthermore, some wheel tracking tests have the facility of crossing to simulate wheels roaming. The experiment was done at specified temperatures or in representative climatic conditions by making pavement sections outside. The sample was loaded at determined passes and the central depth of rut for the loaded region and/or transverse section profile observed with time or the number of load passes as demonstrated in Figure 3. The test was implemented consistent with (EN 12697-22, 2003) where it provided with the rate of permanent deformation from moving and concentrated loads. It used a Linear Value Displacement Transducer (LVDT) to determine the deformation of the sample. The loaded wheel used about (700±10) N of load at contact points and passed repetitively over the specimen up to 10,000 cycles. The center line of the tire path (0.5cm) was from the center of the sample. The center contact area of the frame represents a simple harmonic motion related to the center of the upper surface of the test sample having a total transmission distance of (23.0 ± 1.0) cm. Continuous loading frequency of (26.5 ± 1.0) loading cycle per 1 min of the test device in about 10,000 loading cycles or 2.0 cm with a maximum of acceptable deformation gotten. The design of a permanent deformation test experiment is a full factorial with two asphalt contents, one test temperature (40° C), one type of asphalt which is either native or modified with best percent of (SBS and/ HDPE) and two types of aggregate grading (surface and binder). The compressed samples (400 mm x 300 mm x 40 mm) for the surface layer and (400mm x 300mm x 60mm) for the binder layer were cooled to room temperature for 24 hours in line with (EN-12697-22, 2003).

5. Results and discussion
The test results are gained including the impact the polymer types on modified asphalt concrete mixtures used in construction of wearing and binder courses. Table 6 indicates the results of Marshall tests which are conducted in this study such as stability, bulk density voids in total mix (VTM), and voids in mineral aggregate (VMA) and the optimum asphalt content. The Marshall properties of (wearing and binder) mixtures are consistent with the Iraqi specifications limits (SCRB, 2003).
Table 6. Asphalt Mixtures Properties and Specification limit S. C.B.R for two layers.

| Properties               | Wearing Layer | S.C.R.B Specification | Binder Layer | S.C.R.B Specification |
|--------------------------|---------------|------------------------|--------------|-----------------------|
| Marshall Stability (KN)  | 11.21         | 8 min                  | 9.17         | 7 min                 |
| Marshal Flow (mm)        | 3.05          | 2-4                    | 3.21         | 2-4                   |
| Bulk Density             | 2.327         | ----                   | 2.283        | ----                  |
| VTM. (%)                 | 4.02          | 3-5                    | 4.05         | 3-5                   |
| VMA (%)                  | 15.67         | 14 min                 | 16.31        | 13 min                |
| Optimum AC (%)           | 4.90          | 4-6                    | 4.60         | 4-6                   |

The permanent rutting resistant for surface layer has been assessed utilizing wheel track test. The permanent deformation test is an experimental with two asphalt contents, one testing temperature, two kinds of additive, the details of testing variables could be clarified, as follows:

The optimum asphalt content obtained has two values 4.6% and 4.9% for binder and surface (Type IIIA) layers, respectively, by the weight of total mixture. In this study, the testing temperature is 40°C. Generally, two types and two ratios of polymers have been used; (8%HDPE, 5% SBS) for surface (Type IIIA) layer and (6%HDPE, 2% SBS) for binder layer. Cycles Rate: samples have been tested with one cycling rate; 26.5 cycle/minute. The limitation of the test is in line with EN 12697-22(2003) (put the machine in motion and determine readings at the vertical displacement of the wheel, primarily, thereafter as a minimum 6 or 7 times in the first hours, and as a minimum one reading every 500 load cycles thereafter. The perpendicular position of the wheel has been identified as the average value of the profile of the sample n a length of ± 50 mm about the center of the loading area at the center of traverse, determined in as a minimum 25 points almost correspondingly spaced. The wheel vertical position is determined without bringing it to a stop. Tracking until being continued 10000 load cycles were applied or until a depth of rutting 20 mm was (whatever is the smaller). Table 7 demonstrates the depth of rutting for modified asphalt mixes. Figures (4, 5 and 6) indicate the influence modified mixes on the depth of rutting at 40°C testing temperature for the used additives (HDPE, SBS) at 10000 cycle. Table 8 demonstrates the rut depth (RD) for the optimum asphalt content (4.6 and 4.9) % for the two layers with different percent of HDPE and SBS. The value of RD is much less in the modified mixes than unmodified ones.

Figure 4. Influence of modified mixes on permanent deformation for two layers.
Table 7. The depth of rutting for wearing (Type III A) and binder Layers

| Type of additives | AC (%) | Additive (%) | Thickness (mm) | IR (%) | modified asphalt samples |
|-------------------|--------|--------------|----------------|--------|--------------------------|
| control           | 4.9    | 0            | 10             | 0      |                          |
|                   | 4.6    | 0            | 10             | 0      |                          |
| HDPE              | 4.9    | 8            | 10             | 72     |                          |
|                   | 4.6    | 6            | 10             | 72     |                          |
| SBS               | 4.9    | 6            | 10             | 48     |                          |
|                   | 4.6    | 2            | 10             | 48     |                          |

Table 8. Modified asphalt layers with improved ratio comparing with unmodified asphalt at 10000 cycle

| Optimum Asphalt Content(%) | Thickness (mm) | Polymer percent (%) | Temperate (C°) | Unmodified mixtures RD(mm) | modified mixtures RD(mm) |
|----------------------------|----------------|---------------------|----------------|---------------------------|----------------------------|
| (4.6 & 4.9)%               | 10             | 8% HDPE 6% HDPE     | 40             | 13.27                     | 3.69                       |
| (4.6 & 4.9)%               | 10             | 6% SBS 2% SBS       | 40             | 13.27                     | 6.97                       |

Figure 5 indicates the rutting depth values for modified and unmodified asphalt layers at 10000 cycle and two categories of modifiers. While the number of cycles increases from 0.0 to 10000 for the control mix, the depth of rutting increases from approximately zero value to approximately 13mm. This demonstrates how the number of cycles has the significant effect on developing the rutting distress. Whereas, using SBS reduces the depth of rutting to approximately 7mm which is approximately the half for the control mix. Similarly, using HDPE reduce the value of rutting depth up to half value for the SBS modifier.
Figure 5. The depth of rutting for each polymer at temperature of 40ºc.

Figure 6 demonstrates the difference in the Improvement Ratio (IR) of the RD at 40°C for the two layers. The results reveal that also modified mixes give higher values of IR than unmodified mixes.

6. Conclusions and recommendations

All conclusions for modified mixtures (improvement mixtures performance) as percentages for optimum content of polymers compared with control asphalt mixtures. The modified mixes with Polyethylene and SBS have higher performance properties rather than the other types of polymers, therefore the best plastomers polymer is HDPE and the best elastomers polymer is SBS due to HDPE have higher stiffness related to its molecule weight and SBS-copolymers have different arrangement in molecule structure from other types of polymers. The results from wheel track test indicated that the depth of rutting for the modified specimens are lower than control mixtures, therefore the resistance to permanent deformation for modified mixtures is higher than control mixtures under the test temperatures (40 Cº). It's about (72-48) % for (40 Cº) times higher than control asphalt mixture. This study contributed that the fact is SBS polymer improves the rutting resistance of asphalt mixture. The recommendation of this study is to conduct fatigue test on modified asphalt mixture to study the effect of polymer and repetition loading on fatigue life.
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