Influence of Compaction Method on Rutting Resistance of Hot Mix Asphalt

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Abstract. The main goal of the present investigation is the comparison between conventional Marshall and Superpave design methods for resistance to rutting if applied in the mix design of the wearing course layers in flexible pavements. Detailed work is completed to accomplish the goals of the study by implementing Marshall and Superpave specimens through utilizing aggregate from AL-Taji Quarry and asphalt cement with (40-50) grade from Dourah refinery plant and one sort of mineral filler. Specimens were fabricated by Marshall and Superpave methods and tested by creep tests to evaluate the strain for these mixes. The effect of compaction method and additives were investigated on the performance of these mixes. From the analysis results, it appears that; the Superpave blends are increasingly practical as compared to those with conventional Marshall blends. In addition, adding carbon fibers and lime to the blends decreases the strain mixture. It is additionally seen that the Superpave Gyratory compactor is equipped for accomplishing lower air void contents than the Marshall hammer. Furthermore, the Superpave mix reflects better resistance against permanent deformation. Finally, the present study recognizes the importance of using the Superpave system for design asphalt mix instead of the Marshall method in Iraq.

1. Introduction
Good pavement performance requires an asphalt mixture less susceptible to high-temperature rutting or low temperature cracking. Rutting is a longitudinal depression that occurs in the wheel part after the multi repetitions of axial loading. Due to that, the asphalt properties must be enhanced for getting a better quality of road pavement. The most possible methods used is by modifying present asphalt cement properties by adding additives which may result in better performance, [1].

As per Arabani et al. (2010) [2], there are two keys for constructing a durable asphalt pavement; initially, construct a thicker mix which will expand the construction cost and, secondly, enhancing asphalt qualities by using polymers to increase resistance to rutting and thermal cracking of asphalt pavement  [3,4]. Fibers and polymers have an impact to stabilize asphalt cement on the surface of aggregate particles and keep it stable at high temperatures [5,6,7].

Roads in Iraq are performing poorly with pavement life much shorter than expected. The high traffic intensity in terms of commercial vehicles, the serious overloading of trucks and significant variation in daily and seasonal temperatures of the pavement have been responsible for the early development of distress like rutting, fatigue and thermal cracking on the bituminous surfacing. One of the advantages of the Marshall Mix Design method is that the performance of the mixes can be expected for local materials and environmental impact. Superpave technology as a new design methodology can be rigorously used under varying traffic and environmental conditions. Although Superpave is recognized as a significant system in the evaluation of asphalt concrete mixes, Iraqi
agencies continue to use the Marshall Method as a unique mix design method in road projects. Accordingly, an investigation is needed to compare, analyze and investigate the performance and the properties of Superpave and Marshall Mix Design methods. There are an international concern and interest in implementing Superpave in roads and airport projects to investigate its impact on the economy and performance of these projects. The main objective of the study is the comparison between the traditional Marshall design method and the Superpave system design method in the wearing course mixes for flexible pavements. This process will be carried out by evaluating the mechanical properties.

2. Materials
The materials used in this study are locally available and selected from the currently used materials in road construction in Iraq.

2.1. Asphalt Cement
One type of asphalt cement (40-50) penetration graded was used in this study, which represents PG (64-22) as classified by the Superpave system (Alani, H. M. et. al. 2010) [8]. It is obtained from the Dourah refinery. The physical properties of this type of asphalt cement are shown in Table (1) and the result values are laid within the Iraq specification (SCRB R9) [9].

| Test               | Test Condition                      | Standard ASTM | Results | Unit      |
|--------------------|-------------------------------------|---------------|---------|-----------|
| Penetration        | 25°C, 100 gm, 5 sec.               | D5            | 42      | 1/10 mm   |
| Absolute Viscosity | at 60°C (*)                        | D2171         | 2070    | Poise     |
| Kinematics Viscosity | at 60°C (*)                        | D2170         | 370     | C St.     |
| Ductility          | 25°C, 5 cm/min.                    | D113          | >100    | Cm.       |
| Softening Point    | D 36                               |               | 51.0    | C°        |
| Flash Point        | D 92                               |               | 332     | C°        |

(*) The test was conducted in Dourah refinery

2.2. Aggregate
One type of crushed aggregate was used in this study, which was brought from Amanat Baghdad. The source of this type of aggregate is from the Al-Taji quarry. The physical properties of the aggregate are shown in Table (2), and the aggregate gradation was taken from Iraq expressway No.1 according to SCRB, 2003.

One nominal maximum size of aggregate (12.5 mm) was selected with two aggregate gradations (R1 and R9). From the job mix formula shown in Table 3, it appears that gradation R9 is passing through the Superpave limitation control points and restricted zone, while, the gradation R1 is located out of the Superpave restricted zone requirement. These two gradations were selected to compare the effect of the restricted zone on the mix performance. Mix design was prepared for heavy traffic levels using the Superpave methodology and the traditional Marshall methodology. These gradations are shown in Figure (1) and presented in Table (3).

| Property                  | Standard                       | Coarse Aggregate | Fine Aggregate |
|---------------------------|-------------------------------|------------------|----------------|
| Bulk specific gravity     | ASTM C 128                    | 2.518            | 2.622          | 2.615          |
| Apparent specific gravity | ASTM C127 and C128            | 2.554            | 2.689          | 2.662          |
| Percent of water absorption | ASTM C 127 and C 128       | 0.56             | 0.94           | 0.68           |
Table 3. Job Mix Formula for Wearing Course of the selected gradation.

| Sieve opening (mm) | Percent Passing |
|--------------------|-----------------|
|                    | ARZ (R9)        | TRZ (R1)   |
| 19                 | 100             | 100        |
| 12.5               | 89.5            | 92         |
| 10                 | 77.8            | 83.1       |
| 4.74               | 55.3            | 66.9       |
| 2                  | 40.2            | 41.5       |
| 1                  | 32              | 28.2       |
| 0.63               | 25              | 21.4       |
| 0.25               | 15.1            | 14.4       |
| 0.125              | 12.2            | 11.6       |
| 0.075              | 9.8             | 9.8        |

Figure 1. Gradation of Wearing Course for two sections of the Expressway No.1 in Iraq.

2.3. Mineral Filler

One type of mineral filler (Ordinary Portland Cement) has been used in this study; it is obtained from a local provider. According to product specification from a provider, its specific Gravity equal 3.12, the percent passing sieve No.200 equal 95% according to ASTM C117, 2008.

2.4. Additives

Two types of additives (carbon fiber and lime) have been used in this study. The physical properties of additives are shown in Tables (4), and (5). Two proportions of carbon fiber (1% and 0.5%) by weight of asphalt cement and two proportions of lime (2% and 4%) by weight of aggregate were used in this study as partial replacement of aggregate.

Table 4. Properties of Carbon Fiber*.

| Properties          | Form     | Density   | Tensile modulus |
|---------------------|----------|-----------|-----------------|
|                     | 2.54 cm cut | 1.8 gm/cm³ | 29 psi          |

*Properties from a local provider
Table 5. Chemical Composition and Physical Properties of Hydrated Lime*.

| Properties          | Hydrated lime |
|---------------------|---------------|
| Apparent specific gravity | 2.343        |
| Ca(OH)₂             | 93.88         |

*Properties from a local provider

3. Marshall Mix Design

This method covers the measurement of the resistance to plastic flow of cylindrical specimen of bituminous paving mixtures loaded on the lateral surface by means of the Marshall apparatus according to ASTM (D 1559) 2003.

Two types of mixes were prepared with two-type gradation. Three specimens for each mix were prepared, and the average of results was reported. In order to compare the two-mix design directly, the following two types of mixes were prepared with two optimum asphalt contents of mix design:

- Marshal mixes with optimum asphalt content determined by the Marshall Method.
- Marshal mixes with optimum asphalt content determined by the Superpave system.

The aggregate was obtained from Al-Taji Quarry. The aggregates were processed by washing, oven drying and sieving. Dried aggregate was separated by a set of sieves, and the material retained on each sieve and pan was placed in storage pans. Then three samples of each aggregate gradation were prepared. Aggregate was heated to a temperature of 170°C before mixed with asphalt cement. Asphalt cement was heated to the temperature producing a kinematic viscosity of (170 ± 20) centistokes (up to 163 C° as an upper limit). Then, the desired amount was added to the heated aggregate and mixed thoroughly until all aggregate particles were coated with asphalt, then the mix was compacted in accordance with the method stated in ASTM 1559. The prepared mix was placed in the preheated mold of (4) in, (101.6mm) in diameter by (3) in (76.2mm) in height, and compacted with 75 blows/ end with a hammer of 10 lb (4.536 kg) sliding weight, and a free fall of (18) in, (457.2mm) on the top and bottom of each specimen. The specimens were then left to cool at room temperature for 24 hours. After the required specimen is prepared, the Marshall stability and flow tests are performed on each specimen. The cylindrical specimen is placed in a water bath at 60°C for 30 to 40 minutes and then compressed on the lateral surface at a constant rate of 2 in/min (50.8mm/min) until the maximum load (failure) is reached. The maximum load resistance and corresponding flow are recorded. Three specimens for each combination are prepared and the average results are reported. The Marshall stiffness is then calculated.

4. Superpave Compaction Method

Two blends were compacted at their corresponding initial asphalt content. One compaction effort (Ninit = 9, Ndes=135, Nmax = 220) using Superpave method for the preparation of specimens. For the purpose to determine design asphalt cement, 135 gyrations were used which represent the value of Nd for heavy traffic level. Two types of mixes were prepared by using the Superpave compaction method. The first type of mixes was prepared with the above-restricted zone (ARZ) aggregate gradation and the other mix with the through restricted zone (TRZ) aggregate gradation. Two specimens of each mix were prepared and the average results were reported. For the comparison requirements, the following two types of mixes were prepared with the optimum asphalt content:

- Superpave mixes with optimum asphalt content determined by the Superpave system.
- Superpave mixes with optimum asphalt content determined by the Marshall Method.

Table 6 shows the optimum asphalt content for the two methods.
Table 6. Mixtures Properties

| Gradation Type | Marshall Method | Superpave Method |
|----------------|----------------|-----------------|
|                | R1 (TRZ)       | R9 (ARZ)        | R1 (TRZ)       | R9 (ARZ)        |
| Optimum Asphalt Content % | 4.7            | 4.63            | 4.42            | 4.54            |
| Density gm/cm³  | 2.353          | 2.335           | 2.362           | 2.349           |
| Void Air        | 3.9            | 4.49            | 4                | 4                |

5. Static Creep Test

The diametric – indirect tensile creep test has been used to determine the stiffness of asphalt mixtures by measuring strain – time values. The diametric – indirect creep tests are performed on Marshall specimens at corresponding optimum asphalt content (o.a.c) for various mix types under the constant stress of 0.1 MPa. The specimens are immersed in a water bath for 30 min. at the desired temperature of (25°C). The specimen is loaded to static stress of 0.1 MPa for 1 hour [10], and the deformation is recorded at certain time increments (0.1, 0.25, 0.5, 1, 2, 4, 8, 15, 30, 45, and 60 min). The load is then released, and the recovered strain for 1 hour is recorded, in the same periods. The vertical strain is calculated by using the following formula:

\[ \varepsilon_{mix} = \Delta H/Do \quad (mm/mm) \quad (1) \]

where:
\( \Delta H \) = the total measured vertical deformation at a certain loading time (mm), and
\( Do \) = the original diameter of specimen (mm)

The stiffness modulus of the mixture is calculated by:

\[ S_{mix} = \delta/\varepsilon_{mix} \quad (N/mm^2) \quad (2) \]

where:
\( S_{mix} \) = stiffness modulus (N/mm²),
\( \delta \) = applied stress (N/mm²), and
\( \varepsilon_{mix} \) = vertical strain in the mix specimen.

Three specimens are prepared for each mix combination. Figure 2 shows creep properties.

![Figure 2. Creep Property](image)

6. Results and Discussion

Figures 3 to 15, show that Superpave mixture with optimum of Marshall has higher values of a strain than Superpave mixture with optimum of Superpave, indicating that, the lower asphalt content for both mix design shows smaller strain values than the higher asphalt content mixes. It is observed that Superpave with optimum of Superpave is the strongest mix and Marshall with the optimum of Marshall is the weakest mix among the tested mixes.

From creep test results, it is shown, that the TRZ gradation has higher values of a strain than the ARZ gradation. As a result, TRZ mixes show lower stiffness. This is because the ARZ has lower values of flow, higher stability, and as a result higher stiffness. The figures also show the effect of
adding (hydrated lime) to the mixture on resisting creep, as a result of rutting. Rutting is a permanent deformation of the asphalt and is caused when the elasticity of the material is exceeded. It indicates that increasing the amount of lime (2% to 4%) leads to a decrease in permanent deformation that represents the strain that not recovered. Hydrated lime significantly improves the performance of asphalt in this respect. Lime is chemically active rather than inert. It reacts with the bitumen, removing undesirable components at the same time its tiny particles disperse throughout the mix, making it more resistant to rutting and fatigue cracking. The stiffening that results from the addition of lime can increase the PG rating of asphalt cement, depending upon the amount used.

Other Figures show, the effect of adding carbon fiber on resisting permanent deformation, indicates that increasing carbon fiber leads to lower strain and as a result of more resisting to permanent deformation. Carbon fiber modified asphalt mixtures were expected to show an increased stiffness and resistance to permanent deformation.

![Figure 3. Effect of Gradation on Permanent Deformation for Marshall Mixes.](image1)

![Figure 4. Effect of Additives on Permanent Deformation for Marshall Mixes](image2)
Figure 5. Effect of Additives on Permanent Deformation for Marshall Mixes (for R9 Gradation).

Figure 6. Strain – Time relationship for Superpave Mixes (Without Additives).
Figure 7. Strain–Time relationship for Superpave Mixes (with 0.5% Carbon Fiber).

Figure 8. Strain–Time relationship for Superpave Mixes (with 1% Carbon Fiber).
Figure 9. Strain – Time relationship for Superpave Mixes (with 2% Lime).

Figure 10. Strain – Time relationship for Superpave Mixes (with 4% Lime).
Figure 11. Effect of Gradation on Permanent Deformation for Superpave Mixes.

Figure 12. Strain-Time relationship for R1 Gradation of Superpave Mixes with different Additives.
Figure 13. Strain-Time relationship for R9 Gradation of Superpave Mixes with different Additives.

Figure 14. Effect of Additives on Permanent Deformation for Superpave Mixes (for R1 Gradation).
7. Conclusions

Based on the study findings, the following conclusions are appropriate:

1. Superpave achieves lower air void and asphalt content than Marshall mixes; this prevents additional compaction under traffic, which could result in the wheel path.

2. It is concluded that using (carbon fiber and lime) as additives, results in a decrease in permanent deformation by 40 and 45% respectively for both types of mixes. Accordingly, this will enhance the performance of asphalt concrete mixtures.

3. Mixes with TRZ gradation have 35% higher values of permanent deformation as compared with mixes of ARZ gradation.

4. Using additives (Lime and Carbon fiber) in preparing asphalt mixtures because they give high recovery value of strain that will enhance the performance of asphalt paving mixtures, accordingly, decrease permanent deformation.

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