Comparison Study between Marshall and Superpave Mix Design Methods

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Abstract

In Iraq most of the highways are paved with asphalt concrete mixtures, and they are typically designed for a design life of 20 years. However, the general performance of these pavements was not satisfied, and they have lasted for shorter periods than the design life age. A decrease in life age occurs especially for the pavements exposed to severe conditions and substantial traffic loadings. The key factor for a better performance of the flexible pavement is considered to be the qualities and quantities of the asphalt concrete ingredients which are governed by the design of the mixtures. To do so, the most common methods are Hveem and Marshal methods so far. However, a new method has been developed by Strategic Highway Research Program (SHRP) under the name of Superpave which is claimed to have better performance than the aforementioned methods. It has been proven in the literature that the performance of Superpave is better than Marshall in terms exposure to high loads and severe change of temperature. Therefore, this paper tries to illustrate the main differences between the two methods in the mix design by comparing them to each other.

Keywords: Superpave System, Marshal System, Mix design, Asphalt Pavement

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الخلاصة:

في العراق ، يتم رصف معظم سطوح الطرق السريعة بخلطات خرسانية إسفلتية ، عادة يتم تصميمها وإنشائها لفترة تصميمية تبلغ ٢٠ عامًا. مع ذلك ، الأداء العام لهذه الأرصفة لم يكن راضيًا وولا على المستوى المطلوب بل خارج و اقل من التوقعات. هذا صحيح وينطبق بشكل خاص على الأرصفة المعرضة لظروف قاسية وأحمال مرورية كبيرة. يعتبر العامل الرئيسي لأداء أفضل للرصيف المرن هو جودة الخرسانة الإسفلتية التي يحكمها تصميم الخلطات التي تهدف إلى تحديد المكونات بكمياتها المثلى.للقيام بذلك ، فإن أكثر الطرق شيوعًا هي طرق هفيم و ومارشال «Hveem و Marshal» حتى الآن. مع ذلك ، تم تطوير طريقة جديدة بواسطة البرنامج الاستراتيجي لأبحاث الطرق السريعة (مختصرة SHRP) تحت اسم سوبربيف» Superpave « والذي يُزعم أنه يتمتع بأداء أفضل من الطرق المذكورة أعلاه. ثبت في الأدبيات والمحاضرات بأن أداء طريقة سوبربيف أفضل من أداء طريقة مارشال من حيث التعرض لأحمال عالية وتغير حاد في درجة الحرارة. لذلك ، تحاول هذه الورقة توضيح الاختلافات الرئيسية بين الطريقتين في تصميم الخلطات من خلال مقارنتهما ببعضها البعض.

الكلمات المفتاحية: نظام سوبربيف ، نظام مارشال ، تصميم خلطة ، رصف الأسفلت.

پوخته :

له وولاتی ئێراقدا زۆربەی رووی چینەکانی رێگاوبانی خێرا بەتێکەڵەی کۆنکرێتی ئەسفەلتی بنیاد نراوە،ماوەی دیزاین وخزمەتی پێشکەشکردنی ئەم رێگایانە بریتین لە٢٠ساڵ. لەگەڵ ئەوەی ئاستی خزمەت بەخشینی ئەم چینانە لەئاستی ڕەزامەندی و داخوازیەکان نەک نەبوە،بەڵکو کەمترو لەدەرەوەی ئاستی پێشبینی وچاوەروانیەکان بووە. ئەم ڕاستیە بەرجەستەوپشتڕاستکراوەیە لەسەر ئەورووە چینانەی کە رووبەڕووی بارودۆخ و کەشوهەوای سەخت وباروقورسایی وبارستەی هاتوچۆی گەورە قورس بوونەتەوە.هۆکاری سەرەکی بۆبەبەدەستهینان ودابینکردنی باشترین نەرمە چین، بریتیە لە جۆرایەتی تێکەڵەی کۆنکریتی ئەسفەلتی کە لەلایەن تێکەڵەسازی (سازانی تیکەڵەکە) کۆنترۆل دەکرێت، کەئامانج ومەبەست لێی دیاریکردنی پێکهێنەرەکانی تێکەڵەکەیە بەبڕی نموونەیی. بۆ ئەم مەبەستەش، تا ئێستا بەربڵاوترین رێگا لەم وولاتەدا، بریتین لەرێگاکانی هەڤیم ومارشاڵ،لەگەڵ ئەوەی بەهۆی پرۆگرامی ستراتیجی بۆتوێژینەوەی رِیگا خێراکان ناسراو بە» شرپ-SHRP» رێگایەکی نوێ پەرەپێداوە لەژێر ناوی «سۆپەرپەیڤ» کەبانگەشەدەکات ئەم رێگایە خاوەنی بەرجەستە وبونیادێکی باشترە بەراوورد بەرێگاکانی پێشوو. لەلایەن بانگەشەکەران وئەدەبیات-نووسینەکانەوە پشتڕاست وجێگیر کراوە کەخزمەت ورۆڵی رێگای سۆپەرپەیڤ بۆچینەکان باشترە لەخزمەت وئادای رێگای مارشاڵ، بەتایبەی کاتێک چینەکان رووبەڕووی باروبارستە وقورسایی بەرزو گۆڕینی ناکاووکتوپڕ وزۆری پلەکانی گەرمادەبنەوە. ئەم توێژینەوەیە هەوڵدەدات جیاوازی وجیاکارییە سەرەکییەکانی نێوان ئەم دووڕێگاوسیتەمە ڕۆشن وئاشکرا بکات، لەچوارچێوەی بەراووردکاری نێوان سازانی تێکەڵەکان و خودی تێکەڵەکانیان لەگەڵ یەکتری.

وشەی کلیلی:سیستەمی سۆپەرپەیڤ،سیستەمی مارشاڵ،دیزاینی تیکەڵە، چینی ئەسفەلتی

1.Introduction

The performance of flexible pavements is greatly affected by the quality of the asphalt binder. Typically, the flexible pavement roads are designed for a certain life span. For instance, a 20 year life spans is the average age of the designed and constructed roads in Iraq (Ahmed et al., 2020). Unexpectedly, the actual age of the flexible pavement road in Iraq is frequently less than that of the design (Ahmed et al., 2020). Most of the roads show signs of distress in their early ages. For instance, different crack patterns can be seen on the road surface of the most newly constructed roads in Iraq. The other types of defects can also be seen such as rutting, potholes, patching. There can be plenty of reasons to interpret these defects which range from atmospheric change to heavy applied loads after their usage (Zumrawi and Edrees, 2016). Another factor which plays a major role in the deteriorations of the roads is the mix design before construction and the quality of execution at the time of construction.

Nowadays around the world a variety of asphalt mix design methods are used such as Asphalt Institute Triaxial, Marshall, Hubbard field, Superpave, and Hveem mix design methods. Marshall; Superpave; and Hveem mix design methods are practiced mostly (Bahia, 1993). Among the design methods, Iraqi designers commonly follow Marshal method. One of the biggest problems related to the usage of Marshall method is that it only relies on the laboratory results to count for the properties of the constituents without actual simulation of the road in its field conditions. Therefore, the prediction of how the materials behave in the actual environment would be a difficult task to achieve (Robert et al., 1991). Having all different types of distresses in the flexible pavements in Iraq might be attributed to using Marshal method. A method that counts for the actual simulation and correlates it to the laboratory data is the Superpave method developed by Strategic Highway Research Program (SHRP) (Al-Mistarehi, 2014).

The main difference between Marshall and Superpave method lies in the selection process of the materials, dimensions of the specimens, the method of compaction, analysis of voids and specification (Zumrawi and Edrees, 2016). Many researchers worked on the adaptability of the Superpave method in the Middle East, for instance Asi and Khalayleh, (2014) investigated the efficiency of using Superpave method in tackling bleeding issue for some of the defected roads in Jordan. They found that using the gradation guidelines for selection of the aggregates in the Superpave could improve the performance of the pavement. They used the gradation that is locally available in the selection of the aggregate for the mixes subjected to heavy traffic loads using Superpave method. In their results, they found out that using this gradation leads to the brittleness of the mix as the proportion of the filler is higher than that described and required in Superpave method. Therefore, they recommended using the gradation and other procedures described in Superpave method for better mix designs.

Other researchers have evaluated some mix properties using Marshall and Superpave methods. Jasim, (2012)

compared both Marshal and Superpave methods in terms of moisture exposure, mechanical, volumetric properties and economic aspects. It was found out that Superpave methods leads to an economical design by adapting fewer asphalt content in the mix design. In addition, Wang et al., (2000) compared the two main properties of volumetric and mechanical between Superpave and Marshall method in selecting Typical Taiwanese Mixture (TTM). They discovered that TTM mixes designed using Superpave method had less binder content compared to that of Marshal method. Additionally, Hafez and Witczak, (1995) observed a total decrease of the asphalt binder content of 0.5 to 0.8 percent when using Superpave level 1 method over Marshall method in the same climate condition and traffic loads. However, the asphalt contents in both methods were nearly the same when the traffic level was less than 1 x 107 single axle loads in Superpave mixes and 75 blows in the Marshall method. They studied the climate effects in both methods and figured out a 1 percent increase in asphalt content in Superpave method was over than of Marshall method in cold weather.
Other researchers worked on the effects of the method of design on rutting. Swami et al., (2004) found that a better compaction can be achieved using Superpave method and it leads to better mixes that can resist and prevent rutting.
The main objective of this paper is to compare Marshall Mix design method and the Superpave mix design method in the preparation of asphalt mixtures.

2.Marshal mix design system

This system was developed by Bruce Marshall, a bituminous engineer with the Mississippi highway department in 1939. The original features have been improved by the U.S. Army Corps of Engineers, and the test now is standardized and described in detail in the ASTM D1559(1989). It is still widely used in many countries because the equipment is relative cheap and portable (Garber and Hoel, 2014)
The Marshall method criteria allows the highway engineer to choose an optimum asphalt binder content to be added to specific aggregate blend to a mix where the desired properties of density, flow and stability are met. The Marshall mix design method uses standard hot mix asphalt (HMA) samples which has dimensions of 102 mm in diameter and 63.5 mm high. The procedures of preparation of the samples are carefully specified, and involve heating, mixing, and compacting asphalt/aggregate mixtures. Test specimens are compacted by applying 50 or 75 blows per side with the Marshall compaction hammer tool. The number of blows is estimated by the expected traffic loading of the pavement section (Bahia, 1993). When the Marshall specimens have been prepared, they are used to determine the average asphalt mix properties for each asphalt binder content. A density-voids analysis is used to determine the unit weight, air voids (AV), voids in mineral aggregate (VMA), and percent voids filled with asphalt (VFA). The Marshal test instrument is used to measure flow and stability of the samples. Flow is the amount of deformation that occurs when the specimen fails and sta-

bility is defined as a value for the load under which the specimen fails. If a sample has a high flow and a low stability value, the mixture will tend to rut and deform under a load. If the sample has a low flow and a high stability value, the mix will tend to be brittle and crack under a load (U.S. Army Corps of Engineers, 1991).

The optimum asphalt cement content is determined based on the combined results of Marshall stability and flow, density-void analysis. Plots of asphalt cement content versus measured values of Marshall stability, flow, unit weight, %VFA, %AV, and %VMA are generated. Optimum asphalt cement binder is selected corresponding to maximum stability, maximum unit weight and at 4% air voids. Then check this percentage of asphalt binder content to insure that it is within the allowable criteria for stability, flow, AV, VFA, and VMA, (U.S. Army Corps of Engineers, 1991).

Marshall mixing design method has the following limitations pointed out by Pandey (2003):

*Despite the fact that the actual materials undergo a triaxial stress, this method is unconfined.

*The main parameters of this method cannot be directly connected to the actual performance of the pavement as it will be exposed to cracking and rutting.

*The mixes that can be compacted easily under heavy traffic loads are not identified in this method

*Because the application of the blows is in an impact form, it is not an actual representation to the filed loads.

2.1Marshall mix design tests

a) Aggregate: ASTM D75 (2014) is used as the main guidance in taking the aggregate samples from the stockpiles or from the quarry and ASTM C702 (2015) is used as a guidance in preparing the samples. Then the testing relies on ASTM C136 (2014) for both coarse and fine aggregate gradations which specifies the particle size distribution of the samples which is usually carried out by sieving. To carry out sieving several instruments are needed such as a scale balance, sieve set according to ASTM C136 (2014), shaker machine, and the samples. The samples are weighed and then put on the top sieve. Finally, the whole sieve set is put on the shaking machine for nearly 10 minutes. In this way, the gradation of the aggregates can be found. After gradation of the samples, the specific gravity and absorption should be determined for coarse and fine aggregates in accordance with ASTM C127 (2015) and ASTM C128 (2015) respectively.

b) Mixing asphalt with aggregate: A quantity of the aggregates having the designed gradation is dried at a temperature between 105ºC and 110ºC until a constant weight is obtained. The mixing temperature for this procedure is set as the temperature that will produce a kinematic viscosity of 170±20 centistokes, or a Saybolt Furol viscosity of 85±10 seconds, in the asphalt. The compacting temperature is that which will produce a kinematic viscosity of 280±30 centistokes, or a Saybolt Furol viscosity of 160±15 seconds. These temperatures are determined and recorded. Put the asphalt binder 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 (110º), after that add the asphalt to aggregate in a pan and mixed through until all aggregate mixed with asphalt.

c) Compaction: For compaction process special molds are required to be filled with the asphalt aggregate mixture and then compacted. To prevent the materials from attaching to the mold sides, the mold will be coated with oil. Then, the compaction tools will be prepared and the mold will be put in beneath the compaction hammer in its right position. A filter paper is needed at the bottom of the mold and at the top after filling it with the mixture. The number of blows applied to the specimen varies between 35, 50, and 75 blows based on the design category. The blows are carried out by freely falling a hammer from 450 mm height. The compaction has to be carried out for both of the faces. After completion of the first face, the specimen will be turned to the other face and compacted using the same procedure. After finishing the compaction, the specimen will be tested for flowability and stability. Before working on finding stability and flow, it is cooled down and the bulk specific gravity should be found using Equation (1) as given by Garber and Hoel (2014).

$$Gmb = \left(\frac{Wa}{Wa - Ww}\right) \quad (1)$$

Where Wa is a weight of the sample in air and Ww is a weight of the sample in water

d) Stability and Flow test: In conducting the stability test, the specimen is immersed in a bath of water at a temperature of 60±1ºC for a period of 30 to 40 minutes. It is then placed in the Marsh stability testing machine, and loaded at a constant rate of deformation of 5 mm per minute until failure occurs. The total load N in pounds that causes failure of the specimen at 60˚(140F) is noted as the Marshall stability value of the specimen. The total amount of deformation in units of 0.01 in. that occurs up to the point the load starts decreasing is recorded as the flow value. The total time between removing the specimen from the bath and completion of the test should not exceed 30 seconds (Garber and Hoel, 2014).

2.2 Analysis of results from Marshall Test.

Finding the average bulk specific gravity is considered to be the first step of the analysis which should be carried out for all the samples which have the same asphalt content. Then, the average density of each mix can be calculated by multiplying the specific gravity of water with the obtained average specific graving of the mix. Next, all the achieved data are plot in graph represented by a best fit curve which represents the

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relationship between the density with rate of asphalt. To compute the percent of air voids, the percent voids in the mineral aggregate, and the absorbed asphalt in pounds of the dry aggregate, it is first necessary to compute the aggregate mixture's bulk specific gravity of by using Equation (2) (Garber and Hoel, 2014).

$$Gsb = \left(\frac{Pca + Pfa + Pmf}{\left(\frac{Pca}{Gbca}\right) + \left(\frac{Pfa}{Gbfa}\right) + \left(\frac{Pmf}{Gbmf}\right)} \right) \quad (2)$$

Where;

Pca, Pfa, and Pmf = percent by weight of coarse aggregate, fine aggregate, and mineral filler, respectively, in the mixture.

Gbca, Gbfa, and Gbmf = bulk specific gravities of coarse aggregate, fine aggregate, and mineral filler, respectively.

Finding the apparent specific gravity of the aggregate mixture by applying Equation (3) (Garber and Hoel, 2014).

$$Gasb = \left(\frac{Pca + Pfa + Pmf}{\left(\frac{Pca}{Gaca}\right) + \left(\frac{Pfa}{Gafa}\right) + \left(\frac{Pmf}{Gamf}\right)} \right) \quad (3)$$

Where;

Pca, Pfa, and Pmf = percent by weight of coarse aggregate, fine aggregate, and mineral filler, respectively, in the paving mixture, Gaca, Gafa, and Gamf = apparent specific gravities of coarse aggregate, fine aggregate, and mineral filler, respectively.

After that determine the effective specific gravity of the aggregate mixture by using Equation (4) (Garber and Hoel, 2014).

$$Gse = \left(\frac{100 - Pb}{\left(\frac{100}{Gmm}\right) - \left(\frac{Pb}{Gb}\right)} \right) \quad (4)$$

Where;

Gmm = maximum specific gravity of paving mixture, Pb = asphalt percent by total weight of paving mixture, Gb = specific gravity of the asphalt.

In addition, the calculation of the maximum specific gravity of the paving mixtures for different asphalt contents is required and it could be found out by using Equation (5) (Garber and Hoel, 2014).

$$Gmm = \left(\frac{100}{(\frac{Ps}{Gse} + \frac{Ps}{Gs})}\right) \quad (5)$$

Where;

Ps = percent by weight of aggregates in paving mixture, Pb = percent by weight of asphalt in paving mixture, Gse = an effective specific gravity of the aggregates.

Using the following formula which is given by Garber and Hoel (2014), the effective asphalt content, the asphalt absorption, the percent voids in mineral aggregates (VMA), and the percent air voids in the compacted mixture can be found after finding all the specific gravities:

$$Pba = \left(\frac{100\,Gb\,(Gse - Gsb)}{(Gsb * Gse)}\right) \quad (6)$$

Where:

Pba = amount of asphalt absorbed as a percentage of the total weight of aggregates, Gse = effective specific gravity of the aggregates, Gsb = bulk specific gravity of the aggregates, Gb = specific gravity of asphalt.

$$Pbe = \left(Pb - \left(\frac{Pba}{100}\right) * Ps\right) \quad (7)$$

Where;

Pbe = effective asphalt content in paving mixture (percent by weight), Pb = percent by weight of asphalt in paving mixture, Ps = aggregate percent by weight of paving mixture, Pba = amount of asphalt absorbed as a percentage of the total weight of aggregates.

$$VMA = \left(100 - \left(\frac{Gmb * Ps}{Gsb}\right)\right) \quad (8)$$

Where;

VMA = percent voids in compacted mineral aggregates (percent of bulk volume), Gmb = bulk specific gravity of compacted mixture, Gsb = bulk specific gravity of aggregate, Ps = aggregate percent by weight of total paving mixture.

$$Pa = \left(100 - \left(\frac{Gmm * Gmb}{Gmm}\right)\right) \quad (9)$$

Where;

Pa = percent air voids in compacted paving mixture, Gmm = maximum specific gravity of the compacted paving mixture, Gmb = bulk specific gravity of the compacted paving mixture.

Finally four additional separate smooth curves are drawn: percent voids in total mix versus percent of asphalt, percent voids in mineral aggregate versus percent of asphalt, Marshall stability versus percent of asphalt, and flow versus percent of asphalt. These graphs are used to select the asphalt binder contents for maximum stability, maximum unit weight, and percent voids in the total mix within the limits specified. The average of the asphalt binder contents is the optimum asphalt content. The stability and flow for this optimum asphalt content then can be obtained from the appropriate graphs to determine whether the required criteria are met.

3. Superpave mix design system

Superpave is usually referred to as Superior Performing Asphalt Pavements. Strategic Highway Research Program (SHRP) developed this method in the early of 1990s and the improvement on this method continues to this day. The main purpose of this method was to carry out improvements on the previous Hot Mix Asphalt (HMA) design methods. The method has some objectives which can be summarized as: (1) it tries to combine the effects of traffic loads with climate condition effects, (2) it tries to change the method of selection and evaluation of asphalt and aggregates, (3) it tries to change the mix design approach to a better volumetric method (SHRP, 1996). It is a performance-based plan that has a direct relationship with the analysis and tests which make it stand out amongst the methods of design. Like other methods it has its own specification method based on which the amount of aggregate and asphalt binder will be selected. For compaction, it has a gyratory compactor where the materials will be compacted before testing. U.S Corps of Engineers developed the machine and called it (GTM) which stands for Gyratory Testing Machine. The machine is an imitation of actual rollers that compacts asphalt pavement during construction, so it relying on kneading rather than an impact as the case in Marshall method. The GTM simulates the pressure of the trucks in terms of the tire pressure, 300 revolutions and the angle of gyration. The GTM pressure is 8.2 kg/cm2. The same real field ultimate density can be achieved in the laboratory.

Despite the fact that researchers of Strategic Highway Research Program (SHRP) proved that Marshall method has worked flawlessly for many years. Nevertheless, improvement in the design methods is inevitable because the axle loads are getting heavier and the traffic growth is nearly out of control. Superpave was developed to fill out these needs. The SHRP researches planned a Superpave mix design technique to be carried out at three different levels. The first level is to compute the mix sizes using volumetric analysis. Second level is unachieved level as it requires complicated tools therefore, it has not been applied. The third level is a continuous process of purifying Superpave regarding many aspects and variables such as the effects of aggregate size, type and gradation will be limited on the mixture and linking the available data with the performance of asphalt pavement. The method starts with assessment of aggregate characteristics which it is identified as either source or consensus characteristics. Sourcing property is usually defined by the agency from where the materials are bought. While guarantee that the aggregate used in the mix performs accordingly, Superpave researchers identified consensus characteristics (McLeod, 1956). Table 3.1 shows the source characteristics for Superpave which is the basic necessities of Marshall defined by The West Virginia Department of Transportation (WVDT). In the Table 3.1 there is an exception where the elongated and flat characteristic is processed as a consensus property. Table 3.2 shows requirements for aggregate properties. Also, it worth mentioning that measuring mechanical properties of the asphalt concrete is also considered by some of the researchers (Cominsky et al., 1994).

Table 3.1: WVDT aggregate requirements for the Marshall Mix design method (McGennis et al., 1995).

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 face
Fine Aggregate	
Must met requirements of ASTM D 1073, except gradation	

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Table 3.2: Superpave consensus aggregate properties (McGennis et al., 1995).

Mineral Filler Must met requirements of ASTM D ٢٤٢ except for gradation and must be free of harmful organic compounds				
Design Level	Coarse Aggregate Angularity	Fine Aggregate Angularity	Sand Equivalency	Flat and Elongated
Light Traffic	(%min.)	(% min.)	(% min.)	(% min.)
Medium Traffic	55%	-	40%	-
Heavy Traffic	75%	40%	40%	10%

3.1 Superpave Tests

a) Coarse Aggregate Angularity (CAA): Coarse aggregate angularity is measured by the percent weight of aggregates with one and more than one fractured face. The test is applied on materials retained on the sieve (4.75) mm. This is slightly different than the WVDT Marshall requirements that indicated the minimum percent of material with two fractured faces (McLeod, 1956).

b) Fine Aggregate Angularity (FAA): AASHTO T304 (2010) is used for evaluation of the specimen which counts for the void content and uncompacted samples. The test is performed after sieving and only the parts that passed (2.36) mm sieve will be taken to this test. The texture and angularity of the fine aggregates can be guaranteed using this test which was present before the Superpave method. However, the test was not regarded as necessary in the previous design methods (McLeod, 1956).

c) Sand Equivalency Test (SE): The sand equivalency test is applied to evaluate the clay content of materials passing the (4.75) mm sieve. This test was implemented by some states prior to Superpave, but it is a new requirement for the WVDT (McLeod, 1956).

d) Flat and Elongated Particles Test: It is conducted according to the test method outlined in ASTM D4791 (2019). 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. Coarse aggregate flat and elongated is determined by the percent mass of aggregates whose ratio of longest dimension to smallest dimension is greater than (5). Superpave allows 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. As a result coarse and fine aggregate angularity, elongated particles, and sand equivalency affect pavement resistance to permanent deformation, fatigue and low-temperature cracking, and also affect production and laydown (McLeod, 1956). Table 3.3 shows criteria for Superpave system.

Table 3.3: Criteria of Superpave System (McGennis et al., 1994)

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

e) Aggregate gradation: The aggregate gradation tests are explained in detail in the AASTHO T11 (2010) and AASHTO T27 (2010). Table 3.4 shows all the gradation requirements that need to be met in mixing the coarse and fine aggregate.

Table 3.4: Aggregate gradation for Superpave System (McLeod, 1956).

Sieve Size (mm)	Superpave Mixture (percent Passing)					
	SP-9.5 Nominal Size (A)		SP-12.5 Nominal Size (B)		SP-19.0 Nominal Size (C)	
Gradation Max.	Min.	Max.	Min.	Max.	Min.	Max.
25.0	-	-	-	-	100	-
19.0	-	-	100	-	90	100
12.5	100	-	90	100	-	90
9.5	90	100	-	90	-	-
4.75	-	90	-	-	-	-
2.36	32	67	28	58	23	49
0.075	2	8	2	8	2	7

The modifications of Superpave gradation appears to be minor when compared to that of the Marshall necessity, however, the attempt in Superpave gradation method is to limit the quantity of the fine aggregate (Al-Khateeb et al., 2017). The restriction starts as in the area on the FHWA's 0.45 power chart where that certain sizes are not allowed to pass in Superpave method. If the materials pass this restricted zone, then the pavement is prone to deformations and tenderness (Al-Khateeb et al., 2017). This restriction zone is recommended in Superpave method and not specified (Kandhal and Cooley, 2001). Table 3.5 presents the gradation requirement of (9.5, 12.5, and 19.5) mm nominal aggregate sizes.

Table 3.5: Recommended Aggregate gradation Restricted zone (McLeod, 1956).

Sieve Size	Boundaries of Restricted Zone Superpave Mixture (% Passing)					
	SP-9.5 Nominal Size		SP-12.5 Nominal Size (B)		SP-19.0 Nominal Size	
Gradation Max.	Min.	Max.	Min.	Max.	Min.	Max.
mm	Min.	Max.	Min.	Max.	Min.	Max.
2.36	47.2	47.2	39.1	39.1	34.6	34.6
1.18	31.6	36.6	25.6	31.6	22.3	28.3
0.60	23.5	27.5	19.1	23.1	16.7	20.7
0.30	18.7	18.7	15.5	15.5	13.7	13.7

In the Superpave process both the consensus and gradation aggregate characteristics are required. For the amount of asphalt in the mixes, their initial amounts are estimated using the procedure below:

Firstly, finding the effective specific gravity of the aggregates (Gse) by applying Equation (10).

$$Gse=(Gsb+0.8\,(Gsa-Gsb)) \qquad (10)$$

Where;

Gsa = apparent specific gravity of aggregate blend, Gsb = bulk specific gravity of aggregate blend.

Secondly, finding the volume of absorbed binder (Vba) by using Equation (11).

$$Vba = \left(\frac{Ps\,(1 - Va)}{\left(\frac{Pb}{Gb} + \frac{Ps}{Gse}\right) * \left(\frac{1}{Gsb} - \frac{1}{Gse}\right)} \right) \qquad (11)$$

Where;

Ps = percent of aggregate, Va = volume of air voids, Pb= percent of binder, Gb= specific gravity of binder

Thirdly, finding the volume of effective binder (Vbe) by applying Equation (12).

Vbe=0.176-0.067 log(Sn) (12)

Where;

Sn = nominal maximum sieve size of aggregate blend.

Finally, finding the percent of binder by mass of mix (Pbi) is done by applying Equation (13).

$$Pbi = 100\left(\frac{Gb\ (Vbe + Vba)}{Gb\ \ (Vbe + Vba)} + Ws\right) \qquad (11)$$

To know the compaction properties of an aggregate blend, two specimens are needed. Also, to calculate the peak theoretical specific gravity, another two samples are required. To prepare the samples they need to be compacted with gyratory compactor. The amount of compaction in that instrument is adjusted with the number of the gyrator's revolution. The compaction is categorized into three stages where the compaction rate for each stage is different. The first stage is the starting stage, the second stage is called design level, and the final stage is called the peak or maximum and they are denoted with (Ni, Nd, and Nmax) respectively. The starting stage is used to detect the "tender" mixes and it reflects the ability of the mix to consolidate under low forces. The second stage which is design stage is a real simulation of the mix just after construction. Whereas the maximum stage simulates the density of the asphalt after its construction by 5 to 10 years (Cominsky et al., 1994). In Table 3.6, the number of gyrations is shown which depends strongly on the status of the design.

Table 3.6: Number of gyrations at specific traffic levels (McGennis et al., 1995).

Traffic Level (ESAL) millions				
	< 0.3	0.3 – 3	3 - 30	>30
Nini.	6	7	8	9
Ndes.	50	75	115	125
Nmax.	75	100	160	205

The bulk specific gravities of the compacted specimens are then calculated and found. This along with the calculated maximum specific gravity are used in volumetric analysis. There are some areas and calculations where both Marshall and Superpave methods use exact same equations such as in finding voids filled with

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asphalt, voids in the total mix, and voids in the mineral aggregate. In the Superpave design method, the dust in the aggregate mix is counted for as the percentage of the aggregate that can pass (0.075) mm sieve. It indicates a ratio between the dust and the percentage of effective binder. This percentage of effective binder is the absorbed binder subtracted from the total binder content. Table3.7 shows the Superpave design criteria.

Table 3.7: Superpave mix design criteria (McGennis et al., 1994)

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

The aggregate blend that makes the best compliance with the criteria is indicated as the design aggregate structure for finding the design binder content (Harman 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. In addition three additional separate smooth curves are drawn: % of air void, % VFA, and %VMA respectively vs. % of Asphalt Binder (McGennis et al., 1995). Finally, the moisture susceptibility of the mixture is assessed, six samples are prepared at the design aggregate structure and optimum binder content. Three specimens are conditioned. The tensile strength of all specimens is measured (Huber and Heiman, 1986).

4.CONCLUSION

I. There are analytical and experimental methodologies exist in the literature that may improve the mix design significantly. Especially the methods that depend mostly on volumetric analysis in the establishment of the optimum asphalt content.

II.The decisive factor in establishing the effective volume of the binder mix is the voids in the mineral aggregate. Even though, the method of obtaining VMA surrounded by assumptions on the types of aggregate that are considered as questionable in both methods of design (Marshall and Superpave).

III. To resist everlasting deformations, cracking in low-temperature and due to fatigue, the pavement relies mainly on the type of aggregate whether it is flat or elongated and other criteria of SE, FAA and CAA.

IV. The main differences between Marshall and Superpave mix design systems are shown in Table 4.1.

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

Superpave (SP) Mix Design Method	Marshall (M) Mix Design Method
(CAA, FAA, SE, and F&E particles) mineral aggregate tests are considered	(CAA, FAA, SE, and F&E particles) mineral aggregate tests are not considered
Before compaction, initial binder content is calculated.	
Grades of compaction in SP system with respect to (N design) which depends on: - 1- Average design high air temperature 2- Design ESALs	Grades of compaction varies as follows: 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.
Nmax is used to compact the test specimen & to estimate compatibility of mixture. Nini is used	Nmax & Nini do not exist
SP utilizes the idea of (%Gmm-corrected) in collecting the data and analyzing them to select the design binder content.	The idea (%Gmm-corrected) does not exist in M test.
Nominal Maximum Aggregate size in (mm) is essential in selecting gradation measures of mix & verifying VMA%.	There is not such a property as nominal maximum aggregate size.
The idea of dust ratio which represents ratio between aggregate content passing (0.075) mm sieve to effective binder content.	The idea of dust ratio does not exist in M test.
Both %G mm at Nmax and % Gmm at Nini are valid	%G mm @Nmax & % Gmm @ Nini that are not used
The assessment for sensitivity towards moisture of the mix and determination of tensile strength are valid and the ratio should be more than (80%).	Not valid
Performance Grade binder is valid in this test method	Not valid.
Superpave gyratory compactor which is a simulator of real field rollers is used for compaction.	Marshall compacting hammer is used
The existence of both restricted zone FHWA 0.45 power chart) and Control points in finding the design aggregate structure	Not valid.
The diameter of gyratory is (150) mm. And number of gyrations/min = (30)	The diameter of samples is (102mm).

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