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# QUANTIFICATION OF AGGREGATE DEGRADATION OF ASPHALT MIXES COMPACTED BY GYRATORY AND MARSHAL METHODS

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## ABSTRACT

*This study aims to evaluate the aggregate degradation for the Marshall and gyratory compaction methods. Three different methods were utilized to conduct such evaluation, namely: the percent increase in filler (materials passing No. 200 sieve), the percent increase in fine aggregate (materials passing No. 4 sieve and retained on No. 200 sieve), and the percent increase in surface area of aggregate particles. It was found that the gyratory compaction method gave better results (lower aggregate degradation) than the Marshall compaction method for wearing course mixes, while the Marshall compaction method gave better results (lower aggregate degradation) for base course mixes. Therefore, it is recommended that, before its full implementation in Saudi Arabia, the gyratory compaction method should be further evaluated for the local aggregate in terms of other fundamental properties.*

**Keywords:** *Aggregate Degradation, Marshall, Gyratory, Compaction, Asphalt*

## الملخص

يناقش هذا البحث حساب كميات تفتت الحصى في الخاطات الإسفلتية المجهزة بطريقة مارشال للدك والدك الدوار الخاص بطريقة سوبربيف الجديدة. ولقد استخدمت ثلاثة وسائل لحساب مقدار هذا التفتت هي: الزيادة المئوية في نسبة البودرة (المادة المارة من المنخل رقم ٢٠٠)، والزيادة المئوية في نسبة الحصى الناعم (الفرق بين المار من المنخل رقم ٤ والمنخل رقم ٢٠٠)، والزيادة المئوية في مساحة السطح الإجمالي للحصى. وقد تبين أن طريقة الدك الدوار أعطت نتائج أفضل من طريقة مارشال (كمية تفتت أقل) عند اعتبار حصى خلطة السطح الإسفلتية، بينما أعطت طريقة مارشال نتائج أفضل عند اعتبار حصى خلطة الأساس الإسفلتية. غير أن طريقة الدك الدوّار الخاصة بطريقة سوبربيف لتصميم الخلطات الإسفلتية يجب التأكد من مناسبتها للحصى المتوفر محلياً قبل اعتماد هذه الطريقة وتطبيقها في المملكة العربية السعودية.

## 1. INTRODUCTION

The purpose of pavement is to carry the traffic safely, conveniently, and economically over the design life of the road by protecting the subgrade from effect of traffic and climate and by ensuring that no materials used in the pavement (asphalt mix or soils), suffer any unacceptable deterioration (Peattie, 1978). Asphaltic concrete is a mixture of aggregate of different sizes with a sufficient amount of asphalt binder (bitumen) to reduce the voids between the aggregate. The asphaltic concrete gets its strength mainly due to the aggregate interlock.

Asphaltic concrete, used in road structure has a number of different functions to fulfill (Brien, 1978 and Asphalt Institute, 1992):

1. To have sufficient stability to resist deformation by traffic;
2. To be impervious to protect the lower layers of the road structure from water, but with enough voids to allow additional compaction under traffic loading;
3. To be durable, resisting both effects of weather and abrasion by traffic;
4. To give a skid-resistance surface;
5. To contribute to the strength of the complete road structure; and
6. To provide sufficient workability to permit efficient placement;

In most countries around the world, the continuous grading of aggregate is used in asphaltic concrete mixes for road construction. Other types of aggregate grading such as skip-grading or semi-gap grading are being used in some countries like South Africa and United Kingdom [Subramanyam and Pratapa, 1997].

As the asphaltic concrete mix is placed over the roadbed, the overall pavement performance is governed by the performance and behavior of the component of this pavement. The asphalt binder and the aggregate particles in the mix play important role in determining the pavement performance. However, the properties of these materials change over time under the traffic and environmental loadings. Therefore, the adopted mix design should take into consideration the expected pavement performance.

Several studies have focused on the effect of the compaction methods on asphalt mix design to select the one that can best simulate the field compaction. In a study by [Khan et a. 1998], five different compaction methods were evaluated: Marshall manual impact compactor, Marshall automatic impact compactor, California kneading compactor, Gyratory shear compactor (angle of gyration 6 degrees), and Gyratory shear compactor (angle of gyration 1.25 degree). The comparison of the specimens compacted by different laboratory compaction methods with the filed compacted core was done through several laboratory tests such as bulk specific gravity, void content, Marshall stability, resilient modulus, static creep test for permanent deformation, and particle orientation. The gyratory shear compactor, with angle of gyration 1.25 degree, was found to give the most closely representation of the field cores [Khan et al. 1998].

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In another study [Consuegra et al. 1989], five different compaction methods were compared. They were: mobile steel wheel simulator, the Texas gyratory compactor, California kneading compactor, Marshall impact hammer, and Arizona vibratory kneading compactor. The Texas gyratory compactor demonstrated the ability to provide mixes with engineering properties nearest to those determined from the filed cores.

The aggregate degradation, due to mixing, handling, and compaction, is one of the major factors affecting the overall performance of the asphalt pavement structure. This degradation can be checked and simulated at the mix design phase. Thus, the mix design using specific compaction method determines the amount of this degradation.

Aggregate degradation during compaction may cause changes to the original gradation of the aggregate, and may also change the volumetric properties of the mix design. Thus, the quantification of the degree of degradation determines the accuracy of the mix design method. This effect is more pronounced in the SUPERPAVE mix design since the properties of aggregate plays an important role in the final mix design results [Asphalt Institute, 1993]. The SUPERPAVE gyratory compactor was designed to simulate not only the orientation of aggregate but also the degradation of aggregate during mixing, production, field compaction, and traffic loading [Collins et al 1998].

The basic concept of the Marshall mix design is the selection of asphalt content based on optimization or limits for several variables that are not direct measure of performance, and is a volumetric evaluation based on specimen fabrication under a given set of conditions with a given level of compaction energy. The preset compaction energy is expected to produce density levels similar to those imposed by trafficking [Sousa et al. 1995].

The SUPERPAVE laboratory mix design procedure is intended to be applicable for all types of asphalt mixtures: virgin and recycled hot mixtures, with or without modified binders [Hafez and Witczak, 1995].

In Saudi Arabia, the SUPERPAVE mix design has a high potential implementation in the near future. The issue is being critically reviewed by the Ministry of Communications (MOC), as the governmental agency responsible for the rural highway system in the Kingdom. MOC has asked all contractors working in pavement construction to get prepared for implementation of this new technique in asphalt mix design. Series of training courses are being conducted for personnel in all governmental and private sectors involved in the design, construction, evaluation, and management of asphalt pavements [KFUPM, 2002]. These training courses aim to describe the SUPERPAVE components, critical requirement, why they are needed, and how this new system could impact the production and construction procedures for hot asphalt.

However, before full implementation of the SUPERPAVE mix design method, evaluation and qualification of the local materials is needed. This study is a trial to quantify the amount of degradation of aggregate used in asphalt mixes that are compacted using the SUPERPAVE gyratory compactor with comparison to the aggregate degradation of the conventional Marshall impact compactor.

## 2. TESTING PLAN

### 2.1. Materials

The aggregate and asphalt binder used is this study were collected from a contractor constructing a new pavement in Dammam industrial area roads. The local lime stone aggregate being used in this study was from Abu Hadriyah area, while the asphalt binder is the 60/70-penetration grade produced by RasTanura Refinery, Saudi Aramco. Enough quantities were collected to fabricate the needed laboratory samples. The physical properties of coarse and fine aggregate and quality tests are shown in Table 1. Two aggregate gradations were selected for this study one for the wearing course and one for the base course as specified by Dammam Municipality and shown in Table 2.

### 2.2. Sample Preparation

The aggregate was directly collected from the hot bin of the plant. It was decided to exactly duplicate the mix that is being used in the field in terms of proportioning and mixing method. Therefore, the mix designs for asphalt wearing course and base course adopted by Dammam Municipality were used in the sample preparation.

The collected aggregates were separated according to the sieve sizes shown in Table 2. Samples with 4-inch diameter were prepared using job mix formula (JMF) shown in Table 2 with the specified optimum asphalt content. Eight samples of aggregate blend were prepared for both wearing course and base course. Preparation and mixing of samples was done in accordance to ASTM D1559. Hobart mechanical automatic mixer was used to obtain uniform mixes.

### 2.3. Compaction Methods

As stated earlier, the Marshall and gyratory compaction methods were used in this study. For Marshall compaction method, and upon mixing, the loose mixture was placed in an oven, at 140 °C for one hour to simulate the short-term aging during mixing and lay down condition. After that, the 100 mm diameter samples were compacted using automatic Marshall hammer with 75 blows per side. The ASTM D1559 standard was followed precisely in this compaction. Four samples for wearing course and same for base course were prepared using this compaction method.

As for the gyratory compaction, the design number of gyrations ($N_{design}$) ranges from 68 to 172, as shown in Table 3, and it is a function of climate in which the mix will be placed and the traffic level measured by Equivalent Single Axle Load (ESAL). There are three gyration levels [FHWA, 1995]:

1. Design number of gyrations ($N_{design}$),
2. Initial number of gyrations ($N_{initial}$), and
3. Maximum number of gyrations ($N_{maximum}$)

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Table 1. Aggregate description and quality test results.

| Aggregate Type | Test | Results | Specifications |
|---|---|---|---|
| Wearing Course | Loss Angels Abrasion | 33% | 40% Maximum |
| | Soundness by $Na_2SO_4$ | 5.097% | 10% Maximum |
| | Sand Equivalent | 65 % | 45% Minimum |
| | Plasticity Index | Non-Plastic | 4% Maximum |
| Base Course | Loss Angels Abrasion | 33% | 40% Maximum |
| | Soundness by $Na_2SO_4$ | 5. 7% | 10% Maximum |
| | Sand Equivalent | 68 % | 45% Minimum |
| | Plasticity Index | Non-Plastic | 5% Maximum |

Table 2. Asphalt mix design parameters.

| Aggregate Type | Sieve Size | Percent Passing | Specifications |
|---|---|---|---|
| Wearing Course | 3/4 inch (19 mm) | 100 | 100 |
| | 1/2 inch (12.5 mm) | 84 | 76-92 |
| | 3/8 inch (9.5 mm) | 73 | 64-79 |
| | No. 4 (4.75 mm) | 48 | 41-56 |
| | No. 10 (2.54 mm) | 26 | 23-37 |
| | No. 40 (0.425 mm) | 16 | 7-20 |
| | No. 80 (0.180 mm) | 10 | 5-13 |
| | No. 200 (0.075 mm) | 6 | 3-8 |
| Asphalt Content (%) | | 4.9% | 4.65-5.25% |
| Base Course | 1 inch (25 mm) | 93 | 80-100 |
| | 3/4 inch (19 mm) | 85 | 70-90 |
| | 3/8 inch (9.5 mm) | 68 | 55-75 |
| | No. 4 (4.75 mm) | 51 | 44-62 |
| | No. 10 (2.54 mm) | 35 | 33-48 |
| | No. 40 (0.425 mm) | 20 | 16-27 |
| | No. 200 (0.075 mm) | 6.2 | 3-10 |
| Asphalt Content (%) | | 5% | 4-7% |

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Table 3. Gyratory compactive efforts [Anderson, 1993].

| Design ESAL's (millions) | High Air Temperature °C (Average Design) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | < 39 °C | | | 39-40 °C | | | 41-42 °C | | | 43-44 °C | | |
| | $N_{ini}$ | $N_{des}$ | $N_{max}$ | $N_{ini}$ | $N_{des}$ | $N_{max}$ | $N_{ini}$ | $N_{des}$ | $N_{max}$ | $N_{ini}$ | $N_{des}$ | $N_{max}$ |
| < 0.3 | 7 | 68 | 104 | 7 | 74 | 114 | 7 | 78 | 121 | 7 | 82 | 127 |
| 0.3 – 1 | 7 | 76 | 117 | 7 | 83 | 129 | 7 | 88 | 138 | 8 | 93 | 146 |
| 1 - 3 | 7 | 86 | 134 | 8 | 95 | 150 | 8 | 100 | 158 | 8 | 105 | 167 |
| 3 - 10 | 8 | 96 | 152 | 8 | 106 | 169 | 8 | 113 | 181 | 89 | 119 | 192 |
| 10 - 30 | 8 | 109 | 174 | 9 | 121 | 195 | 9 | 128 | 208 | 9 | 135 | 220 |
| 30 – 100 | 9 | 126 | 204 | 9 | 139 | 228 | 9 | 146 | 240 | 10 | 153 | 253 |
| > 100 | 9 | 142 | 233 | 10 | 158 | 262 | 10 | 165 | 275 | 10 | 172 | 288 |

The average design high air temperature is the average seven-day maximum air temperature for project conditions. The project being constructed is located in Dammam industrial area, which has high traffic volume and traffic loading since most of the traffic there, are trucks. Therefore, a traffic level of 10-30 million ESAL was selected for this study. However, for general consideration, this traffic level is also applicable in Saudi Arabia. The Eastern Province of Saudi Arabia has a high air temperature levels [Ramadhan and Al-AbdulWahhab, 1997] with an average 7-day maximum air temperature of 47 °C. Therefore, $N_{maximum}$ value of 220 was selected for this study.

The compaction procedure specified by SHRP [FHWA, 1995] was followed in this study:

1. After mixing, the loose mix materials were spread in a pan and placed in an oven at 135 °C for four hours to simulate the short-term conditioning. During this process, asphalt mix was stirred every one hour to ensure uniform aging.

2. The compaction molds (100-mm diameter) and base plate are placed in the oven at 135°C for 30-45 minutes prior to use.

3. The vertical pressure of the Gyratory compactor is set to 600 Kpa (100 psi).

4. The $N_{max}$ (Max. Number of gyrations) is set to 220 (this is for average 7-day maximum air temperature of 34-44 °C, and Design ESAL's = 10-30 x $10^6$

5. The base plate is fixed in place, with a paper disk on the top of the plate, then the mold is charged by the conditioned mix in a single shift, and a paper disk is placed on the top of the mix.

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6. The compactor ram is lowered until it contacts the mix with a resting pressure of 100 psi, then the angle of 1.25 is applied, and the compaction is started.

7. When $N_{max}$ is reached the system stops automatically.

8. The mold is removed for the compactor, and is left for cooling, and then the sample is extruded from the mold.

The above procedure was done for eight samples (four for wearing course and four for base course). The 16-compacted samples were subjected to the testing procedure detailed in the next section.

### 2.4. Aggregate Testing for Degradation

All compacted samples were subjected to volumetric analysis in terms of bulk specific gravity in accordance to ASTM D2726 and percent air voids in accordance to ASTM D3203. One sample from each group was selected for determination of maximum specific gravity in accordance to ASTM D2041. The other three samples in each group were subjected to the extraction of asphalt from the mix and reclaiming the clean aggregate in accordance to the procedure presented in ASTM D2172, "Quantitative Extraction of Bitumen from Bituminous Paving Mixtures - Method A".

The reclaimed aggregate from extraction test was sieved again using the same sieves used in fabricating the asphalt-aggregate mixes. The sieve analysis was performed again for each sample, and average of three samples in terms of percent passing of each size is determined. Table 4 shows the basic test results for the compacted asphalt mix samples. Table 5 shows the summary of the aggregate gradation after extraction, while Tables 6 and 7 show the calculated surface area for wearing course and base course aggregate before and after compaction. In these tables, the surface area factors are adopted from a previous study by [Subramanyam and Pratapa, 1989].

Table 4. Results of basic tests for asphalt mixes testing.

| Test | Marshall Compaction | | Gyratory Compaction | |
|---|---|---|---|---|
| | Wearing Course | Base Course | Wearing Course | Base Course |
| Bulk Specific Gravity (g/cc) | 2.300 | 2.316 | 2.380 | 2.353 |
| Maximum Theoretical Specific Gravity (g/cc) | 2.418 | 2.430 | 2.426 | 2.456 |
| Percent Air Voids (%) | 4.88 | 4.69 | 1.90 | 4.21 |

Table 5. Aggregate gradation after compaction.

| Material Type | Sieve Size | Marshall Compaction | | | Gyratory Compaction | | |
|---|---|---|---|---|---|---|---|
| | | Percent Passing Before | Percent Passing After | Specifica-tions | Percent Passing Before | Percent Passing After | Specifica-tions |
| Wearing Course | 3/4 in (19 mm) | 100 | 100 | 100 | 100 | 100 | 100 |
| | 1/2 in (12.5 mm) | 84 | 86.69 | 76-92 | 84 | 85.94 | 76-92 |
| | 3/8 in (9.5 mm) | 73 | 76.44 | 64-79 | 73 | 75.74 | 64-79 |
| | No. 4 (4.75 mm) | 48 | 54.45 | 41-56 | 48 | 53.54 | 41-56 |
| | No. 10 (2.54 mm) | 26 | 32.27 | 23-37 | 26 | 33.11 | 23-37 |
| | No. 40 (0.425 mm) | 16 | 20.31 | 7-20 | 16 | 21.08 | 7-20 |
| | No. 80 (0.180 mm) | 10 | 12.03 | 5-13 | 10 | 11.78 | 5-13 |
| | No. 200 (0.075 mm) | 6 | 7.95 | 3-8 | 6 | 7.91 | 3-8 |
| Base Course | 1 in (25 mm) | 93 | 96.04 | 80-100 | 93 | 95.8 | 80-100 |
| | 3/4 in (19 mm) | 85 | 87.19 | 70-90 | 85 | 88.14 | 70-90 |
| | 3/8 in (9.5 mm) | 68 | 68.89 | 55-75 | 68 | 69.31 | 55-75 |
| | No. 4 (4.75 mm) | 51 | 53.47 | 44-62 | 51 | 54.23 | 44-62 |
| | No. 10 (2.54 mm) | 35 | 37.33 | 33-48 | 35 | 38.43 | 33-48 |
| | No. 40 (0.425 mm) | 20 | 29.46 | 16-27 | 20 | 30.27 | 16-27 |
| | No. 200 (0.075 mm) | 6.2 | 7.94 | 3-10 | 6.2 | 8.69 | 3-10 |

Table 6. Surface Area Calculation for Wearing Course Aggrgegate.

| Sieve Size | Surface Area Factor ($cm^2/gm$)* | Job Mix Formula | | Marshall Method | | Gyratory Method | |
|---|---|---|---|---|---|---|---|
| | | Percent Passing | Surface Area ($cm^2/gm$) | Percent Passing | Surface Area ($cm^2/gm$) | Percent Passing | Surface Area ($cm^2/gm$) |
| 3/4 in (19 mm) | 1.62 | 100 | 1.62 | 100 | 1.62 | 100 | 1.62 |
| 1/2 in (12.5 mm) | 2.29 | 84 | 1.9236 | 86.69 | 1.99 | 85.94 | 1.97 |
| 3/8 in (9.5 mm) | 4.1 | 73 | 2.993 | 76.44 | 3.13 | 75.74 | 3.11 |
| No. 4 (4.75 mm) | 6.4 | 48 | 3.072 | 54.45 | 3.48 | 53.54 | 3.43 |
| No. 10 (2.54 mm) | 14 | 26 | 3.64 | 32.27 | 4.52 | 33.11 | 4.64 |
| No. 40 (0.425 mm) | 50 | 16 | 8 | 20.31 | 10.16 | 21.08 | 10.54 |
| No. 80 (0.180 mm) | 180 | 10 | 18 | 12.03 | 21.65 | 11.78 | 21.20 |
| No. 200 (0.075 mm) | 615 | 6 | 36.90 | 7.95 | 48.89 | 7.91 | 48.65 |
| Total Surface Area ($cm^2/gm$) | | | **76.15** | - | **95.44** | - | **95.15** |

* Adopted from Subramanyam and Pratapa, 1989.

Table 7. Surface Area Calculation for Base Course Aggregate.

| Sieve Size | Surface Area Factor ($cm^2$/gm)* | Job Mix Formula | | Marshall Method | | Gyratory Method | |
|---|---|---|---|---|---|---|---|
| | | Percent Passing | Surface Area ($cm^2$/gm) | Percent Passing | Surface Area ($cm^2$/gm) | Percent Passing | Surface Area ($cm^2$/gm) |
| 1.5 in (37.5 mm) | 1 | 100 | 1 | 100 | 1.00 | 100 | 1.00 |
| 1 in (25 mm) | 1.1 | 93 | 1.023 | 96.04 | 1.06 | 95.8 | 1.05 |
| 3/4 in (19 mm) | 1.62 | 85 | 1.377 | 87.19 | 1.41 | 88.14 | 1.43 |
| 3/8 in (9.5 mm) | 4.1 | 68 | 2.788 | 68.89 | 2.82 | 69.31 | 2.84 |
| No. 4 (4.75 mm) | 6.4 | 51 | 3.264 | 53.47 | 3.42 | 54.23 | 3.47 |
| No. 10 (2.54 mm) | 14 | 35 | 4.9 | 37.33 | 5.23 | 38.43 | 5.38 |
| No. 40 (0.425 mm) | 50 | 20 | 10 | 29.46 | 14.73 | 30.27 | 15.14 |
| No. 200 (0.075 mm) | 615 | 6.2 | 38.13 | 7.94 | 48.83 | 8.69 | 53.44 |
| Total Surface Area ($cm^2$/gm) | | | **62.48** | - | **78.50** | - | **83.75** |

* Adopted from Subramanyam and Pratapa, 1989.

## 3. DATA ANALYSIS

### 3.1. General

As it is evident from Table 5, the highest degradation percentage change occurs (9.46), for the base course, in sieve No. 40 (i.e. from 20 to 29.46%) for Marshall compaction and 10.27% (i.e. from 20 to 30.27%) for gyratory compaction. This amount of aggregate degradation resulted in having the percent passing of this sieve to fall outside the specifications range (16-27), thus changing the original mix properties.

For the wearing course aggregate, the highest degradation occurred in No. 10 sieve (7.1%) for gyratory method and No. 4 sieve (6.45%) for Marshall method. This amount of aggregate degradation resulted in having the percent passing of these sieves to fall outside the specification range as shown in table 5, i.e. 23-37 for sieve No. 10 and 41-56 for sieve No. 4. This would also lead to changing the original mix properties.

Comparing the two-compaction methods, in terms of degradations on particular sieve, the Marshall method gave higher degradation in 5 sieves against 2 sieves for gyratory method for wearing course, while the gyratory gave higher degradation for 6 sieves against only one sieve for the base course.

In this study, the quantification of aggregate degradation is expressed by computing three percentage changes as a result of compaction method. The three percentages are:

1. Percent increase in filler,
2. Percent increase in fine aggregate, and
3. Percent increase in surface area.

### 3.2. Percent increase in filler

The percentage increases in filler expressed as materials passing No. 200 sieve for wearing course aggregate were 1.95% and 1.91% for Marshall compaction and gyratory compaction, respectively. Such increments are not significant. Therefore, it can be decided that the difference between the two methods is not significant either.

However, for the base course aggregate, the percent increment in the materials passing sieve No. 200 was 1.74% and 2.49% for Marshall compaction and gyratory compaction, respectively. Here, the gyratory compaction gave higher degradation that made the amount of filler, 8.69% approaching the upper limit of the specification (3-10%) as shown in Table 5. The higher filler content is not advisable in the asphalt mix as it makes it prone to rutting problems [Al-Abdul Wahhab, 1994] .

### 3.3. Percent increase in fine aggregate

The percent increase in fine aggregate is calculated by the total materials passing sieve No. 4 and retained on sieve No. 200. From Table 7, the fine aggregate portions of base course were 44.8%, 45.53%, and 45.55% for original mix (JMF), Marshall compaction, and gyratory compaction, respectively. Only less than 1% is the overall difference between the two methods of compaction.

On the other hand, the fine aggregate portions of the wearing course were 42%, 46.5%, and 45.63% for original mix (JMF), Marshall compaction, and gyratory compaction, respectively. There is 4.5% difference in the increment for Marshall method and 3.6% for gyratory methods compared to the original mix. Although these values are not dramatically different, however, they represent a difference in the amount of aggregate degradation due to different compaction methods under consideration, with slight superiority to the gyratory method.

### 3.4. Percent increase in surface area

Tables 6 and 7 show the surface area calculation before mixing using JMF gradation, as well as after compaction using Marshall and gyratory compaction methods. The surface area is calculated for each sieve size by multiplying the percent passing of that sieve by the surface area factor in $cm^2/gm$.

It is obvious that the wearing course aggregate is finer than the base course aggregate providing smoother and more impervious pavement surface. The original total surface area for wearing course, is 76.15 $cm^2/gm$, as shown in Table 6. This value has increased to 95.44 $cm^2/gm$ as a result of Marshall compaction and 95.15 $cm^2/gm$ as a result of gyratory compaction, which represent about 25% increment in surface area for both methods. This

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shows that there is no significant difference in surface area increment resulting from the two methods of compaction.

For base course aggregate, as shown in Table 7, the percent increase in surface area was calculated as 25.64% for Marshall method, and 34% for gyratory method. This clearly indicates that the gyratory compaction method has more aggregate degradation than the Marshall method, and that this represents more than one-third of the original surface area. Such high increment in surface area means a need for higher asphalt binder to coat the aggregate particles to provide the necessary adhesion to the whole mix and consequently the sufficient strength of the pavement.

## 4. CONCLUSIONS

The main objective of this study was to give a general method for quantification of the aggregate degradation due to compaction process in the asphalt mixes, and compare the two-compaction methods (Marshall and gyratory) in terms of their effect on aggregate degradation. Therefore, based on the data analysis of this study, the following conclusions are drawn:

1. The aggregate degradation due to mixing, handling, and compaction has a great effect in determining the pavement performance since it changes the original properties of the aggregate and consequently the mix. This is clear when some of the sieves, after compaction, have percent passing beyond the specification limits for both methods of compaction.

2. Considering the methods of compaction, the base course aggregate was generally affected more than the wearing course aggregate.

3. Considering the used type of aggregate and its gradation, the gyratory compaction method showed better results (lower degradation) for wearing course mixes while the Marshall compaction method showed better results (lower degradation) for base course mixes.

4. The percent increase in filler (passing No 200 sieve) is higher for base course aggregate as a result of gyratory compaction than as a result of Marshall compaction. However, for wearing course there was no significant difference between the two methods, nor between each method and the original filler content.

5. The degradation measured by the percent increase in fine aggregate was not significant for both methods for base course aggregate. However, the gyratory method shows a slight superiority for wearing course aggregate than the Marshall method.

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6. The degradation measured by the percent increase in surface area showed that the gyratory method gave higher surface area than the Marshall method for base course. While for the wearing course there is no significant difference between the two methods.

7. Among the three methods for aggregate degradation, the surface area method gave the most significant meaningful results in terms of quantification of this degradation.

8. As a recommendation, and before adapting the gyratory compaction, in Saudi Arabia, it is suggested to further evaluate this method for aggregate blend and mix design. A comprehensive comparison of these two, methods requires rigorous laboratory and field testing including more fundamental test parameters.

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