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Determining the Void Ratio in Hot-Mix Asphalt Pavements Using Different Methods According to EN 12697.

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ABSTRACT

Inaccurate air void ratio based on erroneous bulk density can seriously affect the performance of the roadway and its quality. Therefore, several methods were improved to measure bulk density by using different techniques in the developed countries, while the Saturated Surface Dry (SSD) traditional method has been used in Gaza strip till present days. This study aims at providing a better understanding of the effect of the selected bulk density measurement method on the percentage of voids using four methods namely; Dimensional Method, Dry Method, Surface-Saturated Dry Method, and Paraffin Sealing Method. At Laboratory, sixty-nine specimens were prepared, thirty-three of them were prepared in the Marshal Design System in order to determine the optimum bitumen content of the three different mix types, and thirty-six of the specimens were taken from mixtures design in order to determine bulk density. Laboratory results showed that the SSD method is the best choice for measuring bulk density in dense and mastic mixtures. In addition, there are no differences between SSD and dry methods in mastic mix. The experimental study shows that the dimensional method is the only method suitable for the determination of bulk density (Gmb) in porous mix despite it always gives underestimated results for Gmb in all asphalt mixes. As a result, the dimensional method can be used as an indicator for the upper limit of voids, while the dry method can be used as an indicator to the lowest limit, regardless the type of mix. The study recommended to use new techniques to determine Gmb in open graded mixtures with more accurate methods rather than traditional ones.

Key Words:

Hot Mix Asphalt, Density, Bulk density, Void Ratio, Porous Asphalt, Mastic Asphalt.

1. Introduction

Density is one of the most important parameters used in calculations to determine the quality and quantity of asphalt in design and construction stages. (Brown & Cross, 1989). There are three primary methods of specifying density: percent of control strip, percent of laboratory density, and percent of theoretical maximum density. All three methods can be used to obtain satisfactory compaction if used correctly. The initial in-place air voids must be below approximately eight percent and the final in-place air voids must be above approximately three percent. The initial in-place air voids are determined by comparing bulk density to theoretical maximum density (TMD) and the final in-place air voids are estimated by comparing [1]the bulk density of laboratory compacted sampler to the TMD (TXDOT, 2016). The two methods that have been used to measure bulk density of asphalt mixture are physical measurements of cores and nuclear gage. The nuclear gage is fast and non-destructive but is not as accurate as the core method. (Palmer, 1989)

Hot Mix Asphalt

Hot Mix Asphalt is a combination of two primary ingredients - aggregates and an asphalt binder. The aggregates total ninety to ninety-five percent of the total mixture by weight. They are mixed with approximately four to eight percent asphalt binder to form HMA (CAPA , 2006). Bituminous mixes are complex multiphase materials consisting of a gradation of aggregate, air voids, and bitumen. The purpose of a pavement is to carry traffic safely, conveniently, and economically throughout its design life. (Cebon, 2000). Hot-mix asphalt pavements function properly when they are designed, produced and placed in such a manner as to give them certain desirable performance characteristics such as: permanent deformation (rutting) resistance, durability, flexibility, fatigue resistance, skid resistance, impermeability, workability, and economics. So, The objective of Mix Design Method is to determine the amount of various sizes of mineral aggregates to use to get a mix of maximum density and determines the optimum bitumen content.

Asphalt Mixture Types

Asphalt pavements classified in terms of technology, usage, and many of standards and determinants related to the materials used and their properties. This study will depend on dense-graded mixes, closed- graded mixes,
"Mastic", and open-graded "Porous" HMA in accordance with aggregate mineral gradation.
The grade of asphalt selected depends on:

- The type of construction
- Climatic conditions
- Amount and nature of traffic (Rodriguez, 2017)

As Figure (1) shows, Asphalt mixtures can be categorized into four different types.

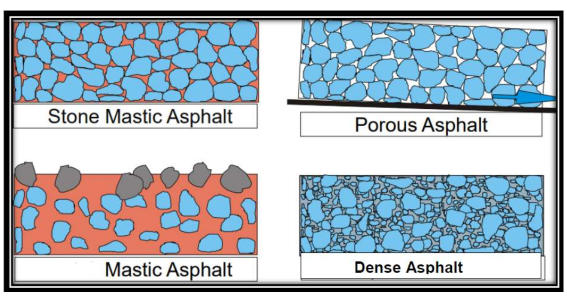

Figure (1): Aggregate packing arrangements of asphalt mixture types. (Cooley, 2008)

Bulk Density in Codes

There are a number of methods available to obtain asphalt density and each one uses a slightly different way to determine specimen volume, which may result in different density values. Table (1) shown the most practical methods for tested (Gmb) according to ASTM, AASHTO, and EN standers.

Air Voids Content

The air void content of asphalt (Va), which is defined as the ratio of volume of voids to total volume of the compacted mix, one has to first measure pavement density, Va was determined using the bulk specific gravity, and theoretical maximum density. The air void content is calculated as the ratio of the asphalt pavement density to the maximum density.

$$Air\ Voids = \left[1 - \left[\frac{G_{mb}}{G_{mm}}\right]\right] * 100\% \quad (1)$$

The variety in asphalt mixture types led to wide range of the properties' values. For example: void ratio value ranges from 0.0% in mastic asphalt to 25% in porous asphalt. This requires more accurate tools for measuring these properties.

2. Methodology

All basic volumetric calculations of compacted HMA specimens depend on the correct measurement of the bulk density. So, this study focuses on measuring an accurate bulk density by using four methods that including the saturated surface dry (SSD) method which is the only one used in Gaza, and also the widely commonly used in general. The following statements illustrates the problem

1. There are some methods available to obtain the asphalt density, and each one of these methods uses a slightly different way to determine specimen volume, which may result in different density values.
2. There is a difficulty in specifying the void ratio especially in the Open Graded Friction Courses (OGFC) mixtures, because of large interconnected air voids which reach the surface, and this reason lead to an error when using SSD method.
3. Some new methods and techniques were developed to determine the bulk density, but, what about the accuracy and confidence of the traditional methods result, this is an essential question in the study.
4. Some recent researches focus on using porous and mastic asphalt, this issue requires providing an accurate estimation result when measuring the bulk density, and taking into consideration gradation of the mixture.

: **Table (1):** Existing Methods with References.

Method	Author/Reference
Water Displacement (SSD Method)	AASHTO T-166 ASTM 2726 or EN 12697-6
Water Displacement (Dry Method)	EN 12697-6
Dimensional Analysis	AASHTO T-269 or EN 12697-6
Paraffin Sealing Method	AASHTO T-275, ASTM D 1188, EN 12697-6

Objectives

This study aims at comparing the methods of specifying bulk density of asphalt mixtures, and also to discuss the following points in particular:

1. Investigate and evaluate the current methods used for determining HMA bulk density.
2. Determine the possible reasons that produce the variability in bulk density and void ratio results.
3. Studying the effects of air void content requirements in design stage on the best method of measuring bulk density.
4. Comparing between the SSD method and the other three methods in measuring bulk density depending on the void ratio in HMA.

The methodology of the study is summarized in the following steps:

1. Reviewing previous studies, the methods for measuring bulk density and void ratio, and the reflection on HMA quality.
2. Studying the asphalt material components and the types of three HMA mixtures: Dense, Mastic, and Porous asphalt.

3. Preparing three types of asphalt mixtures at laboratory by taking twelve samples from each type of mixture, and then carrying out the tests of samples using four different methods to measure the bulk density and void ratio.
4. Analyzing the results, then implementing regression analysis and drawing a box plot.
5. Conclusion, recommendations.

3. Result and Discussion

Material and Testing Program

- **Stage (1):** Material Properties Testing
  Evaluation the properties of used materials such as aggregates, bitumen.

Aggregate Properties

The size of aggregate types which are used in preparing three asphalt mixtures are mentioned below.

Table (2) : Used aggregates types

Type of aggregate		Particle size (mm)
Coarse	Folia	0/19.0
	Adasia	0/12.5
	Simsimia	0/9.50
Fine	Trabia	0/4.75
	Filler	0/0.075

Table (3): Aggregate test results according to ASTM specifications

Specification	Test Results	Reference
Specific Gravity (g/cm^3)	2.61–2.67	ASTM C127-15
Water Absorption	1.8-2.2	ASTM C128
Abrasion Loss Value (%)	20.4-25.9	ASTM C128
Sieve Analysis of Aggregates and Blending Results	See Appendix (A)	*

Bitumen Properties

Asphalt binders 60/70& 75-25 were used in this research, 60/70 for dense and porous asphalt and 75-25 for mastic asphalt replaced the other type of binder, bitumen 85-25.

B60/70:

Bitumen penetration grade 60/70 means the penetration value is in the range 60 to 70 mm at standard test conditions.

B75-25:

The bitumen grade 75-25 means the softening point is 75°c and penetration is 25 mm.

In order to evaluate bitumen properties number of laboratory tests have been performed such as specific gravity, ductility, flash point, softening point and penetration.

Table (4): Bitumen test results according to ASTM specifications

Test	B60/70	B75-25	Reference
Density	1.03 (g/ml)	1.07 (g/ml)	ASTM D 3289-08
Penetration	62 (1/10mm)	20-30 (1/10mm)	ASTM D5/D5M-13
Flash Point	300 (º C)	304(º C)	ASTM D92 – 12b
Ductility	150 (cm)	37 (cm)	ASTM D113-07
Solubility	99.2 (%)	99.3(%)	ASTM D2042-09
Softening Point	48.5 (º C)	70.3(º C)	ASTM D 36

- **Stage (2):**Using Marshal Method to prepare three asphalt Mixtures type .

Blending of Aggregates

Asphalt mix needs the combining of two or more aggregates, having different gradations, to produce an aggregate blend that meets gradation specifications for a particular asphalt mix.

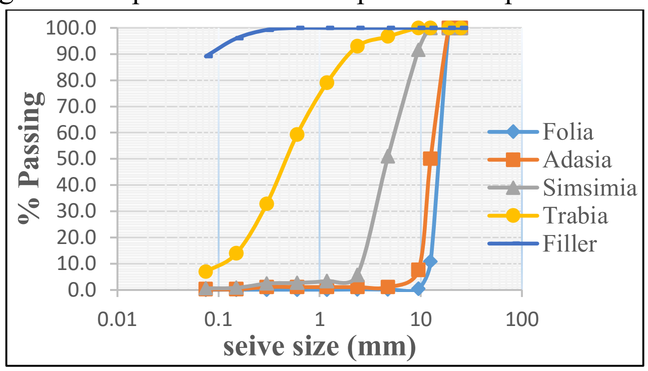

Figure (2): Aggregates gradations Used in Asphalt Mixtures preparing.

The trials are continued until the percentage of each size of aggregate are within allowable limits (Jendia, 2000).

1. **Dense Asphalt**

The proposed aggregates gradation curve is found to be satisfying FHWA specification for dense asphalt course gradation.

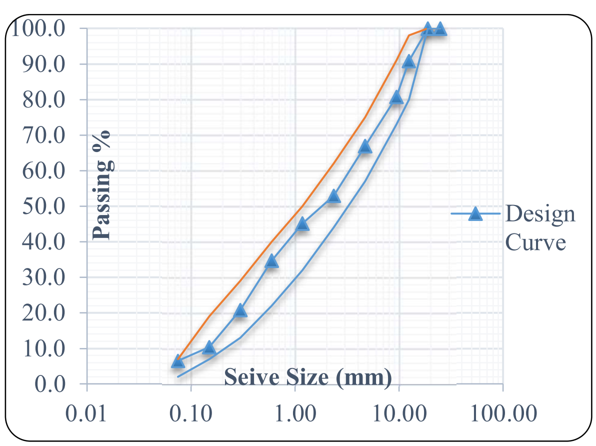

Figure (3): Gradation curve of dense asphalt mix with FHWA Specification.

2. Mastic Asphalt

MA contains three types of aggregates: coarse, fine, and filler. Numerical method used to determine trial blend of aggregates types proportion in mastic mixture, The final ratio of each aggregate material in MA mixture which is presented in appendix A. The proposed aggregates gradation curve is found to satisfy BS EN 13108-6 specification for MA gradation.

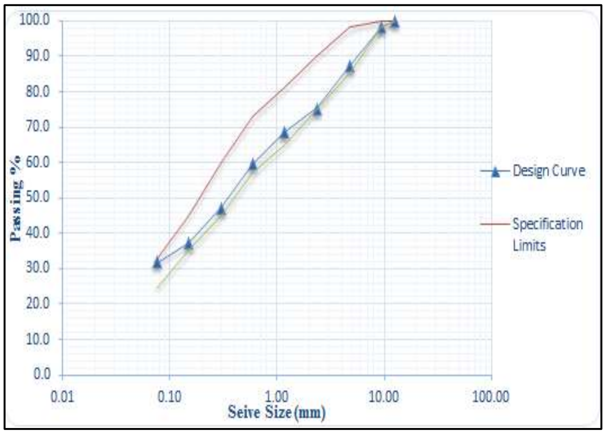

Figure (4): Gradation curve of mastic asphalt mix with BS EN 13108-6 Specification.

3. Porous Asphalt

Porous asphalt mixture in this study depends on the limits of the suggested gradation mentioned in (Jendia et al., 2018**)** article.

PA contains three sizes of coarse aggregates, aggregates types proportion in porous mixture are presented in Figure (5).

Marshal Test

Marshall Method is used to determine the optimum bitumen content (OBC) to be added to specific aggregate blend resulting in a mix where the desired properties of strength and durability are met.

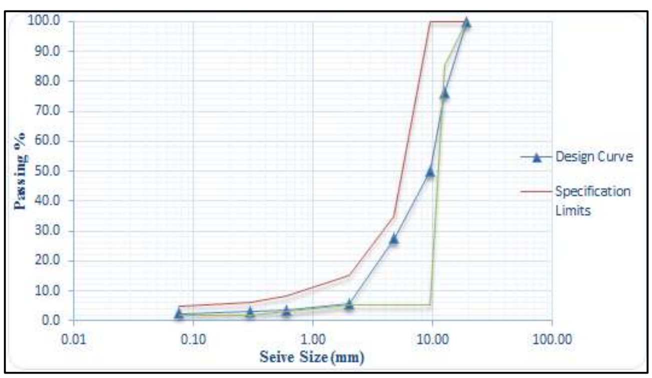

Figure (5): Gradation curve of porous asphalt mix according to Jendia et al., (2018)

Table (5): Three types of mixtures were prepared.

Asphalt mixture	Specimens for Marshal tests	Bitumen content (%)	
		Min	Max
Dense Asphalt	12	4.5	6
Mastic Asphalt	12	11.5	13
Porous asphalt	9	3.5	4.5

Marshall Method for designing hot asphalt mixtures is used to determine the optimum bitumen content (OBC) to be added to specific aggregate blend resulting in a mix where the desired properties of strength and durability are met.
Three types of mixtures were prepared as the following

- **For Dense Asphalt**

The amount of 12 samples, each one approximately 1200g of aggregates types and filler put together is heated to a temperature of 160-170˚C. Bitumen is heated to a temperature of 160˚C with four trials percentage of bitumen (from 4.5 - 6% with 0.5 % incremental), by weight of the mineral aggregates. Then the heated aggregates and bitumen are thoroughly mixed at a temperature of 160 - 170˚C. The mix is placed in a preheated cylindrical mould and compacted by a hammer having a weight of 4.5 kg and a free fall of 45.7 cm giving 75 blows on both sides at a temperature of 160˚C to prepare the laboratory specimens to obtain the optimum bitumen content (OBC) of dense asphalt.

- **For Mastic Asphalt**

The amount of 12 samples, each one approximately 1200g of aggregates types and filler put together is heated to a temperature of 180-195˚C, were prepared, using three different bitumen contents (11.5%, 12%,12.5%,13%),the specimens of mastic asphalt prepared at 180 C mix temperature, (BS EN 13108-6, 2008) is using around 10 Superpave gyratory compactor to prepare mastic asphalt sample, but in the laboratory work, 15 blows by marshal hammer provide satisfactory compaction.

- **For Porous Asphalt**

The amount of 9 samples, each one approximately 1200g of coarse aggregates types put together to made incorporating the recommended combined Grading with bitumen content (3.5%, 4 %, 4.5%). the specimens of porous asphalt prepared at 160 C mix temperature, then 75 blows by marshal hammer provide satisfactory compaction.

- **Stage (3):** Prepare 36 specimens, 12 samples from each type of mixture. Then determination of the Bulk Density and Void Ratio

The main topic in this study is determining the bulk density in asphalt mixture types by using four methods.
Bulk Density Test Methods .
According to EN 12697-6, Four methods used for measuring bulk density, the equations to Determine Bulk density (Gmb) are listed below, in table 6 more details in **Appendix D**.

Table(6): Bulk density equations (g/ cm³)

Method	Equation
Dimensional	$Gmb_{,\dim} = (\frac{m_1}{\frac{\pi}{4} \times h \times d^2} \times 10^3)$
Dry method	$Gmb_{,dry} = \frac{m_1}{m_1 - m_2} * \rho_w$
Saturated surface dry	$Gmb_{,ssd} = \frac{m_1}{m_3 - m_2} * \rho_w$
Paraffin sealing	$Gmb_{,sea} = (\frac{m_1}{(m_2 - m_3)/\rho_w - (m_2 - m_1)/\rho_{sm}})$

➢ Number of Samples

For determining Gmb and Va%, twelve specimens from each mixture were prepared, this number of specimens is due to the following reasons:

1. The method for preparing the mixture is manual, so when increasing the specimen's number this requires repeating the process more than once, this makes sample group exposed to different conditions such as temperature.
2. By using 12 specimens from each mixtures, 48 values of Gmb can be determined, and this is accurate enough when getting the results.
3. Previous studies used approximate number of 12 specimens, for example (Crouch, 2002) used 10 specimens for compering between Gmb determining methods.

In the laboratory, 12 cylindrical specimens were prepared by placing the mixture under a temperature of 160˚C, then they were compacted through a hammer weighting 4.5 kg and with a free fall of 45.7 cm giving 75 blows on both sides. After 24 hours. The bulk density was determined by using the four methods.

Table (7): Codes used to present the results.

Mixture type	Dense Asphalt (DA)
	Mastic Asphalt (MA)
	Porous Asphalt (PA)
Specimen code	D1,D2,D3,………., D12
	M1,M2,M3,…….., M12
	P1,P2,P3,…………, P12
Method code	Dimensional ,Method (DIM)
	Dry method (DM1
	SSD method (SSD)
	Paraffin sealing Method (PSM)

- **For Dense asphalt**

Figure 6 shows void ratio value of cylinder-shaped specimen prepared, it will separately measure the bulk density of mixes with each one of method. While calculating the corresponding air voids. According to the data in the Table 7 below, the difference of bulk specific gravity of mix got from four different density measurement methods is low, the high rang of value appearance between the maximum value of voids in dimension method 6.56% and the minimum value in paraffin sealing method 2.53%.

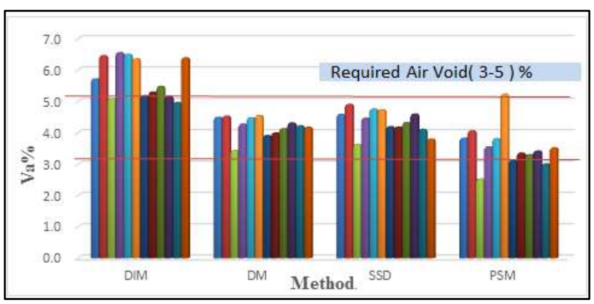

Figure (6): Column chart to represent Va% of each bulk density test method in DA.

As Figure 6 shows, for dense asphalt mixture with voids required between 3-5%. DM, and SSD methods have provided the value of VA% of all specimens of DA within the target limit 3-5 %. In contrast to DIM the upper limit of voids exceeds (5%) in every value of VA%. The PSM provides average value of result with the limit but the minimum value of voids less than lower limit of voids.

Table(8): Summary of MA data results of Va%.

Methods	DIM	DM	SSD	PSM
Average	5.76	4.21	4.36	3.56
Max	6.56	4.55	4.91	5.23
Min	4.97	3.44	3.63	2.53

- **For Mastic asphalt**

The air void percentages for the mastic mixes were calculated by the four methods Gmb determined using the equation (1), TMD/ Gmm which was evaluated by Pycnometer device is (2.312). It is noticed according to the Figure 7 and Table 8 that the Gmb and void ratio which measured specimen's code from M1- M12 is the least different between maximum and minimum value, most of results within 1%. SSD and DM methods are provides very closed results of Va% .

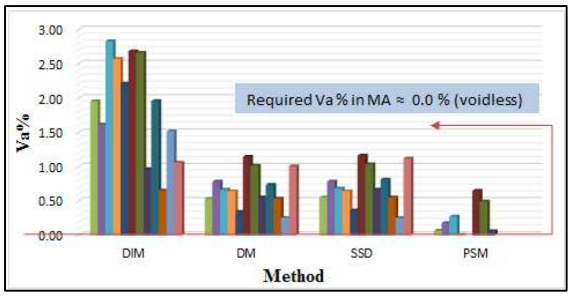

Figure (7): Column chart to represent Va% of each bulk density test method in MA.

Table(9): Summary of MA data results of Va%.

Methods	DIM	DM	SSD	PSM
Average	1.89	0.68	0.72	0.25
Max	2.83	1.14	1.16	0.65
Min	0.65	0.25	0.25	0.0

As Table 9 indicates, DIM method has given Va% with average result 1.89% more than other three methods due to the raveling and deformation have been existed. The surface of two sides not level as the mathematical equation for DIM method proposed. As shown in Figure 8.

Figure(8): Raveling in MA specimen's surface.

- **For Porous Asphalt**

The air void percentages for the PA were difficult to be determined due to the open interconnected voids of the mix structure. The four methods were employed to determine bulk density, then Va% was determined by using the equation (1), TMD/ Gmm, which was evaluated by Pycnometer device, is (2.38). Va% is presented in figure 4.29.

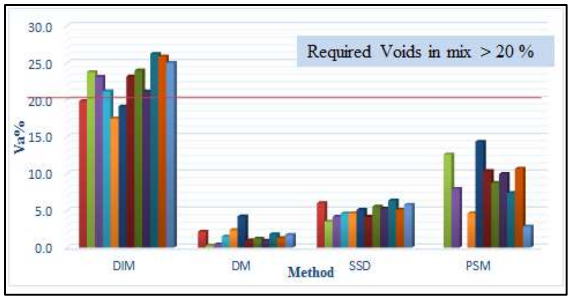

Figure (9): Column chart to represent Va% of each bulk density test method.

As Table 8 shows, the average air voids calculated from the Gmb results obtained by the four methods for the 12 specimens were ranked from P1- P12.

The results obtained by the DIM method produced the highest Va% contents and the results obtained by the PSM produced the second highest Va% contents. The dry method produced the lowest Va% contents.

Table (10): Summary of PA data results of Va%.

Methods	DIM	DM	SSD	PSM
Average	22.47	1.58	5.03	9.0
Max	26.20	4.22	6.36	14.32
Min	17.46	0.28	3.53	2.9

The PSM produced Void ratio higher than those obtained by SSD method and lower than those obtained by DIM.

Practically, when PSM was melted and specimen submerged partially, sometimes the pieces of granular specimen material dropped and the mineral sediment in a bowl. So, the temperature of paraffin affects the sample to be brittle! Another reason, theoretically, paraffin coated the surface of specimen, but in real it goes through connected voids in porous mixture and close them, this is the reason of the wide range between the results, max value of voids is (14%), and the un logical excluded values. As shown in Figure 10.

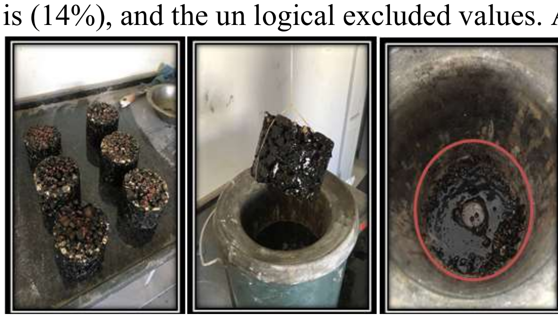

Figure (10): Bulk density by PSM

Stage (3):Data Analysis

Relationship between the Four Methods

Because SSD method is the most widely used in measuring Gmb. So, the comparison procedure between the four methods used in this study based on SSD method. The voids ratio explains the differences in the bulk density results of the four methods.

A linear regression prediction between the Gmb and Va% obtained from SSD method on X- Axis and Dry, Dimensional, Paraffin sealing method on Y- Axis has been conducted.

The relationship of each type of mixtures explained as the following:

- **For Dense asphalt**

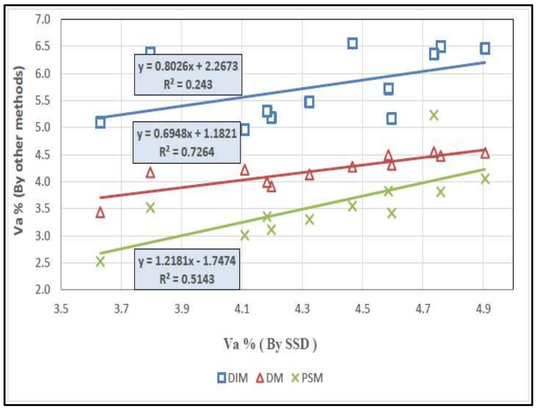

Figure (11): Linear relationship between the air void content obtained by SSD method and other three methods in Dense Asphalt.

Figure 11, shows three relationships: Va% by SSD versus other three methods, according to data analysis, the comment about the results can be mentioned in the following points:

1. The dimensional method provides underestimated results for Gmb so the Va% is always the highest among the other three methods. So the correlation between DIM and SSD method is poor (**$R^2 = 0.243$).**
2. The differences in Va% values, as a result of the differences in Gmb, were insignificant by the DM in comparison to SSD method. So the correlation between the two methods is high (**$R^2 = 0.7264$).**
3. PSM could make a good correlation with SSD method despite of providing Va% less than the SSD method's value. PSM provide the greatest results of Gmb and The lowest results of Va% regards the other three methods .

- **For Mastic Asphalt**

As Figures 12 shows, except DIM, the relationship between SSD and the other two methods is strong.

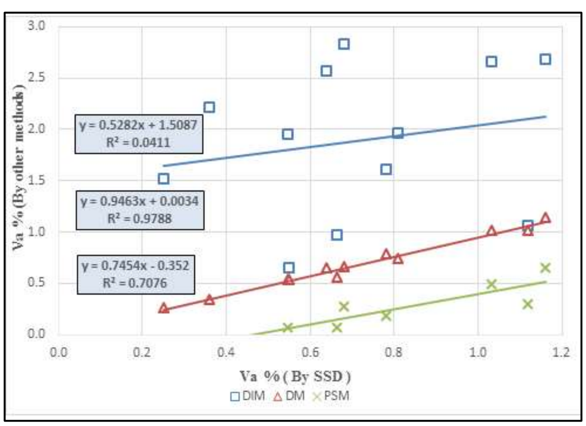

Figure (12): Linear relationship between the air void content obtained by SSD method and other three methods in Mastic Asphalt**.**

The relationship between the SSD and both (PSM and DM) methods is used to determine bulk density and to calculate Va% becomes more stronger than the relationship between SSD and both (PSM and DM) which existed in DA mixtures. In contrast the relationship between SSD and DIM becomes weaker.

The results of regression analysis are as follows

1. The results of the SSD and DM methods are almost identical because of the voids of specimens are almost zero, especially the mastic mixture is used as waterproof so the weight after submerging almost equals the weight before submerge the specimens in the water.
2. The Va%, determined by SSD method, increases according to the linear relationship between SSD method and the other three methods, so when it increases in SSD method, it increases in the other three methods.
3. The DIM is the least correlation with SSD method ($R^2 = 0.0411$), which provides underestimated Gmb results regardless the type of asphalt types.
4. The PSM provides un logical results when measuring Va% because of the closed similarity between the magnitude of Gmm and Gmb, so covering the specimens with melted wax increases it's weight and thus it's density, according to this; there are negative Va% values, so the Gmb is bigger than Gmm after using the melted wax.

- **For Porous Asphalt**

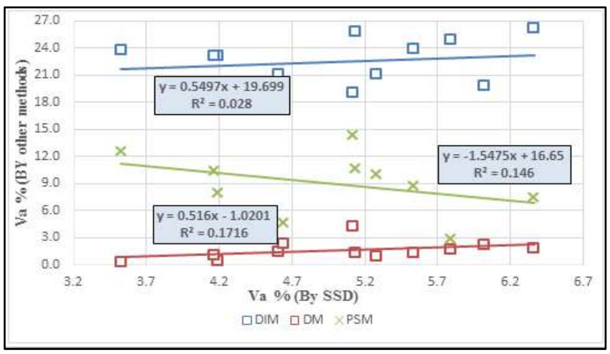

Figure (13): Relationship between the bulk specific gravity obtained by SSD method and other three methods in Pours Asphalt.

Figure 13, shows that there is almost no correlation between the four methods used in this study for measuring void ratio in regard to the bulk density determination in PA mixture, that has voids ratio exceeds 20%.
By regression analysis data the following results can be concluded:

1. The SSD and DM are not capable of determining Gmb and Va% of PA mixtures. The voids measured in DIM exceed those measured in the above two methods by 20%. So by using these two methods, the real volume bulk cannot be evaluated due to water leak inside the connected voids when submerging and weighting the specimen after surface drying.
2. The DIM is the most logical and suitable for determining Gmb. Because of the connected voids in the measured specimens in the other methods, make evaluation of submerged weight and weight after submerging not capable of providing real bulk volume.
3. There is proportional relationship between the SSD method and both DIM and DM in Va% values. While there is reverse relationship between the SSD method and PSM. The last relationship was understood by the decrease in the surface voids, which were included in the PSM and excluded in the SSD.
4. The PSM cannot be supported to measure Gmb due to the un logical results which are shown clearly in the points above and below trend line in figure 4.36.

5. The significant variations in the results of the four methods reflect the need to find more accurate method in determining Gmb in OGFC mixtures.

Data analysis using Box plot

The box plot chart was used to display the air void ratio results of each one method.

It is clear from Figure 15 that 75% of the measured specimens by SSD and DM have 4- 5 % VA. While the rest have 3-4% of VA. This means that there is no importance difference between the two methods regarding the dense asphalt. However, the result showed that VA by DIM method exceed 5% concerning 75% of measured specimens.

Also, Figure 15 illustrates that PSM method determined 2-5 VA, which reflect the high variance between the results. This indicate that PSM used to measure the lowest VA within the dense asphalt.

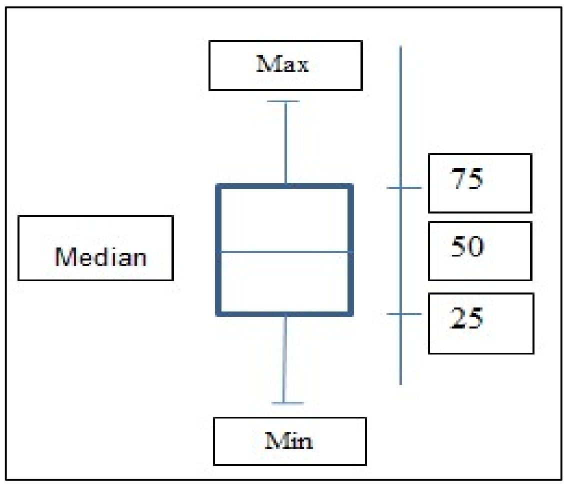

Figure (14): Illustrating Box Blot Chart**.**

- **For Dense Asphalt**

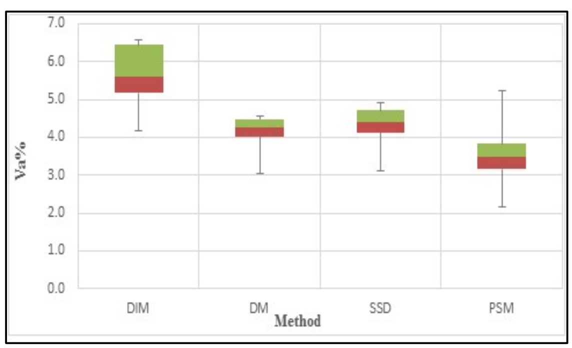

Figure (15): Box Blot for Dense Asphalt Void ratio result.

- **For Mastic Asphalt**

Figure (17) shows that the results of the three methods have less that 1% Va%, while 75% of DIM specimen results determined Va between 1 – 2.8%. Also by the Figure 4.40, in mastic asphalt, the surface voids can be neglected in the light of the similarity of SSD and dry methods results.

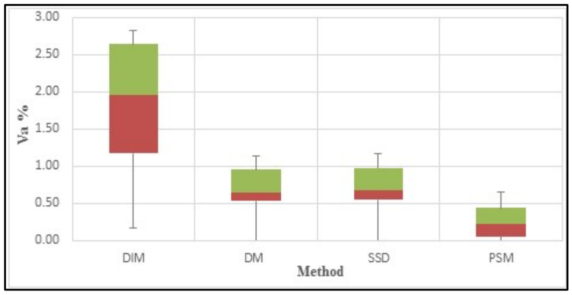

Figure (16): Box Blot for Mastic asphalt Void ratio result.

- **For Porous Asphalt**

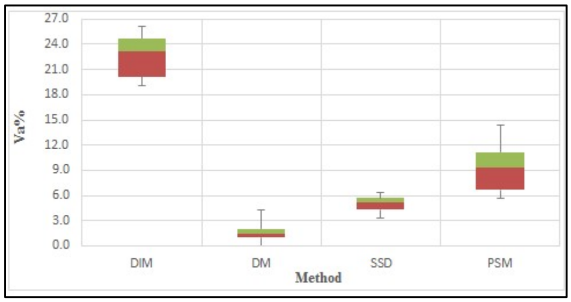

Figure (17): Pox Blot for Pours asphalt Void ratio result.

Figure 17 shows that the results of the three methods have less that 1% Va%, while 75% of DIM specimen results determined Va between 1 – 2.8%. Also by the Figure 4.40, in mastic asphalt, the surface voids can be neglected in the light of the similarity of SSD and dry methods results.

Summary

The relationship between SSD method and the other three methods by using linear and nonlinear regression, which represent with more details in Appendix. It is clear that the correlation is strong as void ratio in mixture is low. So, in mastic asphalt, the correlation is the best. But, in porous asphalt there is no correlation between SSD and other three methods.

- Dimensional Method (DIM)
  - In dense and mastic asphalt mixtures the raveling in the specimens surface affects the volumetric measured, so the deformation in the surface is a part of the voids. Therefore, the voids ratio by DIM is greater than the void ratio by other methods.
  - DIM is the only suitable method for determining bulk density and air void ratio in porous asphalt, but it is not the best method due to the underestimated result of bulk density

- Dry Method (DM)
  - DM is Suitable for determining Gmb in Dense asphalt despite of the surface voids are not included in the volume of voids.
  - Dry method and SSD are the best selected method for determining Gmb in mastic asphalt especially when the surface of mastic specimens has zero voids.
  - In porous asphalt the dry method totally failed in determining Gmb and Void ratio due to the weight in water does not represent the bulk volume of specimens.

➢ SSD Method

- SSD is considered the best method for determining Gmb and Va in both mixtures DA and MA, this method, as previous results shows, provides logical results in these mixtures because the surface and internal voids are included in the amount of bulk volume.
- In porous asphalt, SSD totally failed in determining Gmb and Va due to interconnected voids, the water runs throughout specimens in SSD weight, so the mechanism of this method did not work.

➢ Paraffin Sealing Method (PSM)

- In dense asphalt, it provides the maximum bulk density and lower void ratio in regards to other three methods, paraffin prevents the specimens from water when they are immersed, so it can be used as indicator to predict the lowest air voids in asphalt specimens.
- In mastic asphalt, it provides results nearby from those of SSD and DM, but sometimes the un logical results appeared in 5 from12 specimens, when the Gmb results are greater than Gmm . This happens because the paraffin sticks in specimens and becomes a part of their weight and ,when the Gmm is very close from Gmb in mastic asphalt, this means many of specimens have Gmb greater than Gmm when adding paraffin.
- In Porous asphalt, it succeeds partially in determining Gmb, the results are various between one specimen to another, it can't be adopted because the melt paraffin has closed the deep or internal voids in addition to the surface, the other reason is the effect of melt paraffin on the cohesion of the specimens, 2 from12 samples became brittle.

4. Conclusion

The conclusion of this study could be summarized as follows:

1. There are obvious differences in the results of bulk density and as sequence void ratio by using each method in any of three asphalt mixtures. So, the real air voids cannot be determined. But, these differences are varying from one method to another, and from one mixture to another.
2. The results showed that there is less variability in the asphalt mixtures which have air voids ratio required in the low range (less than 5%) that agrees with AASHTO regulation.
3. The correlation between three of the four methods (SSD, Dry, and Paraffin sealing) that were used to determine bulk density in dense and mastic asphalt mixtures is strong according to the regression analysis. So, SSD can be used to predict the other two method's values.
4. The most widely applicable method SSD, failed obviously in the determination of the void ratio in porous asphalt.
5. The dry method is the simplest method since the voids in the surface of specimen does not included in the bulk volume. So, it gives overestimated to the Gmb and less estimated to void ratio.
6. In dense and mastic asphalt mixtures, the statistical analysis show that there is a significant difference between the measurement made by SSD and dry methods and the measurement made by the dimensional and paraffin methods. SSD and dry methods are more consistent than those made by the dimensional and Paraffin methods.
7. From the four methods, the dimensional analysis method is the only one suitable to measure the Gmb in the porous asphalt. Although the dimensional method gave underestimation for Gmb and overestimation for a void ratio.
8. The Paraffin sealing method suitable for determining bulk density and void ratio in dense asphalt, but in mastic asphalt 5/12 of specimens gave un logical bulk density value since the theoretical maximum density (Gmm/TMD) is very closed to bulk density, when sealing the specimen by paraffin the own weight of specimen increasing so the bulk density is increasing. In porous asphalt 2/12 of specimens gave un logical value due to the following reason:

- The porous asphalt specimens splitted when submersed in paraffin.
- The paraffin is not sealing the surface of specimens only, but also it covers the internal voids of specimens.

9. The value of voids that are determined by SSD form only (60-88) % of the voids that are determining by dimensional method in dense asphalt, (15-70)% in mastic asphalt, and (15-30) % only in porous asphalt

Recommendations

Recommendations were made to improve air void determination and reduce the test variability.

1. Dimension method can be used as an indicator for the upper limit of voids while the paraffin sealing method can be used as an indicator to the lowest limit.
2. The study recommends more accurate methods to be used in determining Gmb in porous asphalt rather than a volumetric method (dimensional method), such as vacuum sealing device and other advanced techniques.
3. Each type of asphalt mixtures used in this study needs to be studied separately with large scale specimens in order to understand deeply the relationship between the four methods that used to determine the bulk density.

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