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Effect of Marshall and Gyratory Compaction Methods on Segregation of Asphalt Mixture by Image Analysis

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ABSTRACT

The distribution of aggregate particles in asphalt mixtures play an important role in determining the properties of asphalt concrete. Segregation is a common failure that occurs during the construction when the factors such as aggregates gradation, compaction and mixing temperature are not controlled well. It increases the risk of early failures such as rutting, lower density and degradation. Thus, it is desired to study the internal structure of asphalt mixtures in terms of aggregate distribution using various compaction methods. The objective of the current study is to compare the distribution of aggregates in asphalt samples compacted by Marshall Compactor (MC) and Superpave Gyratory Compactor (SGC) under different conditions of compactive effort. The MC and SGC samples were prepared and Image J software was used in conjunction with AutoCAD to analyze both types of samples in terms of particles distribution (Segregation). It was concluded that the average segregation ratio of Marshall Compacted Specimens (MCS) is relatively more than the Gyratory Compacted Specimens (SGS).

Key words: Marshall Samples, SGC Samples, Particle distribution, Segregation Ratio.

1. INTRODUCTION

Due to its versatile properties of strength, durability, quick cooling and viscoelasticity, Hot Mix Asphalt (HMA) is the most commonly used composite paving material for roads and parking lots. Many studies have been conducted too improve the performance characteristics of asphalt through numerous ways such as polymer modification [1] and use of recycled concrete aggregates [2]. Compaction of asphalt is an important factor in flexible pavement construction, having direct effect on road's lifespan. Different compaction methods and compaction tools are used to prepare asphalt samples. Previous studies revealed that different compaction methods yield asphalt concrete having varied mechanical properties. Distribution and orientation of aggregates in asphalt mixes compacted in the laboratory by using image analysis procedure was inspected by Hunter et al. [3]. In particles' distribution, significant dissimilarities among the techniques were identified. It is preferred for laboratory compacted specimens to have the identical properties as the one's compacted in site [4,5]. For achieving ideal compaction, the laboratory compaction equipment is fabricated to imitate the site conditions as closely as possible. On the other hand, it is known that various laboratory compaction approaches generate transformations in light of mechanical characteristics [6]. Al-ammari et al. specified that the properties of these specimens depend on compaction methods i.e., direction, magnitude and duration of the applied force [7]. Hence, numerous past studies compared the compacted laboratory samples with field samples.

The differences between laboratory compaction methods of Bituminous Matrix Analysis were studied in National Cooperative Highway Research Program (NCHRP) [8]. Five different laboratories compaction procedures i.e. Texas gyratory compactor, vibratory compactor, Marshall hammer, steel roller and ASTM standard kneading compactor were examined to opt the procedure which is analogous to actual site state. The report revealed that samples compacted by Texas gyratory compactor had identical properties to field samples in terms of mechanical properties. In SHRP, long-lasting deformation properties of specimens compacted in laboratory were explored by Sousa et al. [9]. They compared 3 compaction techniques i.e., Kneading, Rolling wheel and Texas gyratory compactors to evaluate dissimilarities of techniques. They highlighted that kneading compactor yields samples having toughest particle arrangement, whereas gyratory compaction creates weakest asphalt samples.

Relationship among the laboratory compacted samples and cores taken from the site was studied by Button et al. [10]. Field specimens were acquired from 5 sites, while the specimens in the laboratory were prepared by using 4 laboratory compaction approaches (Marshal Hammer, Exxon rolling wheel, Texas gyratory and Elf kneading). They concluded that the Texas gyratory compactor is most suitable compaction approach to imitate actual site compaction. Results of samples compacted in laboratory were looked at by Harvey et al. [11]. They related the site samples with 5 categories of laboratory compaction processes i.e., Marshall Hammer compaction, Texas gyratory, Kneading, Rolling wheel and SHRP gyratory. It was concluded that specimens compacted by rolling wheel method were approximately simulating the site samples. Although the kneading compaction approach were likely to produce stiffer samples as compared to field specimens, while the gyratory compaction was likely to produce fragile specimens in the terms of permanent deformation. Another study revealed that roller compacted asphalt samples imitates field specimen [12]. Study by Brown et al. revealed that vibratory hammer provide similar specimen to field specimen concerning mechanical characteristics [13].

Asphalt mixtures possess different mechanical properties that largely depend on compaction method, mixing techniques, size and shape of aggregates. These parameters control the aggregate segregation in asphalt mixtures. Thus, determination of aggregate segregation in asphalt mixture is required for different compaction methods and mixing techniques. This study is aimed to find the aggregates segregation in asphalt samples prepared by Gyratory compaction and Marshall compaction methods using image analysis through Image J software and to relate the segregation graphs of the two compaction methods with the work done by Masad et al. where they studied the modification in air voids dispersion between Linear Kneading Compacted (LKC) samples and Superpave Gyratory Compacted (SGC) sample.

2. MATERIALS AND METHODS

2.1 Bitumen properties

Bitumen of 60/70 was used in this study. The results of the tests performed on bitumen are tabulates as in Table 1:

Table 1: Properties of Bitumen

Test	Result
Penetration Grade	60/70
Flash Point	257 °C
Fire Point	282 °C
Softening Point	58 °C

2.2 Aggregate Gradation:

Margallah aggregates were used in the study. Aggregate gradation was done as per ASTM D1559 shown in the figure 1 and table 2.

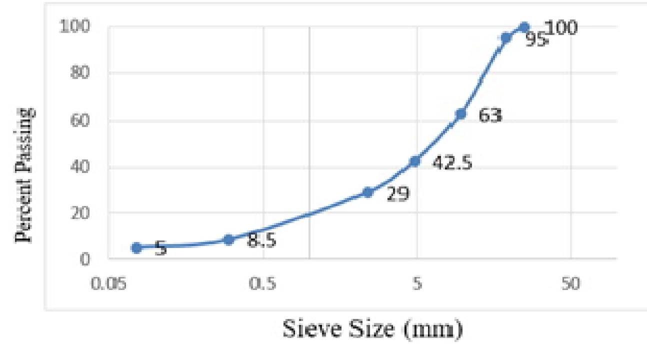

Figure 1: Aggregates Gradation Curve

Table 2: Gradation of Aggregates

Sieve	Master Band (% Passing)	Trial Blend (% Passing)	Total % Retained	% Retained on Each Sieve
1″	100	100	0	0
¾ ″	90-100	95	5	5-0 = 5%
3/8 ″	56-70	63	37	37-5 = 32%
# 4	35-50	42.5	57.5	57.5-37 = 20.5%
# 8	23-35	29	71	71-57.5 = 13.5%
# 50	5-12	8.5	91.5	91.5-71 = 20.5%
# 200	2-8	5	95	95-91.5 = 3.5%
Pan	___	0	100	100-95 = 5%

2.3 Optimum Binder Content (OBC)

OBC was calculated as 4.5% as per ASTM D1559 - 89.

2.3.1 Samples Preparation, Cutting and Analysis

A total of 28 asphalt samples were prepared in laboratory, out of these, 14 were compacted at by Marshall and 14 by Gyratory compaction approaches. These samples were then cut at top and mid-section by using rip saw and hack saw blades. Peripheral and regional segregation ratio and particle distribution in all specimens were computed.

2.3.2 Aggregate Particles Separation

The cut surfaces of compacted specimens were scanned to determine its average particle separation with the help of Image J. application. For this purpose, the scanned images of specimens were brought to the software interface and was analyzed to determine total number of particles, total particles area, individual particle area and its number. The derived sample was imported to AutoCAD software to inspect the separation by applying the approach employed in this research.

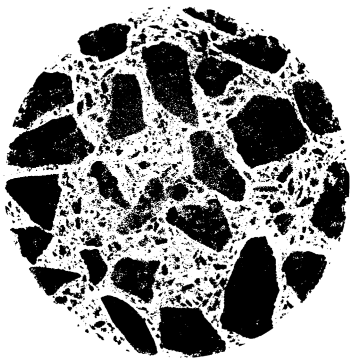

Figure 2: Aggregate particles separated from the bitumen

2.4 Segregation Ratio

Peripheral and regional segregation ratios were obtained for both the Marshall and Gyratory compacted specimens.

For peripheral segregation ratio, all the four quarters were observed in order to get segments of maximum and minimum number of aggregate particles in case of Marshall and Gyratory compacted specimens. Dividing the maximum aggregate particles quadrant by the minimum aggregate particles quadrant gives the peripheral segregation ratio:

Peripheral Segregation Ratio

= Maximum Particles Quarter/Minimum Particles Quarter

To find the regional segregation, the aggregate particles were counted in the internal and external regions of the asphalt compacted specimens using the equation below:

Regional Segregation Ratio = No. of particles in outer region / No. of particles in inner region

2.5 Aggregate Particles Distribution

Different particle distributions were practically observed at different cross-sections at the top and middle of the specimen.

2.6 Voids Dispersion

The variance in voids dispersion among Marshall and Gyratory compacted sample was studied by employing image analysis procedure and using Microsoft Excel,

3 RESULTS AND DISCUSSION

3.1 Segregation Ratio

Peripheral segregation ratio (PSRs) and regional segregation ratio (RSR) were obtained for both the Marshall and Gyratory compacted specimens.

3.1.1 PSR

PSRs and their average were obtained as shown in table 3 and table 4:

Table 3: PSR Calculation for Marshall Compacted Specimens

Arrangements	Q1	Q2	Q3	Q4	PSR
1	37	41	49	51	1.38
2	38	42	47	51	1.34
3	39	42	47	50	1.28
4	**37**	46	47	48	1.30
5	37	46	49	46	1.32
6	37	49	49	43	1.32
7	38	47	52	41	1.37
8	42	42	**54**	40	1.35
9	40	46	53	39	1.36
Average Segregation Ratio					**1.45**

Table 4: PSR Calculation for Gyratory Compacted Specimens

Arrangements	Q1	Q2	Q3	Q4	PSR
1	48	49	45	45	1.09
2	50	47	46	44	1.14
3	52	45	47	**43**	1.21
4	**53**	46	44	44	1.20
5	50	46	44	47	1.14
6	49	46	46	46	1.07
7	49	43	50	45	1.16
8	49	45	49	44	1.11
9	49	46	46	46	1.07
Average Segregation Ratio					**1.23**

The particles per segment in both Gyratory compaction (Figure 3) and Marshall compaction (Figure 4), were plotted in the form of Radar Graph as given below:

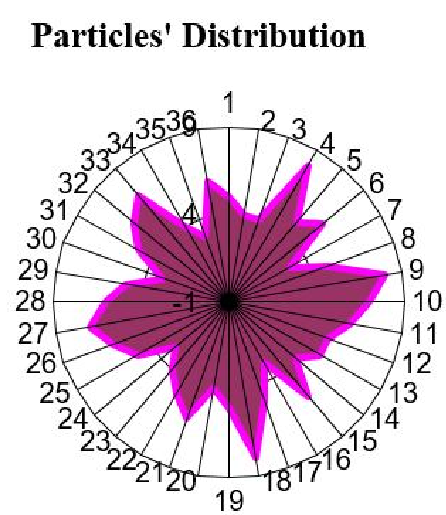

Figure 3: Peripheral Segregation Radar graph for GCS

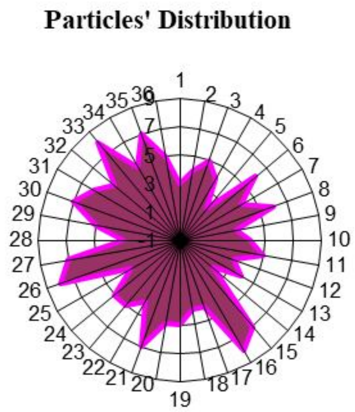

Figure 4: Peripheral Segregation Radar graph for MCS

3.1.2 RSR

RSRs and their average were obtained as illustrated in table 5 and 6 below:

Table 5: RSR Calculation for Marshall Compacted Specimens

	Q1	Q2	Q3	Q4	No. of Particles
Outer Region	12	13	15	12	51
Inner Region	7	8	10	7	33
Regional Segregation Ratio					**1.56**

Table 6: RSR Calculation for Gyratory Compacted Specimens

	Q1	Q2	Q3	Q4	No. of Particles
Outer Region	22	21	23	26	93
Inner Region	21	21	23	25	89
Regional Segregation Ratio					**1.04**

The particles in outer and inner regions in both Marshall and Gyratory Compacted specimens were plotted in the form of Radar Graph as shown in figure 5 and figure 6 below:

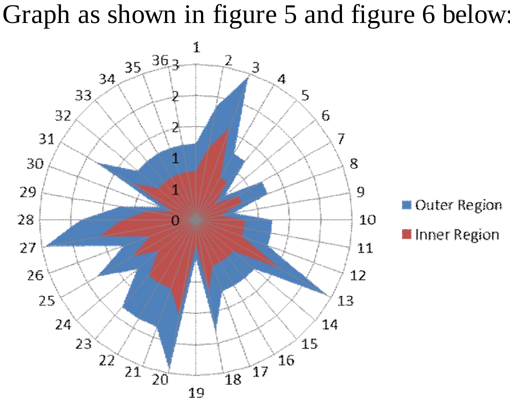

Figure 5: Regional Segregation Radar graph for MCS

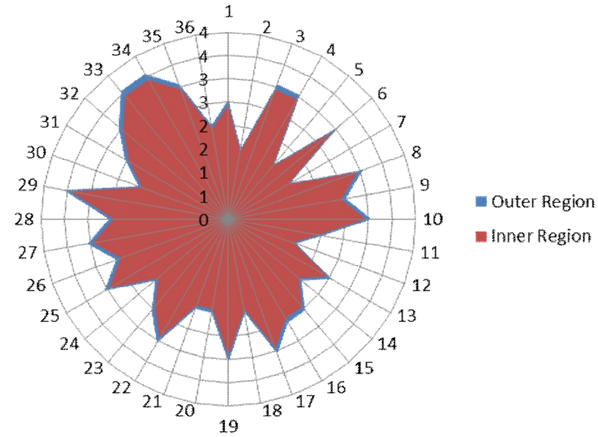

Figure 6: Regional Segregation Radar graph for GCS

In terms of segregation ratio, it was observed that the average segregation ratio of Marshall compacted specimen was relatively more than the average segregation ratio of Gyratory compacted specimen. Marshall compacted specimens had a minimum Peripheral Segregation Ratio of 1.45 and minimum Regional Segregation Ratio of 1.56, while the Gyratory Compacted Specimens had a minimum Peripheral Segregation Ratio of 1.23 and minimum Regional Segregation Ratio of 1.04, which is the indicative of less segregation occurred in gyratory compaction technique. As the presence of segregation negatively affects the overall pavement performance, hence gyratory compaction is a more reliable technique.

3.2 Aggregate Particles Distribution

Different particle distribution were practically observed at different cross-sections at the top and middle of the specimens. The average results of the top and middle cross-sections of the compacted asphalt specimens are shown in table 7, table 8 and the difference of particle distributions is shown in fig. 5.

Table 7: Particles' Distribution in MCS

S. No	VSA Range (mm^2)	No. of Particles
1	25-50	59
2	50-75	21
3	75-100	9
4	100-150	6
5	150-200	5
6	200-250	2
7	250-300	4
8	300-350	3
9	350-400	1
10	400-450	2
11	450-500	1

Table 8: Particles' Distribution in GCS

S. No	VSA Range (mm^2)	No. of Particles
1	25-50	58
2	50-75	18
3	75-100	6
4	100-150	6
5	150-200	4
6	200-250	3
7	250-300	4
8	300-350	2
9	350-400	2
10	400-450	2
11	450-500	2

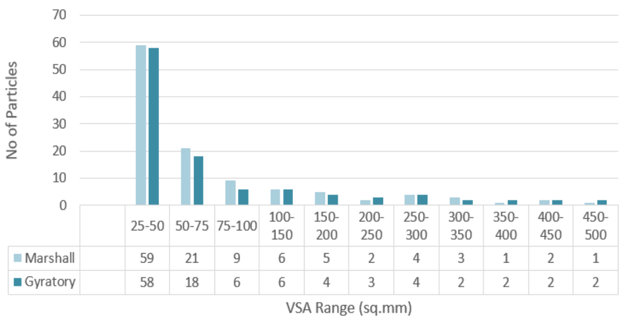

Figure 7: Differences of Particles' Distribution

3.3 Voids Dispersion

Compaction within the middle section of GCS were even and consistent in comparison with bottom and top section, while the MCS were observed to have inconsistent and varying air voids distribution (Figure 8). The percent voids at the top are minor as compared to the bottom and middle section indicating that the top portion is more compacted than middle section in case of Marshall Compaction. So, Gyratory compaction yield relatively uniform air-voids distribution.

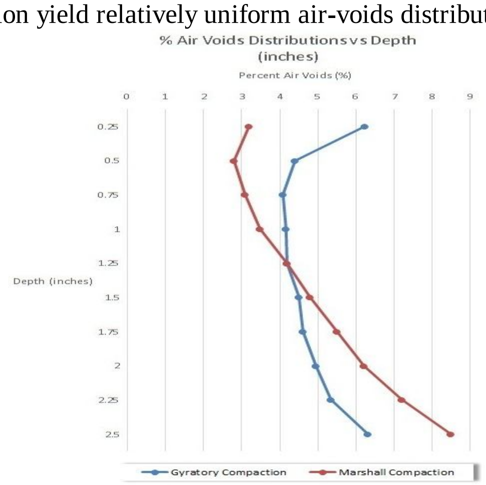

Figure 8: Air voids distribution in MCS & GCS

4. CONCLUSION

Two compaction methods were under consideration in this research work i.e., Marshall and Gyratory compaction methods. The following conclusions can be drawn from the results of the study.

1. The average segregation ratio of Marshall compacted specimen was relatively more than the average segregation ratio of Gyratory compacted specimen.
2. Compaction within the middle section of Gyratory Compacted Specimen was observed to be even and consistent in comparison with the top section as compared to Marshall Compacted Specimen
3. The percent voids at the top are minor as compared to the bottom and middle section indicating that the top portion is more compacted than middle section in case of Marshall Compaction.
4. Overall, gyratory compaction gave better results, thus, should be employed in research activities.

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