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Comparative Study of Hot Asphalt Mixtures Properties Designed by Marshall and Superpave Methods

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KEYWORDS:
Marshall,
Superpave,
Rutting,
Fatigue,
Dynamic Modulus,
Flow Number
Marshall Stability,
Aggregate Gradation.

Abstract—The **Superpave Mix design method takes into consideration many factors that simulate the natural conditions besides the traffic loading which results in better rutting and fatigue resistances. Unfortunately, there are huge limitations to apply Superpave in Egypt because it is expensive, requires a lot of time in addition to the shortage of equipment. Therefore, the scope of this study is to find a relationship between Marshall and Superpave in order to improve the mixtures in terms of rutting and fatigue resistances. Two binders and two surface asphalt mixtures samples were designed by Marshall and compacted with the Gyratory Compactor. Dynamic Modulus and Flow Number tests were applied to the samples and finally analyzing the results of each test to determine the relationship between different performance tests. A directly proportional relationship was found between Marshall Stability results and Dynamic Modulus and Flow Number results which reflects on the rutting and fatigue resistances. Moreover, another sample was designed using Superpave then its properties were compared with the previous Marshall samples, it was found that the sample which was designed using Superpave has higher stability than the sample designed using Marshall although the same materials were used. Finally, Study the effect of applying Superpave aggregate gradation limits (control points and restricted zone) on the properties of a mixture designed using the Marshall, it was found that applying Superpave aggregate gradation limits on Marshall mix design method improve the mixture properties.**

I. INTRODUCTION

THE purpose of any asphalt mix design method is to determine the optimum asphalt content relevant to the designed aggregate structure to achieve its specifications requirements. There is a need to enhance the commonly used Marshall Mix design method in order to increase the lifespan of the roads. This need led the highway engineers to come up with a solution to improve the rutting and fatigue resistances to increase the lifespan of the roads. The solution is to develop the Super Performance Pavements (Superpave) mix design by Strategic Highway Research Program (SHRP). Superpave surpasses the Marshall Mix design method in many factors such as material characterization, precision in its calculations and compaction method which simulates the real compaction conditions applied on the road. Superpave was initially developed by the Strategic Highway Research Program (SHRP) (1987-1993) and it continues to improve. This method was mainly developed to improve previous HMA design methods. Some of the primary goals of this method are to achieve better incorporation of traffic and climatic conditions, better Asphalt binder and aggregate evaluation and selection, better volumetric approaches to mix design and the unique feature of the Superpave system is that it is a performance-based

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specification. The tests and analysis have direct relationships to field performance [1]. But due to its expensiveness, time consuming process and unavailability of its machines in Egypt, the Marshall Mix design method was used in this study along with some performance tests from the Superpave method. This hybrid process was done in order to find a relationship between the different performance tests found in Marshall and Superpave mix design methods to make it easier for the contractors to have an indication for the predicted performance of the mixture on site. Moreover, the hybridization extends to applying the aggregate graduation requirements in the Superpave method into the Marshall Mix design method to determine its effect on the mix properties.

Research Problem : lies in the poor performance of the roads in Egypt having pavement life much shorter than the expected. This poor performance can be attributed to the shortcomings of the Marshall Mix design method such as neglecting the actual field conditions and not representing the loads applied on the real pavement in the compaction process. On the other hand, the Superpave mix design method eliminates the previously mentioned flaws. Yet there are some limitations while trying to apply it in Egypt such as the unavailability of the required machines, the high initial cost, and the time-consuming process.

The Aim of the Research is to firstly, compare between the mixture properties designed by Marshall and Superpave methods. Secondly, determine a relation between different test methods found in Marshall and Superpave mix design methods. Thirdly, study the effect of applying the Superpave's control points and restricted zone on the aggregate gradation and the resulting mix properties in order to improve the Marshall Mix design method.

*Research Importance***:** lies in that it contributes to finding a relation between the Marshall Stability and the Dynamic Modulus and Flow Number. This research also tries to find a hybrid method between Marshall and Superpave mix design methods to facilitate its application in Egypt.

II. LITERATURE REVIEW

A. Marshall Mix Design Method

This method is the most commonly used in a lot of countries due to the relatively low cost and simplicity of its procedures. The Marshall Mix design method consists of four steps: aggregate characterization, binder characterization, aggregate gradation and mix design. These steps are illustrated below

*Aggregate characterization***:** the different aggregate physical properties are tested according to their corresponding specification.

Binder characterization: penetration grading system and viscosity grading system were used to characterize the asphalt binder to choose the right asphalt grade.

*Aggregate gradation***:** the 3D and 4B binder gradations for the binder course and surface layer respectively were the gradations used to prepare the samples according to the Egyptian specifications [3].

Mix Design Procedures: approximately 1200gm of aggregates and filler are heated to a temperature of 175-190^{o}C. Bitumen is heated to a temperature of 121-125^{o}C with the first trial percentage of bitumen equals (3.5 or 4% by weight of the mineral aggregates). The heated aggregates and bitumen are thoroughly mixed at a temperature of 150 - 160^{o}C. The mix is placed in a preheated mold and compacted by a hammer with determined blows on either side at a temperature of 138^{o}C to 149^{o}C. The weight of mixed aggregates taken for the preparation of the specimen may be suitably altered to obtain a compacted thickness of 63.5+/-3 mm. Four more trial mixtures are prepared with the same procedures but the bitumen content is increased by +0.5% from the previous trial [4]. Once the specimens are prepared, their volumetric properties are then calculated.

Then these properties are plotted graphically against the asphalt content. Then the optimum asphalt content (OAC) is determined as the average value of asphalt content corresponding to maximum stability, asphalt content corresponding to maximum specific gravity and asphalt content corresponding to 4% air voids. Finally, the volumetric properties at the chosen OAC are determined and checked against the specifications limit.

B. Superpave Mix Design Method

The Superpave mix design procedure involves four steps which are selection materials that meet the super-pave specifications, selection of a design aggregate structure, Selection of the optimum asphalt content and evaluation of moisture sensitivity of the designed mixture. These steps are summarized below.

Binder Selection: the first step is to choose an asphalt binder having a Performance Grade (PG) suitable to the project location. Reference [3] proved that the PG in Egypt ranges from PG64-10 to PG76-10. Then the asphalt is tested using the Bending Beam Rheometer (BBR) and Dynamic Shear Rheometer (DSR) to determine its PG and check its suitability. The second step is to conduct the rotational viscometer test to determine the compaction and mixing temperatures through the Temperature-Viscosity chart.

Aggregate Selection : Reference [5] states that Superpave specifications divides the aggregate properties into two categories which are consensus and source properties. The source properties include the same properties tested before in the Marshall Mix design method. While the consensus properties include tests illustrated in the table (1).

TABLE 1

AGGREGATE CONSENSUS PROPERTIES

Test	Specification
Coarse Aggregate Angularity	ASTM D 5821
Fine Aggregate Angularity	ASTM TP 33
Flat and Elongated Particles	ASTM D 4791
Sand Equivalent	AASHTO T 176

Design of Aggregate Structure: at least three trial blends are established by combining the gradations of the individual materials into a single blend. The blend is then compared to the Superpave requirements of aggregate gradation. These specifications are selected based on the maximum nominal size of the blend. The first specification is designated as control points which are certain limits at each sieve where the design curve should lie between them. The second specification is called the restricted zone. This restricted zone is an area where the design curve must not pass through. Table (2) illustrates the control points and restricted zones of the maximum nominal size (25mm) used in the study.

TABLE 2
SUPERPAVE CONTROL POINTS & RESTRICTED ZONE

Sieve No	Control Points		Restricted Zone	
1''	*90*	*100*	*-*	*-*
3/4''	*-*	*90*	*-*	*-*
1/2''	*-*	*-*	*-*	*-*
3/8''	*-*	*-*	*-*	*-*
No. 4	*-*	*-*	*39.5*	*39.5*
No. 8	*19*	*45*	*26.8*	*30.8*
No. 16	*-*	*-*	*18.1*	*24.1*
No. 30	*-*	*-*	*13.6*	*17.6*
No. 50	*-*	*-*	*11.4*	*11.4*
No. 100	*-*	*-*	*-*	*-*
No. 200	*1*	*7*	*-*	*-*

Then these trial blends are compacted at (5%) asphalt content using the gyratory compactor to (N_{Design} = 100). Afterward, the volumetric properties of the specimens of each blend are determined and used to calculate the theoretical OAC (Pb_e) corresponding to 4% air voids. Also, the expected volumetric properties associated with the theoretical OAC are calculated. Then the best blend is chosen based on which theoretical OAC meets the Superpave criteria.

Determining OAC: after selecting the design blend and its (Pb_e) is calculated, specimens with asphalt contents equal to Pb_e, 0.5% below Pb_e, 0.5% above Pb_e, 1% above Pb_e are prepared and compacted to (N_{Des}) and their volumetric properties are calculated. These volumetric properties are plotted against asphalt content to determine the optimum asphalt binder content which corresponds to 4% air voids at N_{Des}. Also, the other mixture volumetric properties associated with the chosen OAC are checked against the Superpave limits to verify that they meet the criteria. Finally, if all the mixture properties meet its criteria, two specimens are prepared at the chosen OAC and compacted to a number of gyrations equals to (N_{Max} = 160) to determine %Gmm @ NMax which should be less than (98%).

Evaluation of Moisture Sensitivity: Reference [6] illustrates the specifications and steps required to be performed on the design aggregate structure at the chosen optimum asphalt content. Six specimens are compacted to approximately 7.0% (±1.0%) air voids by trial and error. The specimens are divided into two subsets with three specimens each. The first subset is called the unconditioned subset. On the other hand, the other subset is called the conditioned subset. These subsets are treated as mentioned in specifications. Finally, the moisture sensitivity is determined as a ratio of the tensile strengths of the conditioned subset divided by the tensile strengths of the unconditioned subset. The tensile strength ratio must be higher than 80%.

Dynamic Modulus: the dynamic modulus (E*) represents the stiffness of the asphalt material when tested in a compressive repeated load test. The dynamic modulus is one of the key parameters used to evaluate both rutting and fatigue cracking failures and to determine which mixture is better. The test procedures are done in accordance with specifications [7]. It includes applying repeated load on the test specimens at different temperatures (4.4 °C, 21.1 °C, 37.8 °C, and 54.4 °C) and different frequencies (25 Hz, 10 Hz, 5 Hz, 1 Hz, 0.5 Hz, and 0.1 Hz). Then a dynamic modulus master curve is drawn which represents the relation between the dynamic modulus and the reduced frequency. From the master curve of each mixture specimen, an indication of fatigue resistance and rutting resistance can be determined as shown in figure (1). The mix with a higher curve on the left side of the point of intersection has better rutting resistance. While on the right side of the point of intersection, the mix with the lower curve has better fatigue resistance.

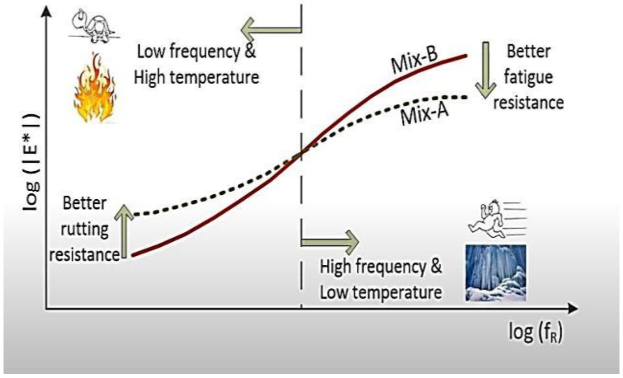

Figure 1: Dynamic Modulus Master Curve

Flow Number: is an empirical way of characterizing a hot-mix asphalt (HMA) mixture's rutting potential. In the flow number test, permanent strain at each cycle is measured while constant deviator stress is applied at each load cycle on the test sample. Then a relation between cumulative permanent strain and the number of loading cycles is drawn. Permanent deformation of asphalt pavements has three zones as shown in figure (2). This test is conducted in accordance with the specifications [8].

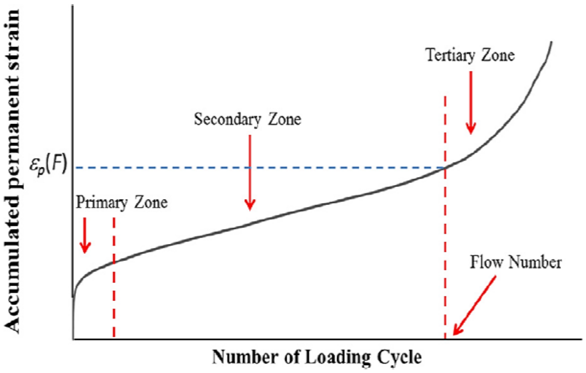

Figure 2: Flow Number Curve

III. STUDY METHODOLOGY

A-Marshall Mix Design

Binder Course Samples: the 3D gradation was used to prepare these samples (B1 & B2) according to the Egyptian specifications as shown in figure (3).

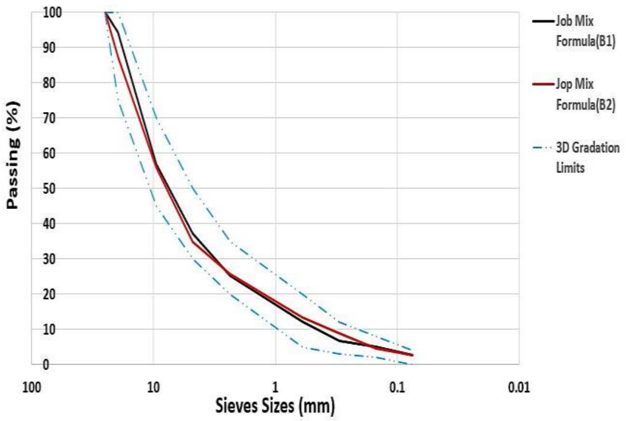

Figure3: Aggregate Gradation for Mix (B1 &B2)

Table (3) summarizes the Volumetric Properties at OAC

TABLE 3

VOLUMETRIC PROPERTIES OF MIXTURES (B1 & B2)

Mix Property	B1	B2	Specifications	
			Min	Max
Optimum Asphalt Content	4.8%	4.6%	-	
Unit Weight (gm/cm3)	2.327	2.276	-	
Theoretical Maximum Density (gm/cm3)	2.463	2.421	-	
Air Voids (%)	5.5	6	3	8
Stability (kg)	1090	1150	1000	
Flow (mm)	2.93	2.71	2	4
Voids in Mineral Aggregate (%)	15.3	16.2	15	
Voids Filled with Asphalt (%)	64	62.9	60	75

Surface Layer Samples: the 4B gradation was used to prepare these samples (S1 & S2) according to the Egyptian specifications as shown in figure (4).

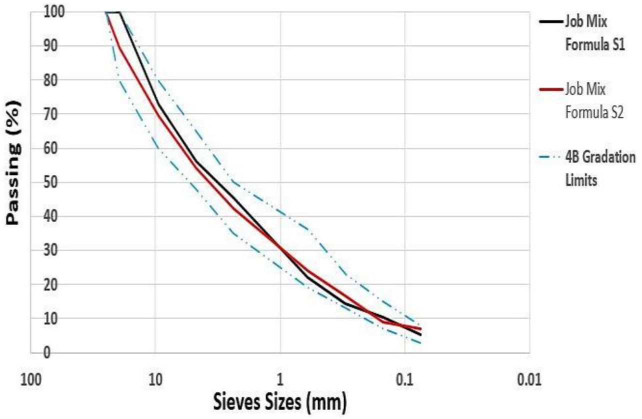

Figure 4: Aggregate Gradation for Mix (S1 & S2)

Table (4) summarizes the Volumetric Properties at OAC

TABLE 4

VOLUMETRIC PROPERTIES OF MIXTURES (S1 & S2)

Mix Property	S1	S2	Specifications	
			Min	Max
Optimum Asphalt Content	5.45%	4.9%	-	
Unit Weight (gm/cm3)	2.356	2.326	-	
Theoretical Maximum Density (gm/cm3)	2.454	2.422	-	
Air Voids (%)	4	4	3	5
Stability (kg)	1284	1275	1200	
Flow (mm)	2.92	2.94	2	4
Voids in Mineral Aggregate (%)	15.5	15.9	15	
Voids Filled with Asphalt (%)	74	74.8	60	75

B-Dynamic Modulus Master Curve

Figure (5) shows the relation between dynamic modulus and loading frequency for mixture B1.

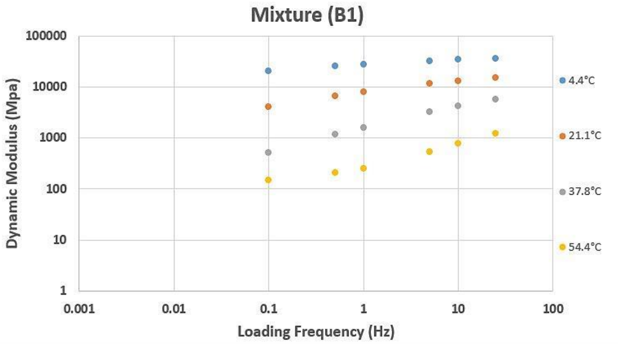

Figure 5: Dynamic Modulus Graph of Mix (B1) Before Shifting

Figure (6) illustrates the master curve for mixture B1

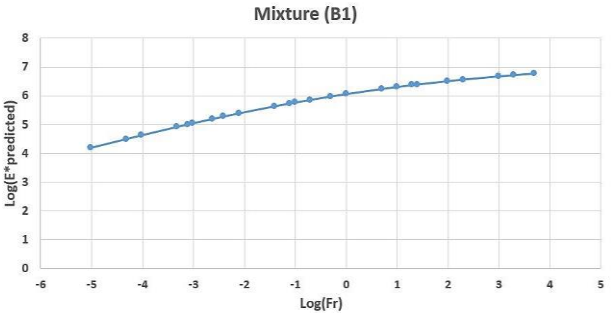

Figure 6: Dynamic Modulus Master Curve of Mix (B1)

Figure (7) shows the relation between dynamic modulus and loading frequency for mixture B2.

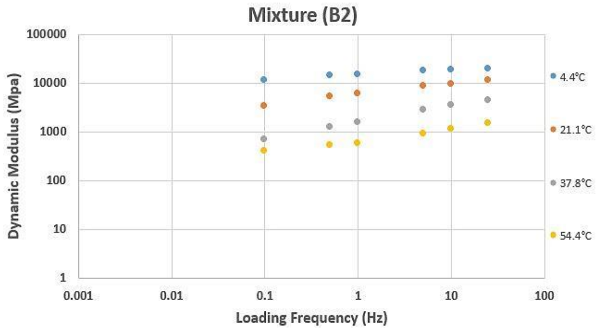

Figure 7: Dynamic Modulus Graph of Mix (B2) Before Shifting

Figure (8) illustrates the master curve for mixture B2.

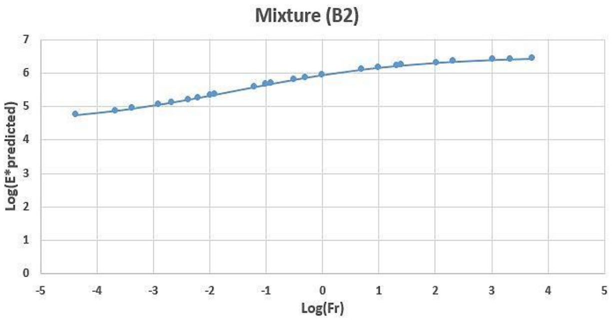

Figure 8: Dynamic Modulus Master Curve of Mix (B2)

Figure (9) shows the relation between dynamic modulus and loading frequency for mixture S1.

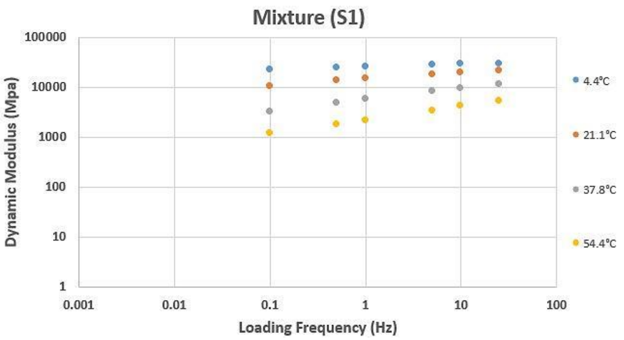

Figure 9: Dynamic Modulus Graph of Mix (S1) Before Shifting

Figure (10) illustrates the master curve for mixture S1

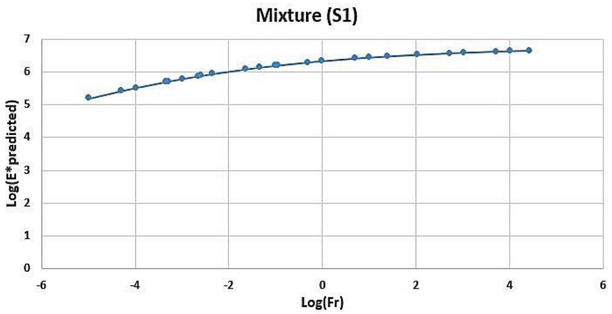

Figure 10: Dynamic Modulus Master Curve of Mix (S1)

Figure (11) shows the relation between dynamic modulus and loading frequency for mixture S2.

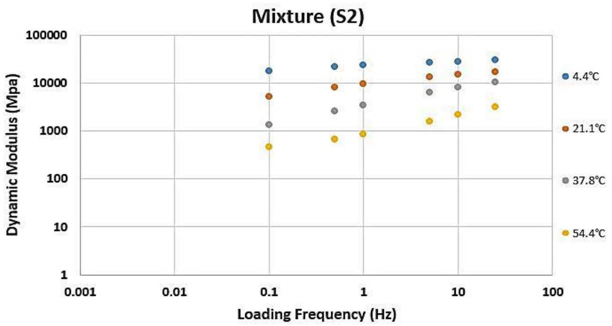

Figure 11: Dynamic Modulus Graph of Mix (S2) Before Shifting

Figure (12) illustrates the master curve for mixture S2

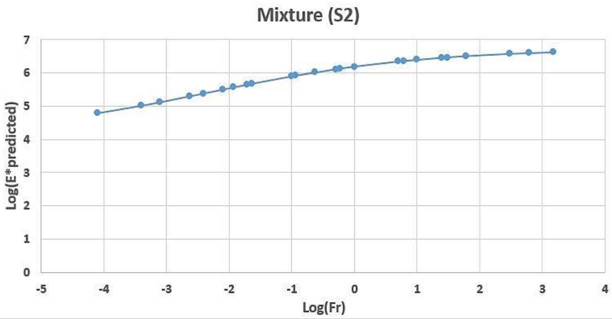

Figure 12: Dynamic Modulus Master Curve of Mix (S2)

C- Flow Number

Figure (13) shows a relation between cumulative permanent strain obtained from (AMPT) and a number of cycles for mixture B1 which was found to be (280) and mixture B2 which was found to be (496).

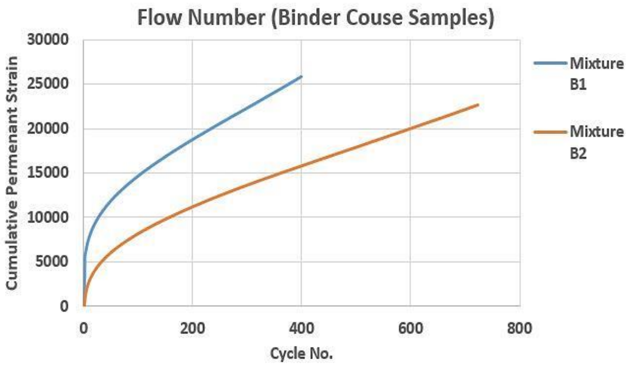

Figure 13: Flow Number Curve of Mix (B1 & B2)

Figure (14) shows a relation between cumulative permanent strain which obtained from (AMPT) and a number of cycles for mixture S1 which was found to be (1301) and mixture S2 which was found to be (1210).

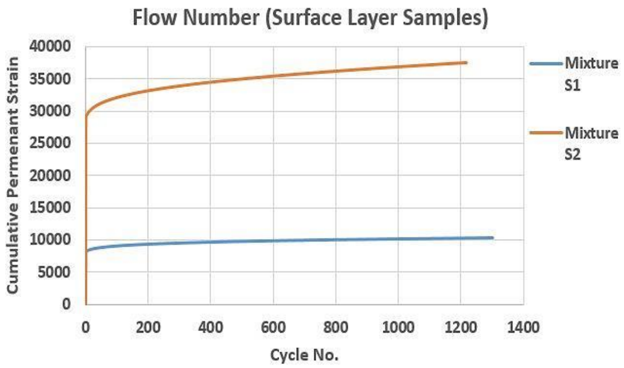

Figure 14: Flow Number Curve of Mix (S1)

D- Superpave Mix Design

The design was made as a binder course using the same aggregate gradation as sample (B2).

(1) Binder Selection

Performance grade: Reference [3] divided the projects in Egypt into two main categories. The high scale projects (with a reliability of more than 98%) have their performance grades ranging between PG64-10 and PG76-10. While the lower scale projects (with reliability of more than 50%) have their performance grades ranging from PG52-10 to PG76-10.

Tests Required for Mixture Design _ as previously mentioned, the rotational viscometer test was used to determine the compaction and mixing temperature ranges.

(2) Aggregate Selection

The aggregate properties are divided into two groups as follows:

Source Properties: the aggregates used are the same as sample (B2).

Consensus Properties: table (5) summarizes the consensus properties for (B_{new})

TABLE 5
CONSENSUS PROPERTIES OF MIXTURE (B_{NEW})

Property	Value	Specifications	
		Min	Max
Coarse Aggregate Angularity (%)	63	60	
Fine Aggregate Angularity (%)	51	45	
Sand Equivalent (%)	49	45	
Flat and Elongated (%)	9		10

(3) Design of Aggregate Structure

The used aggregate gradation was similar to sample (B2). This gradation was compared to the Superpave control points and restricted zone as shown in figure (15).

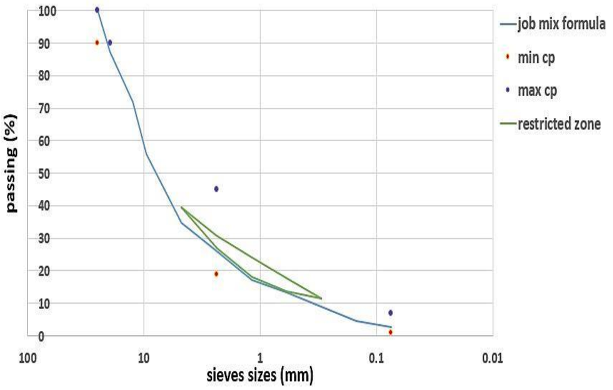

Figure 15: Aggregate Gradation of Superpave Sample (BNew)

(4) Mix Design Procedures

Initial Blend: Three samples were prepared using the aggregate gradation with the chosen initial asphalt content (P_{bi}) which was 5%. Then the samples were compacted using the Superpave Gyratory Compactor to a number of gyration (N_{des}). Theoretical maximum specific gravity (G_{mm}) [9] and bulk specific gravity (G_{mb}) [10] were calculated for each of the three samples and used to determine their volumetric properties as shown in table (6).

TABLE 6
VOLUMETRIC PROPERTIES FOR INITIAL BLEND

Mix Property	Value
Average Bulk Specific Gravity (G_{mb})	2.387
Theoretical Maximum Specific Gravity (G_{mm})	2.4679
Aggregate Bulk Specific Gravity (G_{sb})	2.616
Initial Asphalt Content (P_{bi})	5%
Air Voids	3.283%
Voids in Mineral Aggregate	13.32
Voids Filled with Asphalt	75.35
%G_{mm} @ N_{Ini}	88.038 %

Then the theoretical optimum asphalt content (corresponding to 4% air voids) was found to be (4.71%). And mix volumetric properties (corresponding to 4% air void) were calculated as shown in table (7) and checked that they satisfy the Superpave limits [3].

TABLE 7
ESTIMATED VOLUMETRIC PROPERTIES

Property	Value	Specifications	
		Min	Max
Estimated Optimum Asphalt Content (Pbe)	4.71%	-	-
Estimated Voids in Mineral Aggregates (VMAe)	13.39	12	14
Estimated Voids Filled with Asphalt (VFAe)	70.13	65	75
%Gmm @ NIni	87.321	-	89

*Determining Optimum Asphalt Content***:** Two samples were prepared for asphalt contents equal 0.5% below OAC (A), Theoretical OAC (B), 0.5% above OAC (C) and 1% above OAC (D). Each sample was compacted to the same number of gyrations as the initial blend and their properties are as follows.

Sample (A): the mix volumetric properties of sample (A) were determined as in shown in table (8).

TABLE 8
SAMPLE (A) VOLUMETRIC PROPERTIES

Property	Specification
Theoretical Maximum Specific Gravity (G_{mm})	2.4712
Asphalt Content (Pb)	4.21%
Average Bulk Specific Gravity (G_{mb})	2.362
Air Voids	4.432%
Voids in Mineral Aggregates (VMA)	13.52
Voids Filled with Asphalt (VFA)	67.23
%Gmm @ NIni	88.209

Sample (B): the mix volumetric properties of sample (B) were determined as shown in table (9).

TABLE 9
SAMPLE (B) VOLUMETRIC PROPERTIES

Property	Specification
Theoretical Maximum Specific Gravity (G_{mm})	2.4676
Asphalt Content (Pb)	4.71%
Average Bulk Specific Gravity (G_{mb})	2.368
Air Voids	4.04%
Voids in Mineral Aggregates (VMA)	13.75
Voids Filled with Asphalt (VFA)	70.59
%Gmm @ NIni	88.805

Sample (C): the mix volumetric properties of sample (C) were determined as shown in table (10).

TABLE 10
SAMPLE (C) VOLUMETRIC PROPERTIES

Property	Specification
Theoretical Maximum Specific Gravity (G_{mm})	2.4334
Asphalt Content (Pb)	5.21%
Average Bulk Specific Gravity (G_{mb})	2.3708
Air Voids	2.57%
Voids in Mineral Aggregates (VMA)	14.09
Voids Filled with Asphalt (VFA)	81.74
%Gmm @ NIni	89.648

Sample (D): the mix volumetric properties of sample (D) were determined as in shown in table (11).

TABLE 11
SAMPLE (D) VOLUMETRIC PROPERTIES

Property	Specification
Theoretical Maximum Specific Gravity (G_{mm})	2.4094
Asphalt Content (Pb)	5.71%
Average Bulk Specific Gravity (G_{mb})	2.3737
Air Voids	1.48%
Voids in Mineral Aggregates (VMA)	14.44
Voids Filled with Asphalt (VFA)	89.72
%Gmm @ NIni	89.950

Then a relation between asphalt content and air voids was drawn as shown in figure (16) to determine optimum asphalt content (corresponding to 4% air voids). The optimum asphalt content is found to be (4.713%).

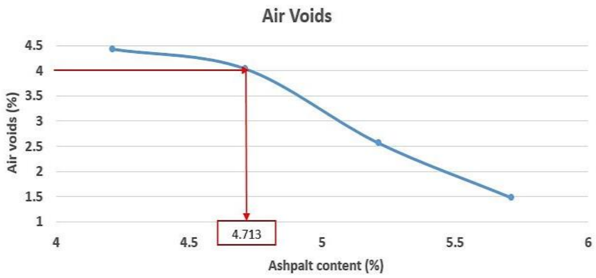

Figure 16: Air Voids versus Asphalt Content

The volumetric properties were then determined at the chosen OAC and checked in accordance with the limits of the specifications as shown in table (12).

TABLE 12
VOLUMETRIC PROPERTIES AT OAC

Property	Value	Specifications	
		Min	Max
Optimum Asphalt Content (P_b)	4.713%	-	-
Expected Voids in Mineral Aggregates (VMA)	13.75	12	14
Expected Voids Filled with Asphalt (VFA)	70.59	65	75
%G_{mm} @ N_{Ini}	88.05	-	89

Finally, two samples at optimum asphalt content (4.713%) were compacted. Each sample was compacted to a number of gyrations equal to N_{Max}. After the samples were compacted to (N_{Max}), the bulk specific gravity (Gmb) test was performed it was found to be (2.352). Then percentage %G_{mm} was calculated (95.314%) and checked in accordance with the specification’s limits (<=98%).

(5) Evaluation of Moisture Sensitivity

Unconditioned Samples: the samples were designated as (M.D 1, M.D 2 and M.D 3). And they were treated as mentioned in specifications [6]. The test results are illustrated below in table (13).

TABLE 13
UNCONDITIONED SAMPLES CALCULATIONS

Sample No.	M.D 1	M.D 2	M.D 3
Diameter (mm)	150	150	150
Thickness (mm)	60	60	60
WDry (A)	2271.67	2258.33	2135.67
WSub	1317.00	1296.67	1226.33
WSSD	2304.67	2272.67	2158.33
Gmb	2.30	2.32	2.29
Gauge Reading	323	278	230
Load (kg)	788.93	679.13	561.20
Load (N)	7731.55	6655.51	5499.76
Tensile Strength (KPa)	543.872	470.780	389.028
Average Tensile Strength (KPa)	467.89		

Conditioned Samples: the samples were designated as (M.W 1, M.W 2 and M.W 3). And they were conditioned by vacuum saturation and warm-water soaking cycle as mentioned in specifications [6]. The test results are illustrated below in table (14).

TABLE 14
CONDITIONED SAMPLES CALCULATIONS

Sample No.	**M.W 1**	**M.W 2**	**M.W 3**
Diameter (mm)	150	150	150
Thickness (mm)	57	59	58
WDry (A)	2311	2384	2107
WSub	1339	1380	1184
WSSD	2322	2394	2141
Gmb	2.352	2.351	2.202
Air Void Percent (Pa)	4.667	4.689	10.738
Bulk Volume (E)	982.67	1013.67	957.00
Volume of Air Void (Va)	45.87	47.53	102.76
WSSD After Partial Vacuum (B')	2344.3	2418.0	2181.7
Volume of Absorbed Water (j')	33.33	34.33	74.33
Degree of Saturation (S')	72.68	72.23	72.34
Specification (70-80)	satisfy	satisfy	satisfy
Gauge Reading	128	142	35
Load (kg)	313	346	85.4
Corrected Load (N)	3068.71	3387.53	836.92
Tensile Strength (KPa)	228.40	243.58	61.22
Average Tensile Strength (KPa)	177.73		

Finally, the tensile strength ratio is calculated (37.99%). And it was checked in accordance with its specification's limits (> 80 %).

E-Marshall Stability & Flow

After the Superpave design was completed and the OAC was determined, a new sample was compacted using the gyratory compactor to (N_{Max} = 160) in order to be tested by the Marshall Stability and Flow device [11]. And the results are illustrated in table (15)

TABLE 15
MARSHALL STABILITY AND FLOW OF SUPERPAVE SAMPLE

Diameter (mm)	**150**
Thickness (mm)	55
WDry (Kg)	2410
WSub (Kg)	1400
WSSD (Kg)	2416
Gmb	2.372
Gauge Reading	420
Stability (kg)	1281
Flow (mm)	4.112

IV. ANALYSIS OF THE RESULTS

A. *Dynamic modulus for Marshall Mixtures*

Binder Course: the comparison between binder course samples is done using dynamic modulus to determine which mix is better in terms of rutting and fatigue resistance. As shown in figure (17) B2 has better rutting resistance than B1 since B2 is higher on the left side of the curve because, in low frequencies and high temperatures, mixture B2 has lower strain than B1 so it has higher dynamic modulus values. Also, it has better fatigue resistance than B1 since B2 is lower on the right side of the curve because, in high frequencies and low temperatures, mixture B2 has higher strain than B1 so it has lower dynamic modulus values.

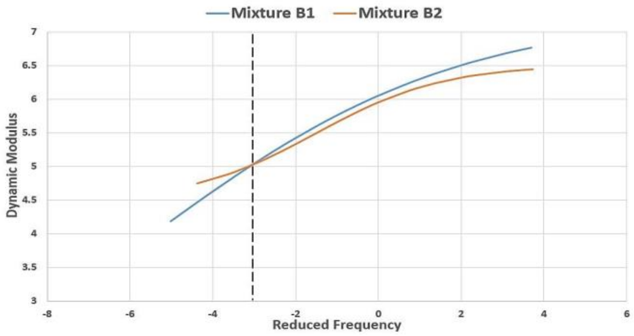

Figure 17: Dynamic Modulus Master Curves of Binder Course Samples

As previously noted, B2 is found to have higher stability (1150 Kg) than B1 (1090 Kg).

Surface Layer: the comparison between surface layer samples is done using dynamic modulus to determine which mix is better in terms of rutting and fatigue resistance. As shown in figure (18) S1 has better rutting resistance than S2 since S1 is higher on the left side of the curve because, in low frequencies and high temperatures, mixture S1 has lower strain than S2 so it has higher dynamic modulus values. Also, it has better fatigue resistance than S2 since S1 is lower on the right side of the curve because, in high frequencies and low temperatures, mixture S1 has higher strain than S2 so it has lower dynamic modulus values.

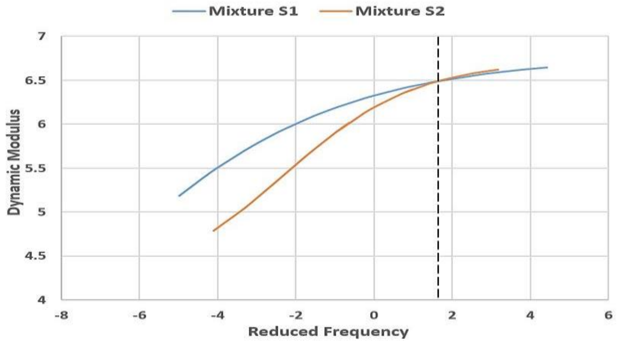

Figure 18: Dynamic Modulus Master Curves of Surface Layer Samples

As illustrated before, S1 is found to have higher stability (1284Kg) than S2 (1275 Kg).

From the previous results, it is obvious that the sample with higher stability has better dynamic modulus results therefore it has better fatigue and rutting resistance.

B. *Flow number for Marshall Mixtures*

Binder Course: the comparison between binder course samples is done using flow number to determine which mix is better in terms of rutting resistance. The FN results for the two binder course samples were as follows:

Mixture B2 has flow number (496) and mixture B1 has flow number (280). This means that the tertiary zone of B2, where the drastic shear failure of the mix occurs, appears at a higher number of cycles than B1. Therefore, Mixture B2 has higher rutting resistance than mixture B1. And as previously noted, mixture B2 has the stability of (1150 kg) and mixture B1 has the stability of (1090 kg).

*Surface Layer***:** the comparison between surface layer samples is done using flow number to determine which mix is better in terms of rutting resistance. The FN results for the two surface layer samples were as follows:

Mixture S1 has flow number (1301) and mixture S2 has flow number (1210). This means that the tertiary zone of S1, where the drastic shear failure of the mix occurs, appears at a higher number of cycles than S2. Therefore Mixture S1 has a higher rutting resistance than mixture S2. And as previously noted, mixture S1 has a stability of (1284 kg) and mixture S2 has a stability of (1275 kg).

From the previous results, it is obvious that the sample with higher stability has a higher flow number which indicates that it has better rutting resistance.

C. *Stability and Flow for Superpave Mixture*

The Superpave sample (B_{New}) and the Marshall sample (B2) were compared using their stability and flow results to determine which mix design method produces a better mixture in terms of rutting and fatigue resistance. Sample (B_{New}) has stability = 1281 kg and flow = 4.112 mm. Sample (B2) has stability = 1150 kg and flow of sample (B2) = 2.71 mm. From the previous data, it is clear that the sample designed using the Superpave method (B_{New}) has a higher stability than the one designed using the Marshall Mix design method (B2). This means that (B_{New}) indicates a better rutting and fatigue resistance than (B2) although they share the same aggregate gradation.

V. ALTERNATIVE METHODOLOGY

A. *Overview*

In this chapter, the effect of mix factors on the results was studied in order to achieve better results. The factor investigated in this study was the aggregate gradation. An alternative design methodology was developed by applying the Superpave's control points and restricted zone on the gradation used in the Marshall Mix design method. In the following sections, the effect of the gradation will be discussed in both the binder course and surface layer.

B. *Binder Course*

Superpave control points and restricted zone were applied to the previous binder course samples in this study. For example, the gradation of the sample (B1) met the Superpave specifications easily as shown in figure (19). Moreover, previous researches have proven that 3D Binder gradation usually used in the Marshall Mix design method fits easily into the Superpave control points therefore there is no need to change the gradation when designing the Binder Course.

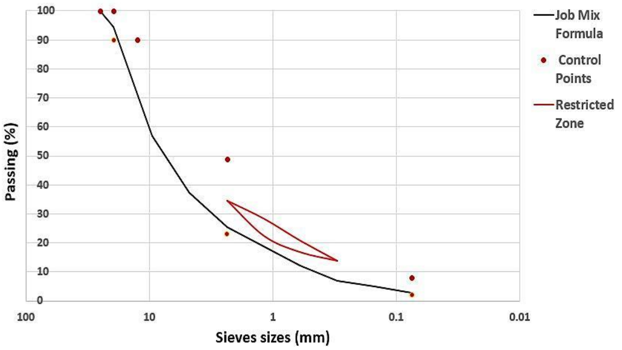

Figure 19: Superpave Limits Check for Sample (B1)

C. *Surface Layer*

As for the surface layer, it was found that the limits of the 4B gradation, which is used in in this study and usually used in the Marshall Mix design method, do not meet the control points and restricted zone of the Superpave method. Therefore, a modified gradation was used as shown in table (16) [3].

TABLE 16
MODIFIED 4B GRADATION

Sieve Size	Modified 4B Gradation	
	Min	Max
1''	100	100
3/4''	100	100
1/2''	80	87
3/8''	70	80
No. 4	50	65
No. 8	30	46
No. 16	20	39
No. 30	15	30
No. 50	13	22
No. 100	8	17
No. 200	3	6

Then a new aggregate gradation was designed for sample (S_{New}) in accordance with the modified gradation limits as shown in figure (20).

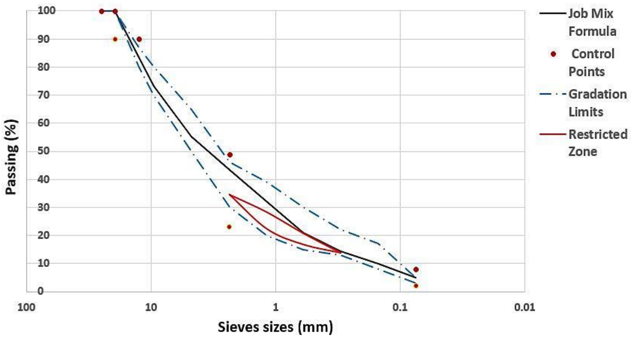

Figure 20: Superpave Limits Check for Sample (S_{New})

Then the mixture was designed using the Marshall Mix design method following the same steps mentioned before to produce a sample designated as (S_{New}). The OAC was found to be 5.4% for mix (S_{New}). Then the mixture volumetric properties are checked with the specification's limits in accordance with the Egyptian specifications as shown in table (17)

TABLE 17
VOLUMETRIC PROPERTIES OF MIXTURE (S_{New})

Mix Property	**Value**	**Specifications**		**State**
		Min	**Max**	
Optimum Asphalt Content	5.4%	-		
Unit Weight (gm/cm3)	2.349	-		
Theoretical Maximum Density (gm/cm3)	2.446	-		
Air Voids (%)	4	3	5	Passed
Stability (kg)	1314	1200		Passed
Flow (mm)	2.96	2	4	Passed
Voids in Mineral Aggregate (%)	15.35	15		Passed
Voids Filled with Asphalt (%)	73.6	60	75	Passed

From the previous results, the stability of S_{New} (1314 kg) is found to be higher than the previous samples although they are made from the same materials. This increase in stability can be attributed to the new aggregate structure and gradation which are designed to meet the Superpave's control points and restricted zone. And as mentioned before, the higher stability gives an indication of better dynamic modulus and flow number results. This also gives an indication of better rutting and fatigue resistances.

VI. CONCLUSION, RECOMMENDATION & FUTURE RESEARCH

A. *Conclusion*

In the end, as a conclusion to what was discussed in the previous chapters. When trying to prepare the samples for this study, it was found that although the Superpave method takes into consideration many factors that simulate the natural conditions besides the traffic loading which results in better rutting and fatigue resistance. But it has huge limitations in Egypt as it is not yet very popular in Egypt. This resulted in a sort of unavailability of the machines required in this particular mix design method, therefore, making the production process very expensive. Moreover, the technicians in Egypt are not so acquainted with the Superpave method which makes them consume more time than usual to prepare just one sample. On the other hand, the Marshall Mix design method is much cheaper and commonly used in Egypt which makes it easier for the contractors to use it in their projects despite having other limitations such as not taking the climatic conditions into consideration. It was proven in this study that the Superpave method produces a mixture that has higher stability than that designed using Marshall Method which means higher rutting and fatigue resistance. Moreover, the aforementioned Superpave limitations extend to its performance tests. Making it difficult and costly to use tests such as Dynamic Modulus and Flow Number when comparing two or more mixtures. That's why this study tries to find a relation between the results from Dynamic Modulus and Flow Number tests with the results from Marshall Stability which is well known in Egypt. The results show that stability results are directly proportional with both Dynamic Modulus and Flow Number results. This means that higher stability gives an indication of better rutting and fatigue resistance. But it must be taken into consideration that the Superpave performance tests simulate the actual traffic loading applied on the pavement in the field thus giving more accurate results. Also, this relation is considered empirical and a numerical relation couldn't be determined as the dynamic modulus has several values at each temperature-frequency combination obtained from performing the test. Also, the flow number value is obtained from the test only.

Finally, the effect of the aggregate gradation requirements used in the Superpave method on the results was studied by applying these requirements to the Marshall Mix design method. It was found that this new gradation system helped increase the stability of the mix while keeping the stiffness between the limits of the specifications, thus, improving rutting and fatigue resistance of the mixture.

B. *Recommendation*

After what has been discussed in this study, it is recommended to apply the Superpave control points and restricted zone on the aggregate gradation when designing a surface layer using Marshall Mix design method as it will result in better stability, thus, better fatigue and rutting resistance. On the other hand, this recommendation can be put aside while designing a binder course using the Marshall Mix design method as it fits easily between the control points and doesn't pass through the restricted zone.

C. *Future Research*

To complement the work of this study, additional research can be conducted to determine an equation that relates the Marshall Stability results with the results of the Dynamic Modulus and Flow Number tests numerically. Also, further research can be performed to determine the effects of the mix factors other than aggregate gradation on Marshall Stability. Moreover, further studies can be done to determine a way that can make the Egyptian asphalt pass the moisture sensitivity.

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Title Arabic:

دراسة مقارنة لخصائص الخليط الأسفلتي المصمم بطريقتي مارشال وسوبربيف

Arabic Abstract:

طريقة تصميم سوبربيف تأخذ في اعتبارها العديد من العوامل التى تحاكي الظروف الطبيعية بجانب الأحمال المرورية تؤدي إلى مقاومة أفضل للتخدد والشروخ الناتجة عن الإجهاد. ولكن هناك قيود كثيرة على محاولة تطبيقها في مصر متمثله في التكلفة المرتفعة واحتياجها لوقت اطول وعدم توافر أجهزتها. لذلك إن موضوع هذه الدراسة هو إيجاد علاقة بين طريقة تصميم مارشال وطريقة تصميم سوبربيف من أجل تحسين الخلطات من حيث مقاومة التخدد والشروخ الناتجة عن الإجهاد. تم تصميم عينتين رابطة و عينتين سطحية بإستخدام طريقة تصميم مارشال. ثم تم إعداد و دمك العينات بجهاز الدك الدوراني، تم تطبيق اختبار المعامل الديناميكي واختبار رقم التدفق على العينات و تحليل نتائج كل اختبار لتحديد العلاقه بين اختبارات الأداء المتخلفه . تم إستنتاج أنه يوجد علاقة طردية بين نتائج اختبار الثبات و نتائج اختبارات المعامل الديناميكي و رقم التدفق. وذلك ينعكس إيجابياً على مقاومة التخدد والشروخ الناتجة عن الإجهاد. ايضاً تم تصميم عينة بطريقة تصميم سوبربيف ومقارنه خصائصها مع العينه الاخري التي صممت بطريقه مارشال.وقد وجد أن العينه التي صممت بطريقه سوبر بيف لها نتائج ثبات أعلي من العينه التى صممت بطريقه مارشال رغم إستخدام نفس المواد .أخيرًا تمت دراسة تأثير تطبيق حدود تدرج الركام بطريقة سوبربيف المتمثلة في نقاط التحكم والمنطقة المحظورة على خصائص الخليط المصمم بإستخدام طريقة مارشال. تم إستنتاج أن تطبيق هذه الحدود مع طريقة مارشال يحسن خصائص الخلطات الأسفلتية.