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Superpave System Versus Marshall Design Procedure for Asphalt Paving Mixtures (Comparative Study)

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Abstract- Over 98% of paved highways in Jordan have a surface course where asphalt cement is used as the binder agent. The prevalence of these pavements is constructed with hot-mix asphalt concrete. Asphalt concrete is a mixture of binder and aggregate under specified volume parameters. Based on empirical evidence, the volume of air used in the mix design process is four percent. Under the performance grade specifications of the Superior Performing Asphalt Pavement (Super Pave) method of mix design the base grade of binder is selected based on the range of pavement temperatures expected for pavements service conditions (McLeod et al. 1956). Aggregates used in asphalt concrete in Jordan are mainly crushed limestone. The asphalt used is mainly the (60/70) penetration grade. The performance of asphalt surface roads is directly affected by the quality of the asphalt concrete. Several methods have been developed for determining the quantities of aggregate and asphalt cement used in the asphalt concrete such as Marshall, Hveem and SuperPave System (Foeter et al. 2009). This paper aims to compare between Marshall, Hveem and SuperPave System to show the difference between them.

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SUPERPAVESYSTEMVERSUSMARSHALLDESIGNPROCEDUREFORASPHALTPAVINGMIXTURESCOMPARATIVESTUDY

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I. Introduction

The purpose of any asphalt mix design method is to determine the optimum proportions of aggregate and asphalt cement to be used in an asphalt pavement mix. Two empirical mix designs methods are traditionally used. These are Marshall and Hveem methods. Superpave method developed by the Strategic Highway Research Program (SHRP), is being considered for full implementation as a design method. The main advantage of Superpave over currently used mix design methods is that it is performance-based method that implies a direct relationship between Laboratory analysis and field performance after construction. Other design methods are empirical and therefore cannot accurately predict how a pavement will perform after construction (Anderson et al. 2007).

II. Overview of the Superpave Method (1987-2012)

Starting in 1987 (35), the Strategic Highway Research Program (SHRP) conducted research into developing new methods to specify, test and design asphalt materials and pavements. This lasted until 1993 when the Federal Highway Administration, FHWA, began implementing the SHRP research program. The Superpave design method, that was a direct result of the SHRP research, is becoming the standard for bituminous pavement design (FHWA 2006).

SHRP researches recognized that the Marshall method of mix design had been used for many years and those pavements have performed well, however, with increased traffic and heavier axle loads, it was decided that an improved method of design was needed. The Supepave mix design method was developed to fill this need. The SHRP researches envisioned a Superpave design system implemented at three levels. The level one method relied totally on volumetric analysis to determine mix proportions. The other levels of Superpave analyses require complex equipment and have not been implemented. There is ongoing research to refine Superpave with respect to quantifying the effects of aggregate size, type and gradation on the mixture and correlating these data with pavement performance. In addition, research is being conducted to develop tests for quantifying the asphalt concrete mechanical properties (Cominsky 1990).

The Superpave mix design process starts with aggregate evaluation. Aggregate characteristics are identified as either source properties or consensus properties. Source properties are defined by the purchasing agency. The WVDOH Marshall requirements in table 2.1 are used as the Superpave source property specifications, with the exception that flat and elongated property is treated as a consensus property. Consensus aggregate properties were defined by theSuperpave researches to ensure mixes made with the aggregate have good performance characteristics. The researcher envisioned that all agencies using Superpave would adopt these specifications without modification for local conditions (McLeod et al. 1956). The consensus aggregate properties are given in table 2.2.

WVDOH has implemented these specifications, but has augmented them with requirements for skid-resistant aggregates. The consensus aggregates properties are;-

a) Coarse aggregate angularity
b) Coarse aggregate flat and elongated

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c) Fine aggregate angularity

d) Sand equivalency.

Table 2.1 : WVDOH Aggregate Requirements for the Marshall Mix Design Method[8]

Coarse Aggregate	
Gravel and Crushed Stone	Clean hard durable rock free from adherent coatings.
Thin or elongated particles (4:1)ratio	5% max
Shale	1% max
Coal and other lightweight materials	1.5% max
Friable particles	0.25% max
Percent water (LA abrasion)	40% max
Soundness	12% max
Additional Gravel and Crushed Particle Requirements	
Bituminous Base I	Min 80% one fractured face
All other asphalt concrete	Min 80% two fractured faces
Fine Aggregate	
Must meet requirements of ASTM D 1073, except gradation	

Table 2.2 : Superpave Consensus Aggregate Properties[8]

Mineral Filler Must meet requirements of ASTM D 242 except for gradation and must be free of harmful organic compounds				
Design Level	Course Aggregate Angularity (% min)	Fine Aggregate Angularity (% min)	Sand Equivalency (% min)	Flat and Elongated (% min)
Light Traffic	55%-	-	40%	-
Medium Traffic	75%-	40%	40%	10%
Heavy Traffic	85/80	45%	45%	10%

Superpave Consensus Aggregate Properties are shown as following:

a) Coarse Aggregate Angularity (CAA)

Coarse aggregate angularity is evaluated by the percent weight of aggregates with one and more than one fractured face. The test is performed on materials retained on the (4.75)mm sieve. This is somewhat different than the WVDOH Marshall requirements that specifies the minimum percent of material with two fractured faces.

Coarse aggregate flat and elongated is evaluated by the percent mass of aggregates whose ratio of longest dimension to smallest dimension is greater than (5). Superpave limits the amount of flat and elongated particles to less than (10%). The WVDOH Marshall specification limits flat and elongated particles to (5%) based on a (4:1) ratio (McLeod et al. 1956).

b) Fine Aggregate Angularity(FAA)

Fine aggregate angularity, FAA, is evaluated using the Uncompacted Void Content procedure, AASHTO T304 – 96 (AASHTO, 2000). The test is performed on material passing the (2.36)mm sieve. This test method was available prior to the development of Superpave, but was not a requirement for asphalt concrete mix design.

The purpose of the test is the test is to ensure the fine aggregates have sufficient angularity and texture to produce a rut resistant mix (McLeod et al. 1956).

c) Sand Equivalency Test(SE)

The sand equivalency test is used to evaluate the clay content of materials passing the (4.75)mm sieve. This test was implemented by some states prior to Superpave, but is a new requirement for the WVDOH (McLeod et al. 1956).

d) Flat and Elongated Particles Test

It is conducted according to the test method outlined in ASTM D4791. The particle is considered a flat and elongated particle if the ratio of the maximum to minimum dimension of the particle is (5:1) or more.

As a result CAA, FAA, elongated particles, and SE affect pavement resistance to rutting, fatigue cracking, and low-temperature cracking, and also affect production and laydown (McLeod et al. 1956). Table 2.3 shows criteria of Superpave system.

Table (2.3) : Criteria of Superpave System[9]

ESAL	*CAA*		*FAA*		*SE*	*F & E*
	<100	>100	<100	>100		
< 0.3	55/-	-/-	-	-	40	-
0.3-to<3	75/-	50/-	40	40	40	10%
3-to<10	85/80	60/-	45	40	45	
10-to<30	95/90	80/75	45	40	45	
>30	100	100	45	45	50	

The Coarse and fine aggregate shall be combined in such proportions to produce an asphalt mixture meeting all the requirements defined in this specification and shall conform to the gradation as defined in table 2.4. Gradation testing shall be conducted in accordance with AASTHO T-11 (-0.075 mm (NO.200) wash) and T-27.

Table 2.4 : Aggregate Gradation Broad Bands[10]

Sieve Size	*Superpave Mixture (Percent Passing)*					
	SP- 9.5(3/8") Nominal size A		SP-12.5 (1/2") Nominal size B		SP -19.0 (3/4") Nominal size C	
Gradation Max	Min	Max	Min	Max	Min	Max
25.0 (1")	-	-	-	-	100	-
19.0 (3/4")	-	-	100	-	90	100
12.5 (1/2")	100	-	90	100	-	90
9.5 (3/8")	90	100	-	90	-	-
4.75 (#4)	-	90	-	-	-	-
2.36 (#8)	32	67	28	58	23	49
0.075 (#200)	2	8	2	8	2	7

The Superpave gradation specifications bands represent a minor revision as compared to the Marshall requirements. However, the concept of a restricted zone in the aggregate gradation was added to the Superpave specification to control the amount of fine material of certain sizes used in pavement mixtures. The restricted zone was introduced to limit the potential for tender mixes. The restricted zone has been removed from the WVDOH Superpave specification, in accordance with national recommendations. The gradation requirements for the 9.5 mm, 12.5 mm, and 19.5 mm mixes are shown in table 2.5 below.

Table 2.5 : Recommended Aggregate Gradation Restricted Zone[10]

Sieve Size	Boundaries of Restricted Zone Superpave Mixture (Percent Passing)					
	SP- 9.5(3/8") Nominal size		SP-12.5 (1/2") Nominal size		SP -19.0 (3/4") Nominal size	
mm (inch)	Min	Max	Min	Max	Min	Max
2.36 (#8)	47.2	47.2	39.1	39.1	34.6	34.6
1.18 mm (#16)	31.6	36.6	25.6	31.6	22.3	28.3
0.60 mm (#30)	23.5	27.5	19.1	23.1	16.7	20.7
0.30 mm (#50)	18.7	18.7	15.5	15.5	13.7	13.7

The Superpave process requires identifying a design aggregate structure using stockpile blends, which meet both the gradation and consensus aggregate properties. The recommended practice is to select three blends. The Federal Highway Administration has prepared a Superpave Mix design workshop that covers the details of the analysis process as presentedin the following in figure 2.1 below (Harmon, et al., 2002).

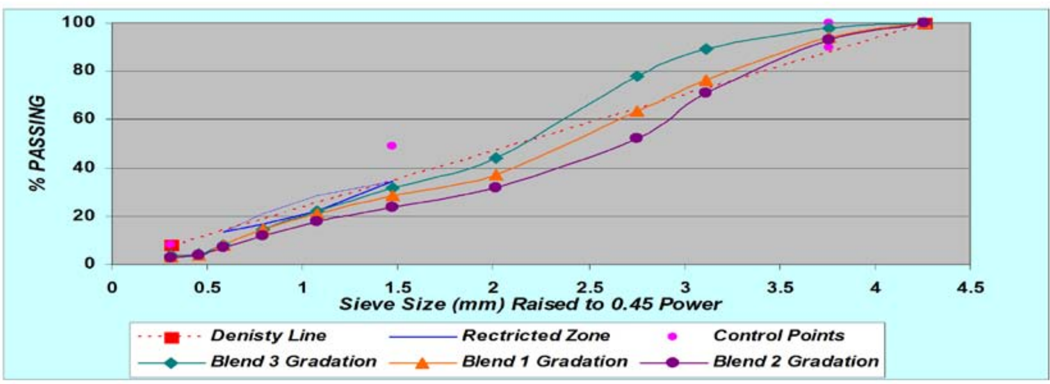


Figure 2.1 : Analysis Superpave Process of three blends[10]

The required asphalt content for each blend is estimated by using general steps to estimate trial (initial) binder content as following:-

1-Estimate Gse

$$Gse=Gsb+0.8*(Gsa-Gsb) \quad (2.1)$$

Where Gse:-effective speaific gravity of aggregate blend
Gsb:-Bluk specific gravity of aggregate blend
Gsa:-apparent specific gravity of aggregate blend

2-Estimate Vba

$$Vba=(Ps(1-Va))/((Pb/Gb)+(Ps/Gse))*((1/Gsb)-(1/Gse)) \quad (2.2)$$

Where Vba:-Volume of absorbed binder
Va:-Volume of air voids, (assumed 4%)
Pb:- Percent of binder (assumed 5%)
Ps:- Percent of aggregate (assumed 95%)
Gb:-Specific gravity of binder

3-Estimate Vbe

$$Vbe=0.176-0.067 \log (Sn) \quad (2.3)$$

Where Vbe= Volume of effective binder (by volume of mix)
Sn= Nominal maximum sieve size of aggregate blend

4- Estimate Pbi:-

$$Pbi= 100*((Gb(Vbe+Vba))/(Gb(Vbe+Vba))+Ws) \quad (2.4)$$

Where Pbi= Percent of binder by mass of mix

For each aggregate blend, two samples are prepared for compaction and two samples are prepared for determining the maximum theoretical specific gravity.

Superpave samples are compacted using the gyratory compactor developed during the SHRP research. The number of the revolutions of the gyratory compactor regulates the amount of compaction effort.

Three levels of compaction effort are used in the Superpave procedure; initial; design and maximum, Ni, Nd, and Nmax, respectively. The initial level is reflective of the ability of the mixture to consolidate under low forces and is used to identify "tender" mixes. The design level compaction simulates the density of the mix immediately after construction. The maximum density level simulates the density of the asphalt after 5 to 10 years of service (Cominsky 1990). The number of gyration depends on the design situation as presented in Table 2.6.

Table 2.6 : Number of Gyrations at Specific Traffic Levels[8]

Traffic Level (ESALmillions)				
	<0.3	0.3 to 3	3 to 30	>30
Ni	6	7	8	9
Nd	50	75	115	125
Nmax	75	100	160	205

The bulk specific gravity is measured for the compacted samples. This is used with the measured maximum specific gravity for the volumetric analysis. The Superpave method uses the same equations as the Marshall methods for voids in the total mix, voids in the mineral aggregate and voids filled with asphalt. The Superpave method defines the dust to binder ratio as the percent aggregate passing the (0.075) mm sieve divided by the percent effective binder. The percent effective binder content is the difference between the total binder content and the absorbed binder as three following equations:-

$$Pba=100((GseGsb)/(GsbGse))*b \qquad (2.5)$$

$$Pbe= Pb- (Pba/100)*Ps \qquad (2.6)$$

$$\text{Dust Ratio}= (PD/Pbe) \qquad (2.7)$$

The adjusted volumetric parameters are compared to the Superpave acceptance criteria shown in Table2.7. The aggregate blend that produces the best compliance with the criteria is selected as the design aggregate structure for determining the design binder content. (Harmon, et al., 2002). If none of the aggregate blends produce a design aggregate structure with acceptable volumetric characteristics, a new aggregate blend and subsequent testing must be selected and evaluated. Table 2.8 shows example of blend (3), and figure 2.8 shows % of AirVoid, % VFA, and %VMA respectively v.s % of Asphalt Binder[8]

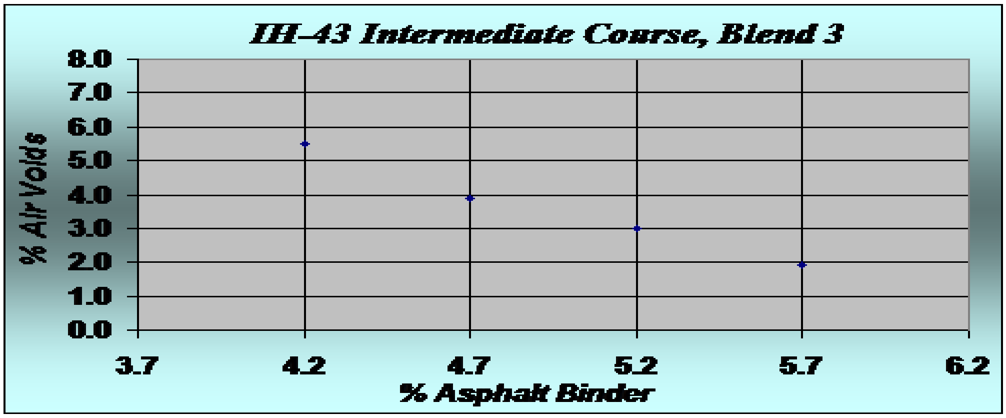
Table 2.7 : Superpave Mix Design Criteria [9]

ESAL)(millons	% Gmm			VMA	VFA	Air Void	Dust Ratio
	Nini	Ndes	Nmax				
<0.3	<91.5	96.0	<98.0	NA	70-80	4%	0.6-1.2
<1	<90.5				65-78		
<3	<90.5				65-78		
<10	<89.0				65-75		
<30	<89.0				65-75		
>30	<89.0				65-75		

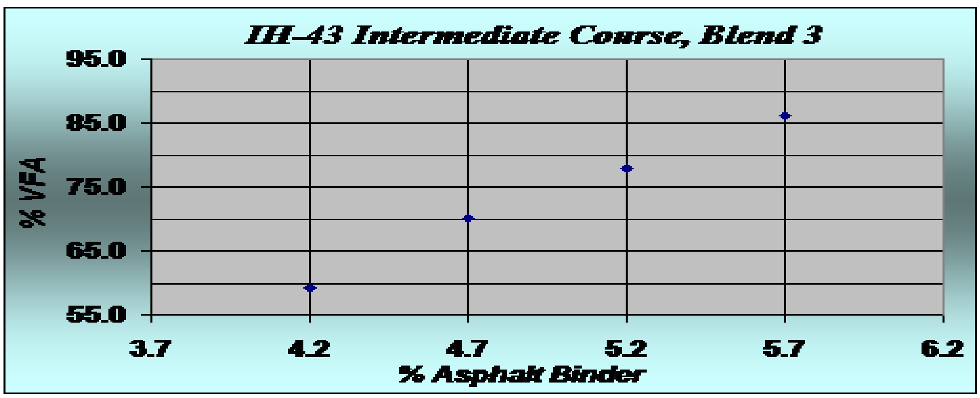
For example for IH-Intermediate Course, Blend (3)

Table 2.8 : Example of Blend (3)8

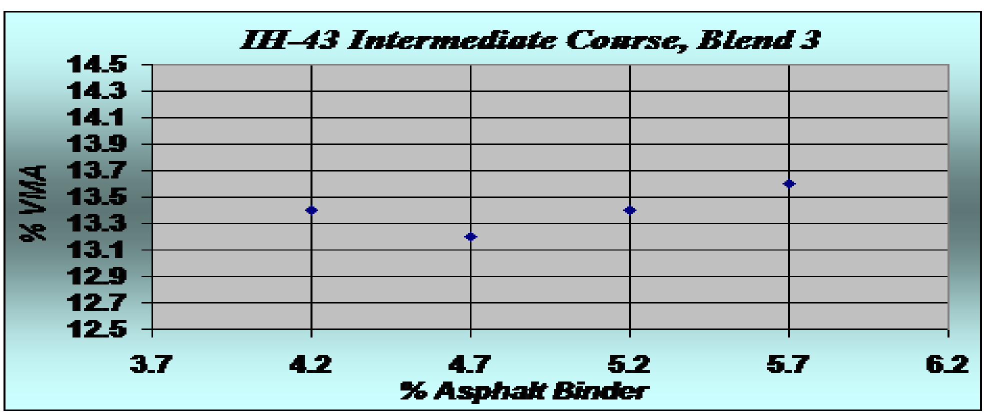
% AC	% Air Voids	%VMA	%VFA
4.2	5.5	13.4	59.3
4.7	3.9	13.2	70.1
5.2	3.0	13.4	77.9
5.7	1.9	13.6	86.2



(a)



(b)



(c)

Figure 2.8 : (a) % of AirVoid, (b) % VFA , (c) % VMA respectively v.s % of Asphalt Binder[8]

Finally, the moisture susceptibility of the mixture is evaluated, Six samples are prepared at the design aggregate structure and optimum binder content. Three samples are conditioned. The tensile strength of all samples is measured (Huber et al. 2007).

III. Overview of the Marshall Method (Kandhal et al. 1985)

a) Seieving the aggregate

Put all sieves above each other in familiar order, then put the sample on the sieves and shaking use the mechanical shaker for you , after that make the graded of aggregate to get the mix of aggregate that meets specification.

b) Mixing Asphalt with aggregate

Put the asphalt cement in an oven for (2 hr), then put aggregate mixture in container, and make check if the aggregate to be with compliance to specifications then heated to (110°), after that add the asphalt to aggregate in a pan and mixed through until all aggregate mixed with asphalt.

c) Compaction

Mould painted with oil to prevent the adhersion between the specimen and the mold, then put the mould at the bottom of compaction in the right position and filter paper was put on the bottom of the mould, then put the mixture of aggregate and asphalt in the mould and put a new filter paper on the top of the mould, then check fastness of mould and rise the hummer to max height. After that release hummer to fall vertically (50) times on the mould for each faces. After a week, weight the specimen in air and dry weight, then immersed the specimen in water for (3-5) min then weight the saturated surface dry (after dying the specimen with clothes).immersed the samples in water for (30)min and weighted it in water.

d) Stability and Flow test

Zero flow water to increase (4 inch) diameter cylinder in the testing head, the specimen is immersed in water path at 60C° for (30 min), then placed the specimen under the test head at constant rate, after that record the load of failure and strain at the point of failure from the results make the calculations.

e) Gmm Test

Specimen resulted from stability test were damaged by separating aggregate from each other

IV. Conclusion and Summary of the Comparative Study

- The review of the literature demonstrates the availability of analytical and experimental methodologies that may be potentially improve the mix design. Such methods rely on the volumetric analysis for establishing the optimum asphalt content.
- The Voids in the mineral aggregate criteria are critical since they initially establish the volume of the effective binder in the mix.
- However, the current VMA criteria used by Marshall and Superpave were derived for mixes with questionable assumptions concerning the type of aggregate.
- (CAA, FAA, Flat and elongated particles, and SE) affect pavement resistance to rutting, fatigue cracking, and low-temperature cracking, and also affect production and laydown.
- There are several Differences between Super pave System v.s Marshall Mix Design for Asphalt Paving Mixtures as shown in table 4.1 below.

Table 4.1 : Mix Design Differences between Super pave System v.s Marshall Mix Design for Asphalt Paving Mixtures

Superpave Mix Design	*Marshall Mix Design*
Tests in Mineral Aggregate like(CAA, FAA, SE, and F&E particles)are considered in the SP	Tests in Mineral Aggregate like(CAA, FAA, SE, and F&E particles)are not considered in the Marshall test
Trial (Intial) binder content is done in the SP to take an idea about binder content before compaction	Trial (Intial) binder content is not done in the Marshall test
Levels of compaction in Super pave System with respect to (N design) which depends on:- 1-Average Design high air Temperture 2- Design ESALs	Levels of compaction in Marshall System depends on Type of traffic as following: 1-Light (ESALs<10000)---Level of compaction= 35. 2-Median (10000<ESALs<1000000)---Level of compaction= 50. 3- Heavy (ESALs>1000000)---Level of compaction= 75.
The Concept of Nmax which is used to compact the test specimen &Nini that is used to estimates Compactibility of mixture.	The Concept of Nmax & N init are not exist in Marshall test.
The Concept (%Gmm-corrected) which is used to collect all the data analysis to select the design binder content.	The Concept (%Gmm-corrected) is not exist in Marshall test.
Nominal Maximum Aggregate size(NMS) (mm)which respected to sieve size larger than the first sieve to retain more than (10%) and it is important to select gradation criteria of mix & make check on VMA% according to (NMS)	The Concept of Nominal Maximum Aggregate size (NMS) is not exist in Marshall test.
The Concept of Dust Ratio which represents ratio between aggregate content passing (0.075) mm sieve to effective binder content.	The Concept of Dust Ratio is not exist in Marshall test.
%G mm @Nmax & % Gmm @ Ninit that are exist in SP	%G mm @Nmax & % Gmm @ Ninit that are exist in SPnot
Evalution of moisture Sensitivity of design mixture and determine tensile strength ratio which should not less than (80%).	Evalution of moisture Sensitivity of design mixture and determine tensile strength ratio are not exist in Marshall test.

Performance Grade binder (PG-binder) which required for any project.	Performance Grade binder (PG-binder) are not exist in Marshall test.
LTPP& Sharp algorithms program are used in the Super ave to calculate T high &T low and to estimate (PG) to the project according to known reliability.	LTPP& Sharp algorithms program are not used in the Marshall test.
Super pave Gyratory Compactor (SGC) which is defined to make compact to mix to select design aggregate structure.	Super pave Gyratory Compactor (SGC) is not used in the Marshall test.
Control point / Restricted zone (FHWA 0.45 power chart) which is used to determine design aggregate structure, determine if the aggregate is Finer or Coarse with respect to max density line and evaluate (NMS).	Control point / Restricted zone (FHWA 0.45 power chart) which are not exist in the Marshall test.
Dimensions of Gyratory are (150)mm diameter which is more than the diameter of Marshall test specimen & number of Gyration per min in Super pave= (30)	The Diameter of specimen in the Marshall test is (102mm) which is less than the diameter of Gyratory in Super pave test.

References Références Referencias

1. Anderson, R.M., and H.U. Bahia. "Evaluation and Selection of aggregate Gradations for Asphalt Mixtures Using Suprpave." Transportation Research Record, Paper No.1583, 2007, pp. 91-97.
2. Cominsky, R. J., R. B. Leahy, and E. T. Harrigan, Level 1 Mix Design; Materials Selection, Compaction, and Conditioning, Report SHRP A-408. Strategic Highway Research Program, National Research Council, 1990.
3. Comparison between Various Methods of Pavement Design. Jordan University of Science & Technology, (M.Sc thesis, 2008).
4. Federal Highway Administration, "Background of Superpave Asphalt Mixture Design and Analysis", Washington, DC. , 2006.
5. Foeter, Charles R., The Effects of Voids in Mineral Aggregate on Pavement Performance, NAPA Information Series 96/86,2009.
6. Huber, G. A., and G. H. Heiman, Effect of Asphalt Concrete Parameters on Rutting Performance:- A Field Investigation, Proceedings of the Assocation of Asphalt Paving Technologists, Vol. 56, 2007.
7. Kandhal, P. S., and W. S. Koehler, Marshall Mix Design Method: Current Practices, Proceedings of the Association of Asphalt Paving Technologists, Vol. 54, 2005.
8. McGennis, R.B.; Anderson, R.M.; Kennedy, T.W.; and Solaimanian, M. Background of SUPERPAVE Asphalt Mixture Design and Analysis, Report No.FHWA-SA-95-003, Federal Highway Administration, Washington, D.C., 2005.
9. Mc Gennis, R.B.; Shuler, S.; and Bahia, H.U. Background of SUPERPAVE Asphalt Binder Test Methods, Report No. FHWA-SA-94-069, Federal Highway Administration, Washington, D.C., 2004.
10. McLeod, N.W. Relationships Between Density, Bitumen Content, and Voids Properties of Compacted Bituminous -Paving Mixtures. Proceeding, Highway Research Board, 1956; (35).
11. Mix Design Methods for Asphalt Concrete and other Hot Mix Types, The Asphalt Institute, MS-2, Sixth Edition, 2003.
12. Mix Design Methods for Asphalt Concrete. MS-2. 2d ed. Asphalt Institute May 2003.
13. Superpave 1999-2008 National Implementation, Report to the AASHTO Task Force on SHRP Implementation, May 2000.
14. Superpave Construction Guidelines, Special Report 180, National Asphalt Pavement Association, Lanham, Maryland, 2007.
15. The SUPERPAVE Mix Design System Manual of Specifications, Test Methods, and Practices, Report No. SHRP-A-379, National Research Council (Strategic Highway Research Program), Washington, D.C., 2004.