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Experimental Characterization of Rutting Performance of HMA Designed with Aggregate Gradations According to Superpave and Marshall Methods

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Abstract

The permanent deformation (rutting) of pavement is a major distress in flexible pavement. It is related to vehicles properties and/or pavement materials and conditions. This article presents an extensive experimental investigation in order to compare between the aggregate gradation according to Superpave and Marshall methods of asphalt concrete mix design on pavement rutting and to examine the sensitivity of rutting resistance to aggregate gradation. A wheel truck machine has been used for measurement of pavement rutting (permanent deformation). The tests were carried out at two controlled different air temperature 55˚C and 25˚C. The results obtained showed that the adopting of aggregate gradation procedure of Superpave method of pavement mix design for Marshall method of asphalt concrete mix design can reduce the pavement rutting by about 50%. This achievement may be related to missing of three sieves in aggregate gradation procedure of Marshall method which controls rounded and finer aggregate particles. These sieves provide more continuity for aggregate gradation to ensure filling unnecessary gaps and produce more contact points between the aggregates in Hot Mix Asphalt (HMA). The outputs of the research support modifying Marshall method of asphalt concrete mix design by adopting aggregate gradation proposed in Superpave method. The results of study also showed that the coarser aggregate provided more resistance to pavement rutting.

Keywords

Superpave, Marshall Method, Pavement Rutting, Aggregate Gradation, Experimental Investigation

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1. Introduction

Hot Mix Asphalt (HMA) is one of the most popular types of asphalt pavement design used in different countries around the world. Although, there are several methods for designing HMA, such as Marshall method, Haveem method, and asphalt institute method; the design of these mixes is still rely on the Marshall procedure in several countries [1]. Marshall mix design procedure (ASTM D 1559) [2] is based upon a purely an empirical experimental tests and has a several limitations in detecting the effect of several traffic and environmental factors, and material properties (aggregate and binder) on pavement performance [3].

In recent years, the Strategic Highway Research Program (SHRP) developed a new mix design method namely Superior Performing Asphalt Pavements (SUPERPAVE). This method consists of three main steps: 1) Performance Grade (PG) of binder which depends on a range of degrees of temperature and adjust according to traffic consideration, 2) criteria for aggregate gradation including more restrictions compared with Marshall method, 3) mix design procedure simulates the field conditions and performance tests, consequently; it ties the materials selection to traffic and climates considerations [4]-[6].

The aggregate gradation is an important difference between the Superpave and Marshall methods for design of HMA. Aggregate consists the vast bulk of asphalt mixtures components, generally comprises 92 to 96 percent of the weight of HMA. Several studies had showed that the aggregate gradation is one of most factors affecting permanent deformation (rutting) of pavement [7]-[9]. They showed that the resistance to rutting is highly depending on aggregate gradation.

The permanent deformation (rutting) is one of the major distresses occur in flexible pavement as an accumulative depression pavement in wheel paths of vehicles under traffic load [10]. There are three main factors affecting the occurrence of pavement rutting: climate conditions, traffic considerations, and pavement (materials and design) [11] [12]. In the climate condition aspect, the prevailing degree of temperature has a significant effect on pavement deformation in which the increase in degree of temperature increases the possibility of pavement rutting. Similarly, the increasing of accumulative number of wheels and slow moving vehicle may lead to more pavement rutting. The third important factor involves the materials selection (binder and aggregate) and HMA design [13].

Several researches have been conducted to compare between the Superpave mix design procedure and a traditional procedure of mix design according to Marshall method. The results of these studies revealed that the new design procedure of pavement (Superpave) can attribute to better pavement performance and more longevity [1] [2] [14]-[16]. Most of these studies focused on the effect of these two procedures on design aspects and pavement distresses. Therefore, these researches were always adopted similar mix components to be completely design according to these two methods. Even thought that provided a good indication on the differences in these methods as overall but it may not clearly shows the effect of each parameter in design procedure.

The current research focuses on the effect of aggregate gradation (as one of design parameters) on pavement rutting depth. The aggregate gradations according to Marshall method and the aggregate gradations according to Superpave method were implemented in Marshall method for asphalt concrete mix design to clarify the effect of aggregate gradation on rutting resistance. This allows for modification of the traditional procedure of Marshall method usually used for asphalt concrete mix design.

2. Materials

2.1. Asphalt Binder

An Asphalt cement 40 - 50 grade (obtained from Nasirya refinery) has been used as binder for all mixtures investigated in this research. The rheological properties of binder were determined according to traditional tests shown in **Table 1**. These tests involved penetration test, softening point test, ductility test and flash point test. The result of these test are shown in **Table 1**.

2.2. Aggregate

Natural crushed aggregate (available locally-Badra site) with maximum size of 19 mm was used for all mixes as suitable for binder layer of flexible pavement (SORB/R9) [17]. The gradations of aggregate were design to compare between Superpave and Marshall procedures for designing aggregate gradation in asphalt concrete mixes. Three aggregate gradations were adopted according to Superpave procedure: above the restricted zone

Table 1. The rheological properties of binder.

Type of test	Penetration (100 g, 5 s, 25˚C), 0.1 mm	Softening point (˚C)	Ductility (25˚C, 5 cm/min), cm	Flash point (˚C)
Specification	ASTM D5-13	ASTM D92-12b	ASTM D113-07	ASTM D36-12
Result of test	44	51	>100	255

(S-AR), through the restricted zone (S-TR), and below the restricted zone (S-BR). Similarly, three aggregate gradations were adopted according to Marshall procedure: upper limit (M-UL), mid-specification (M-MS), and lower limit (M-LL). **Figure 1** shows the aggregate gradations according to both Superpave and Marshall methods. From **Figure 1**, it can be noticed that the discontinuity of Marshall aggregate gradation in fine aggregate zone due to missing of three sieves at this region (1.18 mm, 0.6 mm and 0.15 mm).

3. Methodology and Experimental Program

The research was primarily aimed to study the effect of aggregate gradation on pavement rutting according to Superpave and Marshall methods. **Figure 2** shows the research frame work for the entire experimental programme.

3.1. Optimum Asphalt Contents (OAC)

Optimum Asphalt Contents (OAC) were determined for each aggregate gradation as shown in **Table 2**. Five percentages of asphalt content were examined to find OAC starting with 4% and ending by 6% at interval of 0.5%, consequently, 90 (3 × 5 × 6) samples were tested for this purpose. The sample of OAC determination is illustrated in **Figure 3**.

3.2. Pavement Rutting Testing Machine

The pavement rutting test has been carried out using wheel track machine manufactured in road laboratory, college of engineering, University of Al-Qadisiyah for the purpose of doing this research and other research in future. The machine consists of metal cabinet with digital control electric heater with heating temperature reached up to 55˚C. Inside the cabinet there is a wheel with frame to carry the desired load and can move up and down only. In the middle of cabinet there is a movable base with five wheels on each side connected to motor with three speeds (34 passes/min., 100 passes/min., and 345 passes/min.). This base moves over two thick plates forward and backward. The mould of specimen is fixed on the movable base after removing the upper part of it. **Figure 4** shows the testing machine. A dial gauge is used to measure the depth of pavement rutting after each specific number of wheel passes.

3.3. Preparing the Specimen

A mould was design to closely represent the real pavement especially the thickness of pavement layer. The mould consists of three parts: base with clear dimensions of 300 × 200 mm, lower sides as one piece with height of 30 mm and upper sides as two pieces with height of 60 mm, consequently the inside dimensions of mould are 300 × 200 × 90 mm. The upper part of mould (with height of 60 mm) is removed after the compaction of the specimens. **Figure 5** illustrates the parts of moulds.

The specimens are prepared according to the each specific aggregate gradation by blending the components according to Marshall procedure described in ASTM D 1559-89. After the completion of blending of component, the specimens is put in the mould for compaction process. The compaction was made by pressing the specimens in universal loading machine. The magnitude of load was determined by compacting several specimens with different load values then selected the value which give similar density to that obtained from Marshall specimens (2.33 gm/cm^3). The selected load value (240 kN) was adopted for all specimens. **Figure 6** shows the compaction process of specimen, as well as **Figure 7** shows the selection of compaction load.

3.4. Testing of Specimens

After the completion of compaction process, the upper part of mould was removed and the specimens were left

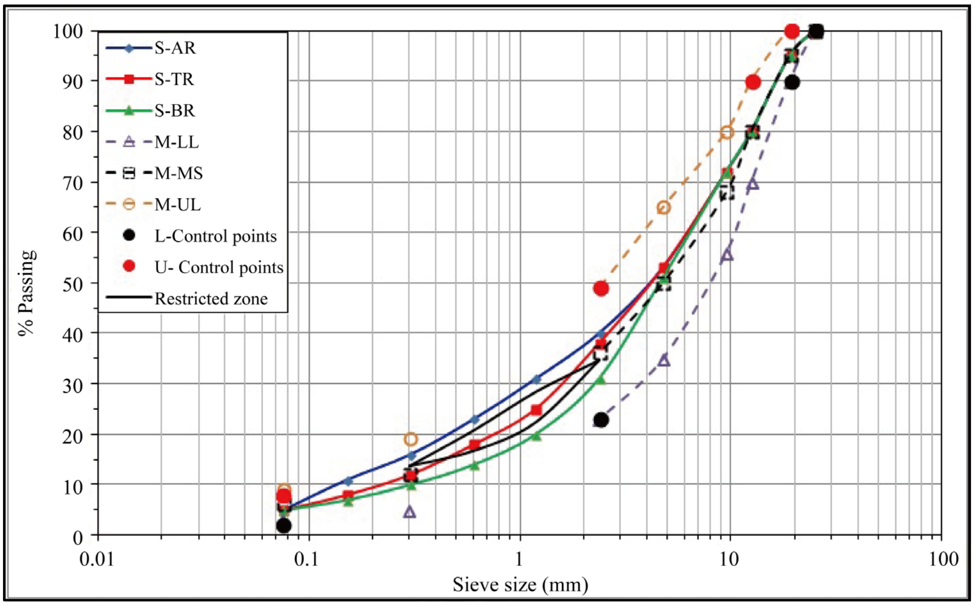

Figure 1. Aggregate gradations according to Superpave and Marshall methods (log scale is used for x-axis).

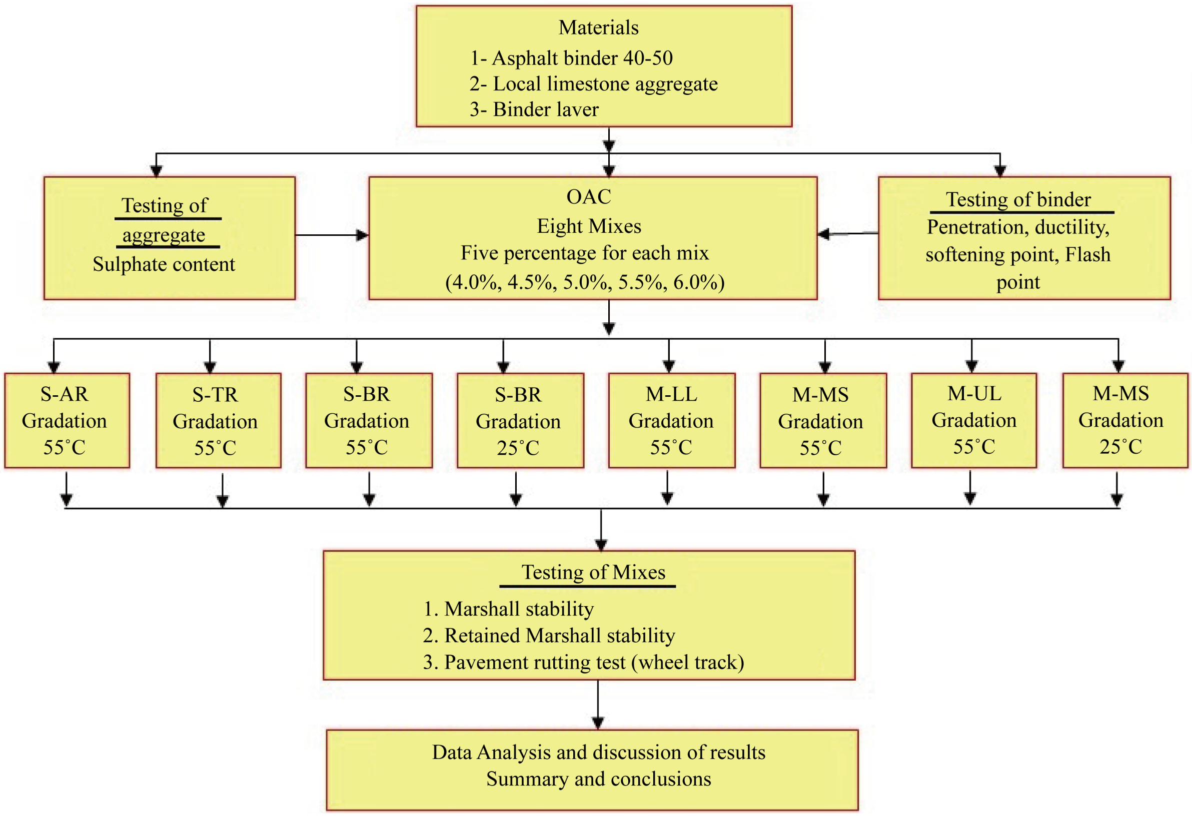

Figure 2. The research frame work (experimental programme).

Table 2. Optimum asphalt contents (OAC) for different aggregate gradations.

Type of aggregategradation in HMA	S-AR	S-TR	S-BR	M-UL	M-MS	M-LL
% OAC	5.2	4.9	4.7	5.1	5	4.8

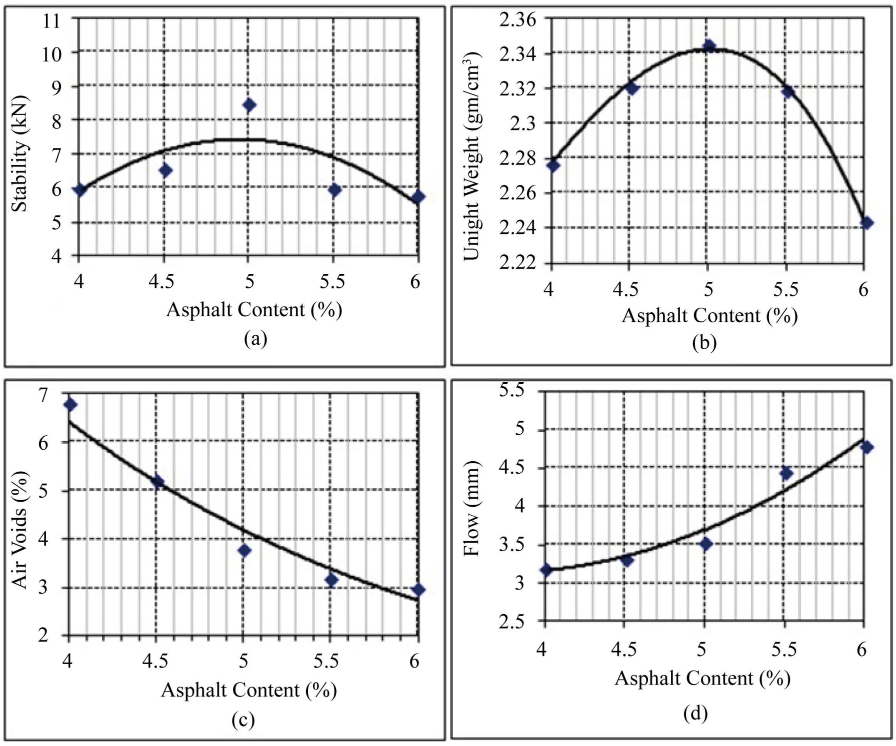

Figure 3. Determination of OAC according to Marshall method: (a) Relationship between Stability and %AC; (b) Relationship between Unit weight and %AC; (c) Relationship between Air void and %AC; (d) Relationship between Flow and %AC.

Figure 4. Pavement rutting testing machine.

(a) (b)

Figure 5. The parts of the used mould of specimen. (a) Complete mould; (b) Mould with specimen after removing upper part.

Figure 6. The compaction process of specimen.

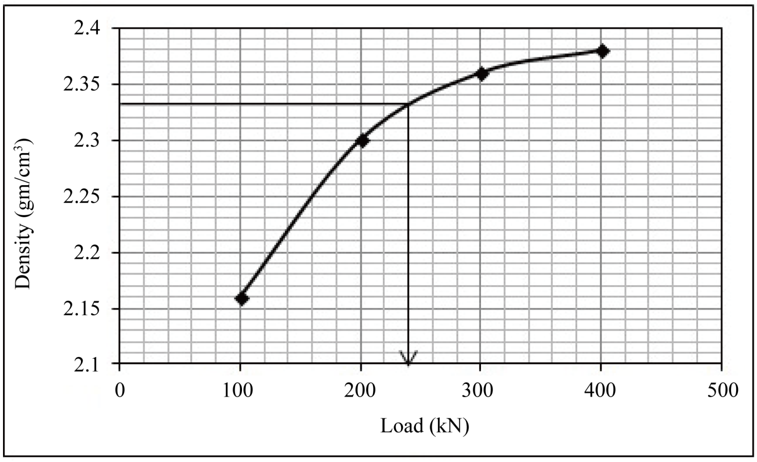

Figure 7. The selection of compaction loadaccording to density of Marshall specimen.

for 24 hours. Next, the specimens were cured in oven for 1 hour to reach the desired testing temperature, then it was placed in testing machine to start testing process. Load was applied on the wheel to produce a tire pressure of 560 kPa. Each specimen was loaded for 10,000 passes and the rutting depth was measured in the middle of specimen after each specific numbers of passes.

In addition to pavement rutting test, Marshall stability and Marshall retained stability were carried out on Marshall specimens for each type of mix according to selected aggregate gradation.

4. Results and Discussion

4.1. Marshall Stability

The Marshall stability test was conducted by testing three specimens for each aggregate gradation. The specimens were prepared and tested according to ASTM D 1559-89. The specimens were cured in water bath for 30 minute at 60˚C then they were tested to measure the ultimate load. The test results illustrated in **Figure 8** show that the specimens prepared with aggregate gradation according to Superpave method give more Marshall stability than those produced with aggregate gradation according to Marshall method. Also, the coarse aggregates yield more Marshall stability compared with finer particles. This can be attributed to stiffness of coarse aggregate and more interlock between the coarse aggregate particles. The mix that contained aggregate has a gradation pass through the restricted zone (S-TR) gives lower Marshall stability than the other types of Superpave base aggregate gradation mixes. This region is usually recommended to be removed from Superpave aggregate

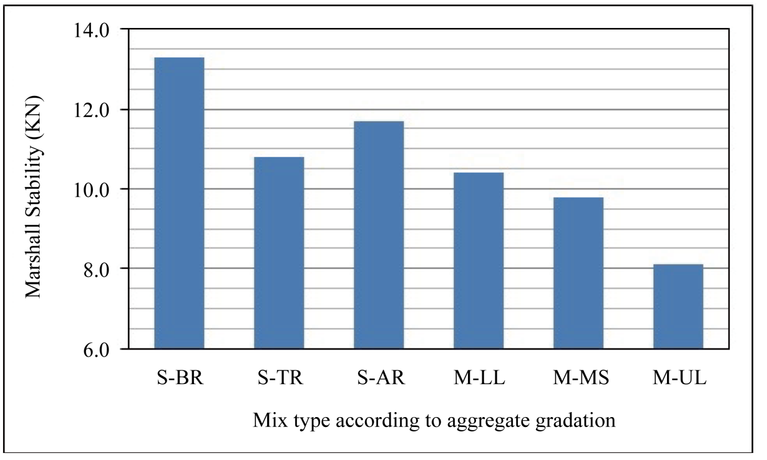

Figure 8. Test results of Marshall stability.

gradation [18].

4.2. Index of Retained Strength

Six specimens were prepared for each aggregate gradation according to [19] to have same specific gravity. Three of each six specimens were cured by immersion them in water bath for 24 hrs at temperature of 60˚C (wet). The other three specimens were left for normal curing in an air bath for 4 hrs at temperature of 25˚C (dry) [20]. Each group (three samples) was tested to measure the ultimate load. The index of retained strength was calculated according to Equation (1).

$$\%\ \text{Index of retained strength} = \frac{S1}{S2} \times 100\% \tag{1}$$

$S1$: Compressive strength of wet specimens.

$S2$: Compressive strength of dry specimens.

Figure 9 presents the results of index of retained strength for all mixes. From that figure, it can be observed that the average percentage of index of retained strength for all specimens prepared with aggregate gradations based on Superpave method is more than these specimens prepared with aggregate gradations based on Marshall method. The other observation is that, the coarser aggregate gradation has less index of retained strength. This may be due to more air voids initiated with coarse aggregate. However, it still gives adequate level of index of retained strength.

4.3. Rutting Test Results

As mentioned earlier, six aggregate gradations were adopted for the current research. Three of these gradations were according to Marshall method as lower limit of specification (M-LL), mid-specification (M-MS), and upper limit of specification (M-UL). The other three represented aggregate gradations according to Superpave method as blow restricted zone (S-BR), through restricted zone (S-TR) and above restricted zone (S-AR).

The rutting depths were measured after 250, 500, 1000, 2000, 3000, 4000, 5000, and 10,000 passes. The testing machine was stopped after each specific number of passes at the middle of specimens to measure the rutting depth. Six specimens were tested at the temperature of 55˚C, this temperature represents the maximum prevailing temperature at Summer in most of middle east countries. Also; at such hot weather, the pavement rutting probability increases.

Figure 10 shows the results obtained of the six specimens prepared with different aggregate gradations according to Marshall and Superpave methods. The general trend of results for all specimens shows that for coarser aggregate gradation the rutting depth decreases. This behaviour attributes to better interlock of coarse aggregates that have rough surface texture (crushed) which gives more stability and stiffness for HMA. This finding agrees with other research in literature [21]-[23].

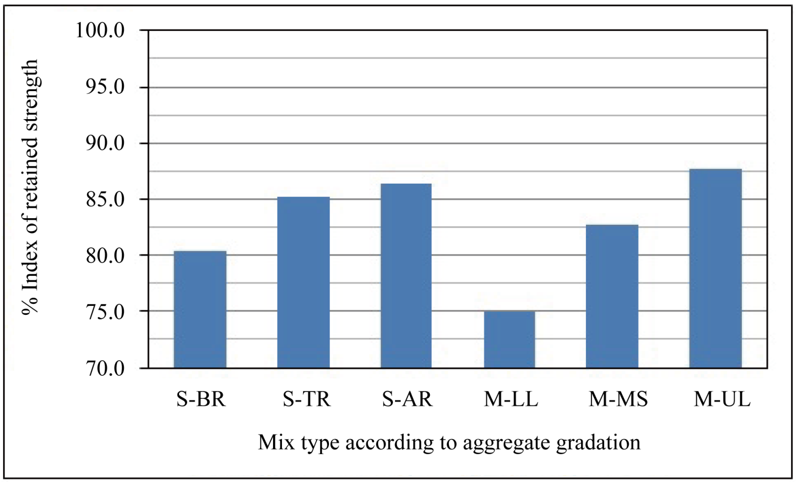

Figure 9. Index of retained strength.

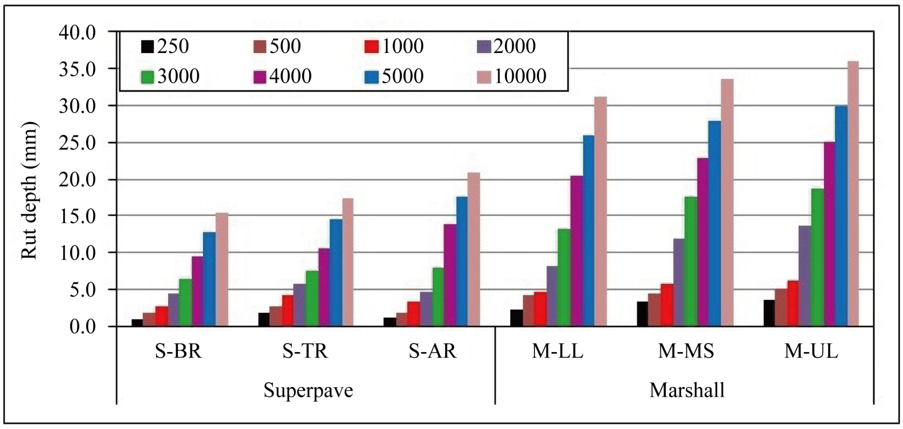

Figure 10. Rutting depth at temperature of 55˚C.

The most important point can be observed from **Figure 10** is that the average rutting depth for specimens prepared according to Superpave aggregate gradations is about 50% of those prepared according to Marshall aggregate gradations. This may be due to the restriction procedure follows by Superpave in selecting of aggregate gradation, which involve three additional sieves (1.18 mm, 0.6 mm and 0.15 mm) control the amount of rounded and finer aggregate which can cause the rutting. These sieves are missing in aggregate gradation according to Marshall procedure. The fine aggregate is graded using five sieves in Superpave procedure which can provide best and well gradation for aggregate at this important zone for rutting occurrence, while only two sieves were included for same zone in Marshall procedure. Unlike Marshall method, the continuous aggregate gradation in Superpave method provides the appropriate sizes of aggregate to fill unnecessary gaps in HMA and creates more contact points between the aggregate then consequently, increase the cohesion between the particles which gives more rutting resistance. The fine aggregate consists about 40% - 50% of total aggregate in mixture, therefore the less control on this zone may allow for more inappropriate sizes to come in.

Figure 11 presents the photos of rutting depth of the six specimens at 55˚C, these photos clearly show the difference in rutting depth for the considered specimens.

Two specimens were tested at 25˚C as shown in **Figure 12**, No clear differences or trend can be observed between these specimens. This can be attributed to moderate temperature and normal load, which reasonable does not cause rutting.

Figure 13 illustrates the photos of rutting depth of the two specimens at 25˚C. There is no clear difference in rutting depth between the two specimens.

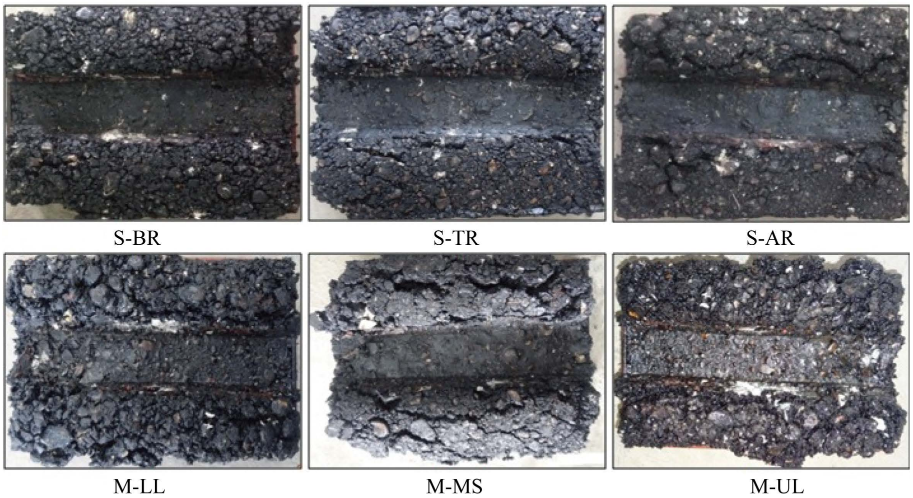

Figure 11. Photos of specimens after 10,000 passes at 55˚C.

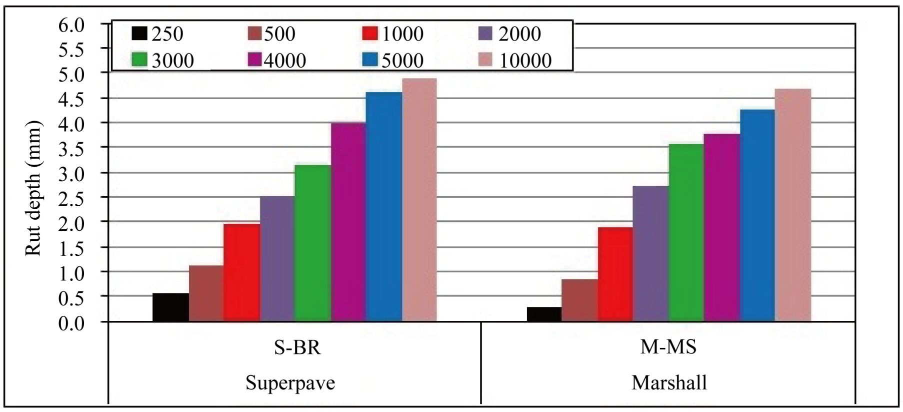

Figure 12. Rutting depth at temperature of 25˚C.

Figure 13. Photos of specimens after 10,000 passes at 25˚C.

5. Summary and Conclusions

Extensive experimental investigations have been conducted to study the effect of aggregate gradation on permanent deformation (rutting depth) in flexible pavement. The investigations involve examine of both gradations formula according to Superpave and Marshall methods. The following conclusions were obtained from the study.

1) All mixes which designed according to Superpave aggregate gradation procedure gives more resistance to permanent deformation and less rutting depth (about 50%) compared with mixes designed according to Marshall aggregate gradation procedure. This is because the restrictions on finer rounded particles in aggregate gradation procedure of Superpave method.

2) Adopting of aggregate gradation procedure of Superpave method in Marshall method significantly improves rutting resistance. This point is very important in case of Superpave equipments are limited.

3) The coarser aggregate gradation provides more resistance to permanent deformation (rutting) due to more interlock and more stiffness.

4) Results of Marshall stability and an index of retained strength tests agree favourable with the pavement rutting test results.

6. Recommendations for Future Studies

According to the output of the study, the following recommendations can be suggested:

1) The effect of aggregate gradation on other parameters affecting pavement performance such as moisture induced damage and fatigue life of pavement needto be investigated.

2) New limits for Iraqi specification (SORB/R9) for aggregate gradation (in fine aggregate zone) can be suggested, comparative to that of Superpave aggregate gradation.

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