Reduced Permanent Deformation of Asphalt Pavement by Enhancing Aggregate Gradation

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Abstract. Permanent deformation (rutting Phenomena) of asphalt mixes is considered as one of the major forms of distress that affects the performance of flexible pavement structures. Many factors can cause permanent deformation to occur in asphalt mixtures, but aggregate gradation is one of the key factors responsible for this deterioration.

In this study, aggregate structure was designed using the Bailey method. Eight aggregate gradations were used to analyze their effect on rutting resistance of asphalt mixtures. Three additional mixes were then designed using Styrene Butadiene Styrene (SBS) as a modifier to improve the rutting resistance. Three percentages of SBS, namely (2 %, 4 % and 6 %) by weight of asphalt cement, were mixed for 60 min at a temperature of 180°C using a shear mixer with a rotation speed of 3000 rpm.

The asphalt mixtures were subjected to rutting test using a wheel tracking device at an air void level of 4% corresponding to optimum asphalt content. The results showed that the Bailey method maintained good resistance to permanent deformation as compared to conventional mixes. Overall, mixes with coarser gradation (Bailey Parameter, CACUW, greater than 95 %) and 4% SBS modified asphalt produced more resistance to rutting.

Keywords: Aggregate Gradation, Bailey method, Rutting, wheel tracking test.

1. Introduction

Hot mix asphalt (HMA) is designed to resist all types of distresses that developed from the applied stresses. These distresses including fatigue cracking, rutting, moisture damage and thermal cracking minimize the services life of HMA and increase the maintenance costs [1]. Rutting is considered to be one of the major distresses that frequently occurs in flexible pavements due to the non-linear, viscous and plastic behaviours of asphalt mixes [2].

Rutting refers to the surface depression that form in the wheel paths that primarily occurs at high pavement temperatures under loaded conditions and in slow-moving traffic areas, especially intersections or bus lanes. However, rutting also can occur in high-speed traffic [3].

Mineral aggregates constitute a high proportion of an asphalt mixture, hence, it is predicted to have a large impact on the properties of asphalt mixtures. Aggregate gradation is considered to be one of the key factors affecting asphalt mixture performance, especially in terms of rutting resistance of asphalt.
mixtures. This research thus focuses on the permanent deformation (rutting) of asphalt mixtures as a function of aggregate gradation [4,5].

In this study, the aggregate structure of asphalt mixtures, manufactured with different gradations, was designed using the Bailey method of gradation analysis within Superpave control points. The Bailey method is a systematic approach in blending aggregates that provides good aggregate interlocking structure and develops strong aggregate skeletons to enhance both rutting resistance and durability. The Bailey method allows the designer to select an aggregate skeleton that is more resistant to permanent deformation and adjust the VMA by changing the coarse and fine aggregates’ packing to ensure that the mix has sufficient asphalt binder [6].

In the Bailey Method, the desired level of coarse aggregate interlock is selected by choosing the unit weight of coarse aggregate (Chosen Unit Weight, CUW), which is usually expressed as percent of the Loose Unit Weight (LUW) [7]. Besides using aggregate gradations designed by the Bailey method, the use of polymer modified asphalt is one of the options commonly selected for improving the rutting resistance of asphalt mixes [8]. The effect of modified asphalt binders with styrene butadiene styrene (SBS) on the rutting resistance of asphalt mixes was thus also investigated and a wheel tracking test has been used as an effective laboratory method for evaluating the rutting susceptibility of asphalt mixes [9].

2. Research Objectives
The objective of this study was to evaluate the rutting resistance of Bailey asphalt mixtures and compared with conventional asphalt mixtures. The effects of aggregate gradation using gradation parameters from the Bailey method and SBS-modified asphalt binders on the rutting parameters obtained from wheel track testing including post compaction (PC), dynamic stability (DS), and final rutting depth were also evaluated.

3. Experimental Plan

3.1. Materials Selection
The materials used in this study are widely used in asphalt paving works in Iraq. The properties of the selected materials were evaluated using traditional tests and the obtained results compared with the SCRB (R/9, 2003) [10] and Superpave requirements, as presented in the following sections.

3.1.1. Asphalt Binder. One type of asphalt cement with (40-50) penetration grade was used. This type of asphalt cement was brought from AL-Daurah refinery. Tests were carried out on the asphalt binder to determine its physical properties as shown in Table 1.

Table 1. Traditional tests of asphalt cement
3.1.2. Mineral aggregate. Crushed coarse aggregates obtained from AL-Nebai quarry in the middle of Iraq with two types of fine aggregate (crushed sand and natural sand) obtained from Al-Ekheder quarry within the Karbala Province were used. Both coarse and fine aggregates were sieved and then recombined in the proper proportions to meet the required gradation of SCRB specifications (SCRB, R/9, 2003) for surface layer. The physical properties of aggregates are shown in Table 2, and tests were implemented to make sure that the selected aggregates were appropriate for asphalt mix design, as shown in Table 3.

Table 2. Test results for aggregate specific gravity and absorption

| Test                          | ASTM Designation | Test results |
|-------------------------------|------------------|--------------|
| Coarse Aggregate              |                  |              |
| Bulk Specific Gravity         | C-127            | 2.576        |
| Apparent Specific Gravity     | C-127            | 2.626        |
| Water Absorption %            | C-127            | 0.729        |
| Fine Aggregate                |                  |              |
| Bulk Specific Gravity         | C-128            | 2.6          |
| Apparent Specific Gravity     | C-128            | 2.694        |
| Water Absorption %            | C-128            | 1.419        |

Table 3. Test results and Superpave aggregate requirements

| Test                          | ASTM / AASHTO [12] Designation | Test results | Superpave Requirements |
|-------------------------------|---------------------------------|--------------|------------------------|
| Consensus properties          |                                 |              |                        |
| Coarse aggregate angularity (CAA) | ASTM D-5821                   | 95           | Min. 95                |
| Fine aggregate angularity (FAA) | AASHTO T-304                   | 47.4         | Min. 45                |
| Flat and elongated particles (F&E) | ASTM D-4791                   | 1            | Max. 10                |
| Sand Equivalent (SE)          | ASTM D2419                    |              |                        |
| Source properties             |                                 |              |                        |
| Toughness test                | ASTM C-131                    | 15.28        | Max. 30                |
|                              | AASHTO T-96                    |              |                        |
| Soundness                     | Coarse aggregate              | 2.08         | Max. 15                |
|                              | Fine aggregate                | 3.20         |                        |
| Deleterious materials         | Coarse aggregate              | 0.2          | 0.2-10                 |
|                              | Fine aggregate                | 4            |                        |

3.1.3. Mineral Filler. Limestone dust from Karbala lime plant was used as filler material. The gradation and physical properties of the filler used are presented in Table 4.
Table 4. Properties of mineral filler

| Sieve size | % passing | SCRIB specification |
|------------|-----------|---------------------|
| 0.6 mm     | N0.30     | 100                 |
| 0.3 mm     | N0.50     | 98.4                |
| 0.075 mm   | N0.200    | 91                  |

Physical Properties
- Specific gravity: 2.727
- Plasticity Index (P.I): Non-plastic

3.1.4. Additive. Thermoplastic elastomeric polymers are usually more effective than plastomers for asphalt binder modification. The most popular thermoplastic elastomer for use as asphalt binder modifiers is styrene butadiene styrene (SBS) [13].

SBS, provided by the Kraton company, was used in this study to improve the properties of asphalt binder.

Three percentages of SBS, namely (2 %, 4 % and 6 %) by weight of asphalt cement, were added to asphalt binder using the wet process. For the purpose of preparing a homogenous asphalt polymer blend, the pure asphalt binder and SBS were mixed for 60 min at 180 °C using a shear mixer with a rotation speed of 3000 rpm.

3.2. Design Aggregate Structure based on the Bailey and Conventional Methods

3.2.1. Conventional Method. The conventional gradation was selected from the midpoint of the limits specified in SCRB (R/9, 2003), as recommended for the wearing course.

3.2.2. Bailey Method. Improved aggregate structure were designed using the Bailey method for aggregate gradation evaluation within the Superpave control points.

For a dense-graded mix design, the following information was required for the Bailey method: the unit weight for each coarse and fine aggregate and the sieve size distribution [14].

The Bailey method uses the methods outlined in AASHTO T-19 to determine the Loose Unit Weight (LUW) and the Rodded Unit Weight (RUW) for coarse aggregate and the RUW for the fine aggregate. Tables 5 and 6 show the data for LUW and RUW of each aggregate used in the study.

Table 5. Loose and Rodded Unit Weight of Coarse Aggregate (Kg/ m³)

|          | Mass of cylindrical measure +water (g) | Mass of cylindrical measure (g) | Mass of water (g) | Volume of measure (m³) | Mass of aggregate +measure (g) | Mass of aggregate (g) | Bulk density of coarse aggregate (kg/ m³) |
|----------|--------------------------------------|---------------------------------|-------------------|------------------------|-------------------------------|-----------------------|------------------------------------------|
| LUW      | 9770                                 | 322                             | 9448              | 0.00948                | 13796                         | 13474                 | 1420.2                                   |
| RUW      | 9770                                 | 322                             | 9448              | 0.00948                | 15429                         | 15107                 | 1592.3                                   |
Table 6. Rodded Unit Weight of Fine Aggregate (Kg/m³)

| RUW of fine aggregate | Mass of proctor mould + sand (g) | Mass of proctor mould (g) | Mass of sand (g) | Volume of proctor mould (m³) | Bulk density of fine aggregate (kg/m³) |
|-----------------------|----------------------------------|---------------------------|-----------------|-------------------------------|---------------------------------------|
| Natural sand          | RUW 4615                         | 2910                      | 1705            | 0.0009479                     | 1798.8                                |
| Crushed sand          | RUW 4514                         | 2910                      | 1604            | 0.0009479                     | 1692.2                                |

The Chosen Unit Weight of Coarse Aggregate (CACUW) determines the level of the aggregate interlock, which in turn specifies the types of mixture either coarse or fine graded mixture. As CACUW increases, the blend becomes coarser and vice versa [14].

In this study, eight aggregate gradations are established using a 6% passing sieve No. 200 and a 75% - 25% blend by volume of manufactured and natural sand. The change between the eight blends was in the percentages of CACUW, which ranged from 60% to 105%. The selected gradations are presented in Table 7.

Table 7. Selected Aggregate Gradations for Asphalt Concrete Mixtures

| sieve size | 60 | 70 | 80 | 90 | 97 | 100 | 102 | 105 | Superpave and Bailey Requirements |
|------------|----|----|----|----|----|-----|-----|-----|----------------------------------|
| 3/4"       | 19 | 100| 100| 100| 100| 100 | 100 | 100 | 100                              |
| 1/2"       | 12.5| 96.8| 96.2| 95.5| 94.9| 94.5| 94.3| 94.2| 94.0                              |
| 3/8"       | 9.5 | 87.1| 84.4| 81.7| 79.2| 77.5| 76.7| 76.3| 75.6                              |
| No.4       | 4.75| 74.0| 69.5| 65.2| 61.0| 58.2| 57.1| 56.3| 55.1                              |
| No.8       | 2.36| 56.3| 50.7| 45.4| 40.2| 36.8| 35.3| 34.4| 32.9                              |
| No.16      | 1.18| 39.4| 35.5| 31.8| 28.2| 25.8| 24.8| 24.2| 23.2                              |
| No.30      | 0.6 | 23.7| 21.6| 19.7| 17.8| 16.6| 16.0| 15.7| 15.2                              |
| No.50      | 0.3 | 13.6| 12.7| 11.9| 11.1| 10.6| 10.4| 10.3| 10.0                              |
| No.100     | 0.15| 8.6 | 8.4 | 8.1 | 7.9 | 7.7 | 7.6 | 7.6 | 7.5                               |
| No.200     | 0.075| 5.89| 5.88| 5.88| 5.88| 5.87| 5.87| 5.87| 2-10                              |
| CA Ratio   | 0.681| 0.615| 0.568| 0.533| 0.514| 0.506| 0.502| 0.495| 0.5-65                             |
| FAc Ratio  | 0.420| 0.426| 0.434| 0.443| 0.450| 0.454| 0.457| 0.461| 0.35-50                            |
| FAf Ratio  | 0.365| 0.387| 0.412| 0.441| 0.465| 0.476| 0.483| 0.495| 0.35-50                            |
| New CA Ratio | 0.933| 0.916| 0.896| 0.871| 0.6-1                            |
| New FAc Ratio | 0.365| 0.387| 0.412| 0.441| 0.35-50                           |
| New FAf Ratio | 0.35-50          |

After blending the aggregates using the design procedure of Bailey Method shown in Figure 1, the packing within the three portions of the combined aggregate gradation was evaluated using three different ratios: the coarse aggregate ratio CA ratio, the fine aggregate ratio of coarse portion FA_c ratio and the fine aggregate ratio of the fine portion FA_f ratio. Bailey ratios were then calculated and compared with the Bailey recommended ranges as presented in Table 7.

A gradation curve was controlled by these Bailey ratios. Figure 2 shows the aggregate gradations used to prepare the mix of the wearing course.
Figure 1. Design procedure using the Bailey method in Superpave mix design.
3.3. Determination of Mixing and Compaction Temperatures

Asphalt mix design procedures use equiviscous temperature ranges to select laboratory mixing and compaction temperatures [15]. In the equiviscous method, the viscosity of asphalt is determined at 135°C and 165°C according to (ASTM D-4402) using a Rotational Viscometer (Brookfield) [15]. The temperatures that produce asphalt viscosities of 0.17 ± 0.02 Pa.s and 0.28 ± 0.03 Pa.s are established as the mixing and compaction temperatures, respectively. In order to estimate the mixing and compaction temperatures, asphalt viscosity was thus plotted against temperature as shown in Figure 3.

![Figure 3. Mixing and compaction temperature chart](image-url)
From the chart, the mixing and compaction temperatures for asphalt binder of (40-50) penetration grade are 161 and 150°C respectively.

3.4. Determining Optimum Asphalt Content (OAC)
Cylindrical specimens of 150 mm in diameter and 115 mm in height, with total aggregate mass of 4700 g were used for this purpose, as recommended by the Asphalt Institute [15]. The aggregate and asphalt binder were oven heated at the mixing temperature before mixing, then mixed in the mechanical mixer. The loose mixtures were aged for 2 hours at the compaction temperature and then placed in the gyratory mould and compacted using a gyratory compactor at the compaction temperature using the gyration number-controlled mode [15]. Specimen preparation was performed in accordance with AASHTO T-312.

Three specimens for each gradation were compacted at different asphalt contents to calculate the OAC. Optimum asphalt content was selected at 4.0 % air voids at N_{des} and must verify the other mixture properties conformed to the specifications as indicated in Table 8.

### Table 8. Design Mixture Properties

| Spec. | Test result | Spec. | Test result | Spec. | Test result | Spec. | Test result | % G_{mm} @ N_{max} | Dust proportion | VFA | VMA | % G_{mm} @ N_{ini} | OAC | CACUW |
|-------|-------------|-------|-------------|-------|-------------|-------|-------------|-------------------|-----------------|-----|-----|-------------------|-----|-------|
| 60    | 96.65       | 1.108 | 75          | 16.14 | 87.15       | 5.7   | 60          | ≤ 89              | 0.6–1.2         |     |     |                   |     |       |
| 96.61 |             | 1.137 | 74.5        | 15.7  | 87.8        | 5.6   | 70          |                   |                 |     |     |                   |     |       |
| 97.42 |             | 1.18  | 74          | 15.58 | 87.2        | 5.3   | 80          |                   |                 |     |     |                   |     |       |
| 96.80 |             | 1.18  | 73.5        | 15.08 | 87.3        | 5     | 90          | ≤ 89              | 65–75           |     |     |                   |     |       |
| 97.14 |             | 1.18  | 72.5        | 14.36 | 87.4        | 5.1   | 97          |                   |                 |     |     |                   |     |       |
| 96.30 |             | 1.3   | 71.7        | 14    | 87.1        | 4.9   | 100         |                   |                 |     |     |                   |     |       |
| 96.93 |             | 1.24  | 72          | 14.25 | 87.4        | 5.1   | 102         |                   |                 |     |     |                   |     |       |
| 97.56 |             | 1.18  | 72          | 14.3  | 87         | 5.4   | 105         |                   |                 |     |     |                   |     |       |

3.5. Slab Preparation by Roller Compactor
Asphalt concrete slabs were prepared and compacted to the target density using a roller compactor shown in Plate (1) according to (BS EN 12697-35:2016) [16]. The dimensions of the asphalt concrete slabs used are of (400 mm length× 300 mm width × 40 mm height) as proposed by (EN 12697-Part 22:2003) [17]. The weight of the bituminous mixture required for the manufacture of asphalt slabs was calculated using equation (1).

\[
M = 10^6 \cdot L \cdot I \cdot e \cdot \rho_m \cdot \frac{100-V}{100} \quad (1)
\]

where
M is the mass of asphalt concrete slab, kg
L is the length of mould, mm
I is the width of mould, mm
e is the thickness of asphalt concrete slab, mm
\( \rho_m \) is the maximum theoretical specific gravity of a bituminous mixture, kg/m³
V is the air voids level in slab, in percent (%).

The weight of specimen for eight aggregate blends according to equation (1) are summarised in Table 9.
Table 9. Weight of specimens for wheel tracking test

| Mass (kg) | V (%) | $G_{mm}$ (kg/m³) | t (mm) | w (mm) | L (mm) | CACUW |
|-----------|-------|------------------|-------|--------|--------|-------|
| 11.232    | 4     | 2.438            | 40    | 300    | 400    | 60    |
| 11.260    | 4     | 2.444            | 40    | 300    | 400    | 70    |
| 11.225    | 4     | 2.436            | 40    | 300    | 400    | 80    |
| 11.241    | 4     | 2.440            | 40    | 300    | 400    | 90    |
| 11.326    | 4     | 2.458            | 40    | 300    | 400    | 97    |
| 11.350    | 4     | 2.463            | 40    | 300    | 400    | 100   |
| 11.324    | 4     | 2.457            | 40    | 300    | 400    | 102   |
| 11.352    | 4     | 2.464            | 40    | 300    | 400    | 105   |

The aggregate and asphalt binder were heated in the oven and brought to the required mixing temperature for at least two hours before mixing. Then, the weighed aggregate sample and required asphalt binder were placed in the preheated mixing bowl and mixed using a mechanical mixer at the mixing temperature for approximately 3 minutes for unmodified asphalt binder and 5 minutes for SBS-modified asphalt binder.

After the mixing process was completed and the aggregate particles were well coated with binder, the loose mixture was placed in the oven for 2 hours at a temperature equal to the mixture’s compaction temperature for short-term aging. Then, the mixture was removed from the oven and spread in a preheated mould with a shovel. The mixture was then tamped throughout, including the corners, and compacted to an air void level of 4% using the roller Compactor according to (BS EN 12697-33:2003)[18].

The applied loads on the specimens are from 0.5 to 4 kN in five steps to achieve proper compaction and sufficient air voids, as shown in Table 10 and Plate 2.

Plate 1. Roller Wheel Compactor Machine with a slab specimen.
Table 10. The variable loads applied on the specimens.

| Step | F (KN) | Cycles No. |
|------|--------|------------|
| 1    | 0.5    | 5          |
| 2    | 1      | 5          |
| 3    | 2      | 5          |
| 4    | 3      | 5          |
| 5    | 4      | 10         |

Plate 2. Display screen of the roller compacter.

3.6. Wheel Tracking Test
This test was conducted at highway laboratory in the National Center for Construction Laboratories and Research in Baghdad for characterisation of the rutting susceptibility of asphalt mixtures in accordance with BS EN 12697-22:2003 [17] procedure, using a wheel tracker device as shown in Plate 3. According to this standard, the asphalt samples were conditioned with air. The wheel tracking test is a laboratory-controlled rut depth test undertaken by rolling a loaded wheel on the surface of each asphalt concrete slab. The load applied to the wheel is 700 ± 10 N with a frequency of 26.5 ± 1.0 load cycles per 60 seconds. Rotation of the drive shaft from an electric motor is translated to a linear reciprocating motion, the geometry of which fixes at test path of (230±10) mm. The compacted specimens of dimension (400 mm length, 300 mm width and 40 mm height) were left to cool at room temperature for 24 hours and then placed in the test frame of wheel tracking device. Prior to testing, the asphalt concrete slab was placed in the environmental chamber for 4 hours at the test temperature. After conditioning, the machine was set in motion and the sample deformation measured using linear variable displacement transducers (LVDT). The test was run for 10,000 cycles (20,000 passes) or until a deformation of 20 millimetres was reached, whichever came first.
Plate 3. Wheel tracking machine

4. Results and Discussion

4.1. Effect of aggregate gradation on rutting parameters

The wheel tracking test was performed to compare the rutting resistance of different types of asphalt mixtures. The parameters obtained from wheel track test included the post compaction consolidation (PC), dynamic stability (DS), and rutting depth (RD) were employed to evaluate the performance of asphalt mixtures in terms of rutting resistance. The effect of aggregate gradation on the results of the wheel track test was evaluated using the Bailey method parameter (CACUW) and conventional methods.

4.1.1. Effect of aggregate gradation on rutting depth. Figure 4 shows the rutting depth of asphalt mixtures with different aggregate gradations. From this figure, the aggregate gradations designed by the Bailey method show higher resistance against rutting when compared with those designed by conventional method of gradation.

In addition, when comparing the eight aggregate gradations designed using the Bailey method, the aggregate gradation with 100 % CACUW had a lower rutting depth.
4.1.2. Effect of aggregate gradation on post compaction (PC). Post-compaction consolidation (PC) is defined as the amount of deformation that occurs within the first 500 load cycles [19]. Figure 5 shows the PC values for different aggregate gradations. The post compaction for conventional method of gradation is higher than that for the Bailey method, as shown in Figure 5. Compared with aggregate gradation designed by Bailey method, the fine graded mixtures have higher PC values as compared with the coarse graded mixtures. In addition, when CACUW decreases towards fine-graded mixtures (from 80 % to 60 %), PC increases due to higher air void levels. The lower PC value indicate greater resistance of mixtures to rutting in the PC area. Therefore, aggregate gradation with 100 % CACUW has the greater resistance to rutting in the PC area.

![Figure 5. Post compaction values of asphalt mixtures for different aggregate gradations](image)

4.1.3. Effect of aggregate gradation on dynamic stability (DS). Dynamic stability is calculated using the following equation [20]:

\[
DS = \frac{1}{\frac{1}{L_1} + \frac{1}{L_2}}
\]
Where:

\[ DS = \frac{N_{15}}{D_{60} - D_{45}} \]

DS is Dynamic stability (passes/mm)

\( N_{15} \) is the number of wheel passes within 15 minutes of testing.

\( D_{60} - D_{45} \) is the change in rut depth within the last 15 minutes of testing.

The test results as seen in Figure 6 demonstrate that the dynamic stability for conventional method of gradation is lower than that of the Bailey method. Higher DS values represent higher resistance to permanent deformation at 60°C; Therefore, aggregate gradation with 100% CACUW provides better rutting resistance of asphalt mixtures.

![Figure 6. Dynamic stability results of asphalt mixtures for different aggregate gradations](image)

**Figure 6.** Dynamic stability results of asphalt mixtures for different aggregate gradations

### 4.2. Effect of SBS on Rutting parameters

The 100% CACUW was chosen as the preferred gradation for the rest of the tests because it produced better rutting resistance. Hence, it is important to clarify whether SBS-modified asphalt mixtures can produce better-performing mixtures than the unmodified sample. Therefore, three percentages of SBS were used to evaluate the modified mixture under wheel track testing.

#### 4.2.1. Effect of SBS on rutting depth

In order to clarify the effect of SBS content on rutting depth, rutting depth was plotted against SBS content, as shown in Figure 7. Figure 7 shows that the mixtures modified with SBS had a lower rutting depth as compared with the control mixtures. The optimum SBS content for significant enhancement in the rutting behaviour of asphalt mixtures was 4%.
4.2.2. Effect of SBS on post compaction (PC). Figure 8 illustrates the PC results for control and SBS-modified asphalt mixtures. The results indicated that the mixtures modified with 4\% SBS exhibited a lower PC as compared with all other mixtures.

**Figure 7.** Rutting depths for control and SBS modified asphalt mixtures.

**Figure 8.** Post compaction values for control and SBS modified asphalt mixtures.
4.2.3. Effect of SBS on dynamic stability. It is observed from figure (9) that the dynamic stability of SBS modified asphalt mixtures was greater than that of the unmodified mixtures. Also, this figure indicates that the maximum dynamic stability value occurs at 4% SBS modification.

![Figure 9. Dynamic stability results for control and SBS modified asphalt mixtures.](image)

5. Conclusion
Based on analysis and discussion of the test data, the following conclusions can be drawn:

1- Asphalt mixtures designed using the Bailey method maintained better resistance to permanent deformation as compared with conventional mixes.
2- Mixes with coarser gradations produced more resistance to rutting than finer mixtures because of their greater amount of larger aggregate particles.
3- Compared with the eight types of asphalt mixtures prepared using different aggregate gradations with 60%, 70%, 80%, 90%, 97%, 100%, 102%, and 105% of CACUW, the asphalt mixtures with aggregate gradation of 100% CACUW provides better resistance to permanent deformation.
4- SBS modified asphalt mixtures have lower rutting depths than unmodified mixtures.
5- The modified mixtures with 4% SBS produced higher rutting resistance than others percentages of SBS polymer or the control sample.

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