Selecting the Optimum Graphical Method to Find Aggregate Blend Proportions in the Production of HMA

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Abstract

The proportions of aggregate directly affect the performance of HMA depending on their shape, texture, and strongly on the gradation.The determination of aggregate proportions depends strongly on the number of aggregate typesto be blended, and the limits of the desired gradation.

In this research, ten samples had been taken from different text books and papers. Each one contains three types of aggregates; coarse, fine, and filler. The samples were solved individually by seven different methods; five of them by graphical method, the sixth method was solved by running MATLAB, and the last method by using Excel sheet. In this research, five graphical methods were applied, and the aim of using them is to find graphically the tentative blending values and then compare their results individually with optimum values which was found from Excel spreadsheet, and finally selecting the optimum method. For this purpose, more than 210 readings were utilized.

SPSS program was run two times. In the first run, the values of person correlation (r) of method Balanced-Areas (Rothfuchs), Walace, Equal Distance, Triangular, and Asphalt Institute when correlated with optimum values were 0.973, 0.964, 0.958, 0.953, and 0.869, respectively. In second SPSS run, the values of samples No.4 and No.10 were removed because they gave zeros readings, the person correlation of Triangular, Balanced-Area, Walace, Equal Distance, and Asphalt Institute methods were 0.972, 0.970, 0.959, 0.952, and 0.869, respectively.

In this research, It has been found that the Equal Distances method would be considered as an accurate, fast, and even easy method, and can be used for any number of aggregate.

Keywords: Graphical methods, aggregate, blending, gradation, proportions, HMA.

أختيار طريقة الرسم البياني المثلى لايجاد نسب خلط الركام في انتاج المزيج الاسفلتي الساخن

الخلاصة

خصائص الركام تؤثر بشكل مباشر على أداء HMA اعتمادا على شكلها، والملمس، وبقوة على نوع التدرج المطلوب. ان تحديد نسب خلط الركام يعتمد بشدة على عدد انواع الركام المشترك لتكوين الخليط، وحدود تدرج المواصفات المطلوبة.

في هذا البحث، تم استخدام عشرة عينات من خلطات ذات تدرج معلوم اخذت من كتب وبحوث مختلفة. كل واحد منها يحتوي على ثلاثة أنواع من الركام. الخشنة، الناعمة، والفلر. تم حل العينات بشكل فردي عن

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طريق سبع طرق مختلفة؛ خمس منها باستخدام الأساليب البيانية،والطريقة السادسة عن طريق تطبيق برناج MATLAB، والأسلوب الأخير باستخدام برنامج الاكسل.
في هذا البحث، استخدمت خمس طرق من طرق الرسم البياني والهدف منها هو العثور بيانيا على قيم مزج مؤقتة ومن ثم مقارنتها بشكل فردي مع القيم المثلى التي وجدت من بيانات لبرنامج إكسل، وأخيرا اختيار الطريقة الأمثل. لهذا الغرض تم استخدم أكثر من 210 قراءات.
تم تشغيل برنامج SPSS مرتين. في المرة الأولى، كانت قيم ارتباط بيرسون (r) لطريقة المساحات المتساوية (روفيوجس)، والاس، المسافات المتساوية، المثلث، ومعهد الأسفلت عندما يتم مقارنتها مع القيم المثلى هي 0.973، 0.964، 0.958، 0.953، 0.869 على التوالي. و في المرة الثانية لاستخدام SPSS، أزيلت قيم عينات رقم 4 و 10 بالكامل لأنها أعطت قيم أصفارا لبعض القراءات لطريقتين، كانت قيم ارتباط بيرسون (r) عند مقارنتها مع القيم المثلى لطريقة المثلث، المساحات المتساوية ، والاس، المسافات المتساوية، وأساليب معهد الأسفلت كانت 0.972، 0.970، 0.959، 0.952 و0.869 على التوالي.
في هذا البحث تبين ان طريقة المسافات المتساوية دقيقة وسهلة وسريعة، ويمكن استخدامها لأي عدد من المجاميع.

INTRODUCTION

Hot Mix Asphalt (HMA) is a mixture of aggregates of various sizes and asphalt. The performance of HMA is highly influenced by the properties and proportions of these components, but the aggregate which contributes more than 90% of HMA total weight is the cornerstone.

Aggregates in HMA can be divided into three types according to their size: coarse aggregates (retained on sieve 4.75 mm), fine aggregates (passing sieve 4.75 mm retained on sieve 0.075 mm), and filler (passing sieve 0.075 mm) [1].

Depending on the type of HMA specification and layer purposes, the kind of aggregate gradations (particle size distributions) can be described: as dense-graded (maximum density gradation), gap-graded, uniformly-graded, or open-graded [2, 3]. The dense-graded can be directly found either from application of fuller or by Federal Highway Administration (FHWA), equations [1]:

$$\%\,(PMD)_i = \left(\frac{d_i}{D}\right)^n \times 100 \qquad \ldots(1)$$

Where

$\%\,(PMD)_i$ is the percentage passing maximum design gradation for sieve (i), d_i is the sieve size (mm), D is the maximum sieve size(mm), and n is equal to 0.45 for FHWA equation, n=0.5 for fuller equation.

The properties of the aggregate directly affect the performance of the HMA depending on the aggregates' shape, texture, and particularly the type of gradation of the aggregate. The latter property is responsible for controlling the volumetric properties of HMA. Recent research and studies have concentrated on studying the influence of aggregate gradation, and the gradation's effect on the performance of an HMA mixture.

David Hernando (2012) explained that the aggregate gradation is the key factor which affects the volumetric properties and performance of asphalt concrete. Furthermore, he stated that the effect of gradation on rutting and cracking has been extensively studied. In brief, he concludes that the coarse-graded mixtures seem to provide slightly inferior rutting resistance,whereas the fine-graded mixtures show better fatigue performances [3].

Randolph C. (1996) described that the performance of HMA mixtures is greatly affected by the aggregate gradation as it controls the void structure matrix. He also concluded that the asphalt-aggregate mixtures that produced better permanent deformation characteristics were with an aggregate gradation finer than the maximum density line of the Federal Aviation Administration (FAA) gradation band [4].

Jaime Reyes etal. (2008) found that a proper HMA mix is needed to ensure adequate durability, structural capacity and performance (after optimizing the gradation). Additionally, he stated that the gradation of HMA influences almost all important properties including stiffness, stability, durability, permeability, workability, fatigue resistance, frictional resistance, and resistance to moisture damage [2].

Hasan H. J. (2010)explained that the aggregates are the basic structure of the asphalt concrete which gives its homogenous solid state, controls the volumetric properties and the most effective for the asphalt concrete performance. The aggregate gradation has different engineering effects because it is the basis for the design of asphalt mixtures which is determine the quality of the road, the size and nature of the loads to be carried and the type of the pavement layer[5].

Qais S.(2010)in his conclusion found that the use of Iraqi surface aggregate gradation type II gives a higher resistance to reflection cracking, compared with gradation I (typeII being finer than I) [6].

Mohammed Aziz and Nahla Y. (2014) found that mixes prepared from aggregate gradation above the restricted zone had shown more permanent deformation resistance and gave high tensile strength than mixes of passing through and under restricted zone [7].

Due to the importance of gradation, another methods were created and used to find it like, Superpave (2001) dealing with Restricted zone& control points [8] , Bailey method(2002) [9] ,Dominant Aggregate Size Range-Interstitial Component (DASAR-IC 2012) model[3], and others.

Accordingly, in order to find the gradation which gives the desired properties of HMA, it is necessary to understand aggregate blending. The blending of aggregates is a process in which two, three, or more of aggregates, which have different types of sources and sizes, are mixed together to give a blend with a specified gradation.

The blending of aggregates is done because:

1- There are no individual sources, sizes, and types of aggregates (natural or artificial) that individually can supply aggregate of gradation to meet a specific or desired gradation.

2- It is more economical to use some natural sands or rounded aggregates in addition to crushed or manufactured aggregates, and this process (mixing natural and crushed) cannot be held without using a blending operation.

There are different methods and techniques which can be employed to find percentage values. None of these should give a blend outside the specified grading. Obviously, there may be several acceptable combinations. An optimal combination is achieved when the blended or composite percentages match the original desired percentages [10].

The determination of aggregate proportions depend strongly on; firstly, the number of aggregate types to be blended; if the number increased, then the determination becomes more complex. Secondly, the range and limits of the target gradation specification.

Regardless of which method will be used, there are two important pieces of information that must be known before finding the proportion values. These are the sieve analysis of each material, and the limits of desired specification. Following are the commonly used methods which are used to find blending values:

a- Trial-and-error method: Is the most common method of determining the proportions of aggregate which meets specification requirements [11]. The designer, who has plenty of experience, can estimate the percentage value of each aggregate contributes in the blend. He also can predict the first approximation value by interpreting the sieve analysis of each type and desired gradation. By repeating the trial process several times, the contribution of each one can be estimated.

b- Mathematical method: depending on the basic formula of this method which is true for any number of aggregates combined; [12]

$$P = A \cdot a + B \cdot b + C \cdot c + \cdots \quad - \qquad \text{…. (2)}$$

$$\mathrm{a} + \mathrm{b} + \mathrm{c} + \cdots = 1 \qquad \text{….(3)}$$

Where

P is the percentage of material passing through a given sieve for the combined aggregates A, B, C.

A, B, and C are the percentages of material passing a given sieve for aggregates A, B, C, respectively.

a, b, and c are the proportions of aggregate A, B, and C used in the combination.

The Asphalt Institute designed SW-2 Mix Design Program, which is a computer program that can be used to visually evaluate the gradation plot of numerous blends very rapidly [10].

c- Methods which involve optimization techniques: different methods are encompassed by this technique such as the least square method, linear and nonlinear programming, simulated annealing techniques and genetic algorithm [13]. Kahaled and Al-Sobky (2013) conducted a new method which used a fuzzy triangle membership function to develop a linear program model. The output of the developed model appears to be that the program is able to effectively determine the optimum aggregate blending for HMA [14].

d- Graphical methods: These techniques have been devised for determining combinations of aggregates to obtain a desired gradation. They are applied for early stage of asphalt construction and are still popular among engineers due to their simplicity and rapidity of use [13]. In these methods, only graph paper and simple engineering drawing tools are needed. However, as the number of aggregates to be combined is increased, the graphical method becomes increasingly complicated. [15].

Research objectives

The aims of this research are to:

1- Study in detail the different graphical methods which can be utilized to find aggregate blend percentages, leading to a greater knowledge of their utility for designers and engineers.

2- Compare the results and values of these methods with the optimum blending values which are obtained from Excel spreadsheets.

3- Evaluate the results of the graphical methods in order to conclude the best one regarding the time efficiency, simplicity, and the designer skill.

Significance of the study

The significance of the work is demonstrating the simplicity, and applicability, of graphical methods in finding blend percentages which can be applied to produce blending of HMA, Portland Cement Concrete (PCC), granular materials, subbase, soil, and others.

Experimental Program

Samples' Features

Ten samples were taken from different text books and papers. Each of them contains three types of aggregates (A= coarse, B= fine, and C= filler). The general characteristics of these samples were determined as follows:

- Gradation and specification limits were tabulated in their sources (text book or paper).
- The proportion values, which represent the contribution of each type of aggregate (i.e. values of a, b, and c) in the total mix, had been given in the source of the sample. Therefore, it had a special name in solving process as source values.

Sample One data, shown in Table (1), will be used as an example in description of the application to all methods.

Table (1): General gradation and data of sample one [11]

Sieve Size mm [inches.]	% Passing				
	A	B	C	Mid. Point	Specification
19 [3/4]	100	100	100	100	100
12.5 [1/2]	63	100	100	78	70 - 85
4.75 [No.4]	19	100	100	48	40 - 55
2.38 [No.8]	8	93	100	36	30 - 42
0.3 [No.50]	5	55	100	25	20 - 30
0.15 [No.100]	3	36	97	17	12 - 22
0.075 [No.200]	0	3	88	8	5 - 11
Source Values	a=0.66	b=0.28	c= 0.06		

Aggregate	(+ No.8)	(-No.8 to+No.200)	(-No.200)
A	92	8	0
B	7	90	3
C	0	12	88
Specification	58 – 70*	----------	5 – 11**

Notes: *Values of% retained onsieve No.8 in Table(1)of specification limits
** Values of% passing sieve No.200 in Table(1)of specification limits

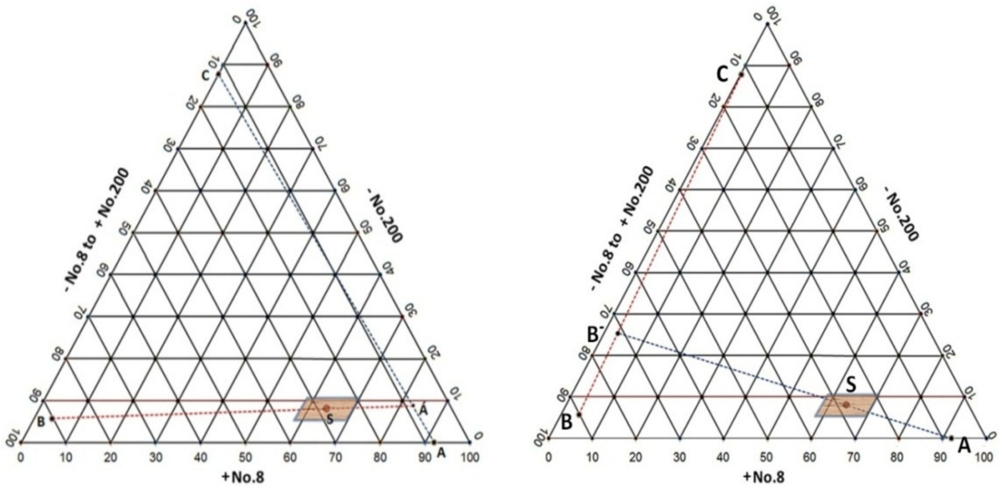
Methods of application

In order to find blending values, each sample of the ten was solved individually by seven different methods; five of them graphical methods, one method was by running a MATLAB program that was written in this research for this purpose, and the final method was by using an Excel sheet program to find the optimum values of combined materials.

Graphical methods

The aim of these methods is to find the tentative blending valuesgraphically, and then adjust them by using a trial and error method to approach the optimum values. The general description of each graphical method can be summarized as below:

1) Triangular-chart method (1960). This method is applied on an equilateral triangle, each side of which is divided from 0 to 100 with a constant increment of 10. The gradation of aggregates A, B, and C , are separated into three parts. The first part contains the aggregate retained on the sieve 2.38mm (+No.8), the second that passing sieve 2.38mm (No.8) and retained on sieve 0.075mm (No.200), and the third part which passed sieve 0.075mm(- No.200). In addition to these, the specification limits must be separated in the same manner. All these parts, which are shown at the bottom of Table (1), projected onto the named sides of triangle. Figure (1), representing aggregates of sample one, shows a graph of the application of this method in two directions (three directions can be applied in this method). More explanations can be seen in References [15, 16].



First Direction **Second Direction**

Figure (1): Application of two directions in Triangular method on sample one[15&16]

2) Balanced- area method, by Rothfuchs (1939). This method is well known and well described in references [16&17]. From Figure (2), the following points describe the main procedure of it :

1- Draw a diagonal from origin of coordinates to upper right corner of the diagram (from point I to point III)

2- From the midpoint of specification limits, determine the percentage passing each sieve size (for sieve 12.5mm is 78%, for sieve 4.74mm is 48% and so on for remaing sieves).and fix them on y-axis

3- Draw a horizontal line from the point (determined in step2) to the diagonal and down to the x-axis. Place the corresponding sieve size number on the x-axis at this location. Repeat this for all sieve sizes in step 2. A relative scale is now placed on the x-axis.

4- Draw the sieve size distribution for all aggregate fractions into diagram.

5- For each aggregate fraction, draw and select a line which gives equal areas above and below it like line **fd** for aggregate A. Repeat for aggregate B (line **hg**) and C (line **rm**). Each line contain two points, one of them represents 100% like point **f** for line **fd** and the second point **d** represents 0% and same for other lines.

6- For two lines **fd** and **hg**, connect the 0% point of line **fd** with the 100% point of line **hg.** The new line **fh** cross the diagonal line **I II** in point **n**. Repeat similar procedure for others leading to give points **n** and **o**.

7- From point **n** and **o**, aggregate A contributes by 0.63, B by 0.30, and aggregate C by 0.07.

This method depends on selected lines, with minimum balanced areas around each one. For example there are two areas around the dotted line (df). The first area, which is enclosed between the points (e, d, III, p, e) must be equal to that, above the line, which is enclosed between the points (e, q, g, f, e). In this research, some difficulties appeared during plotting and computing the areas around the line, therefore (and for more accuracy) the AutoCAD program was applied to compute these areas and so on for other areas of lines of other samples. Figure (2) shows the final graph of sample one aggregates.

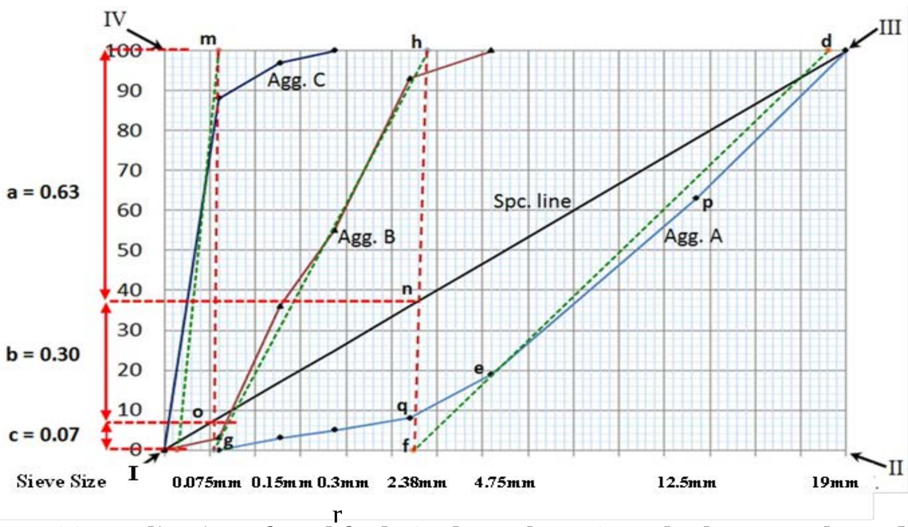


Figure (2) Application of Rothfuchs(Balanced-area) method on sample one[17]

3) Equal distances & spaces method. This method was applied by the Ministry of Works, United Republic of Tanzania(2000) [18]. The principle of this method (as in Rothfuch's method) is in finding the locations of sieves by projecting the midpoint values of specification from line (I IV), in Figure (3), to the diagonal line (I III), and then the final projection of their on line (I II). After locating the sieve positions, the gradation of each type of aggregate was plotted as in the Figure. Then, a line was chosenwith equal distances between the lines of aggregates A and B. The equal distances line like (gfed), which gave the distance (fg) equal to distance(ed), would be dependent. After choosing lines is completed, like lines (gfed) and (nmkj) in which they cross the diagonal line in points. From the points of confliction, the blending values are estimated. Figure (3) exhibits sample one gradation solved by this method.

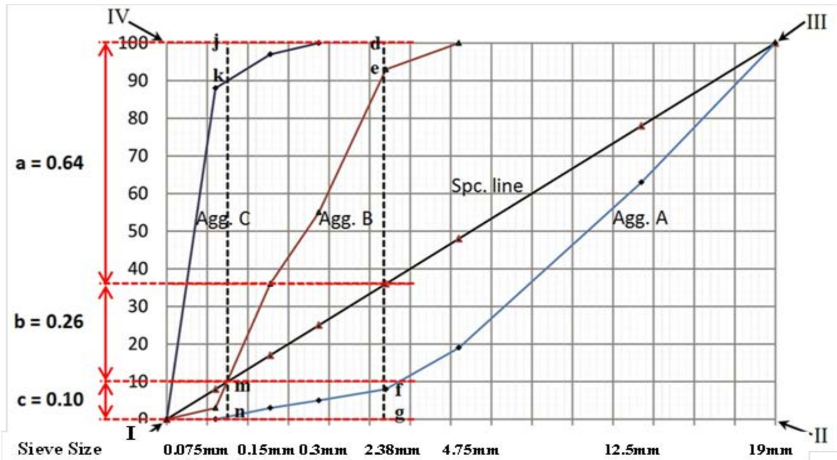


Figure (3)Application of Equal distance and spaces method on sample one gradation[18]

4) Asphalt Institute method (1984). This method is the most popular and widely used in text books because it was created and used by the American Asphalt Institute [15]. The method can be efficiently applied for two types of aggregates needed to be blended. However, it seems to be more complicated when three aggregates need to be mixed together. The following points, listed in reference[15], are used to describe the procedure of this method,for Figure (4**I**):

1. The percents passing the various sizes for aggregate A are plotted on the right-hand vertical scale (representing 100 percent aggregate A).
2. The percents passing the various sizes for aggregate B are plotted on the left-hand vertical scale (representing 100 percent aggregate B).
3. Connect the points common to the same size with straight lines, and label.
4. For a particular size, indicate on the straight line where the line crosses the specification limits measured on the vertical scale. (Note that for the12.5mm size, two points are plotted on the line at 70 and 85 percent on the vertical scale).
5. That portion of the line between the two points represents the proportions of aggregate A and B measured on the horizontal scale will not exceed specification limits for that particular size.
6. The portion of the horizontal scale designated by two vertical lines, when projected vertically, is within specification limits for all sizes and represents the limits of proportions possible for satisfactory blends. In this case, 58 to 70 percent of aggregate A and 30 to 42 percent of aggregate B will meet specification when blended.
7. For blending, usually the midpoint of that horizontal scale is selected for the blend representing by line **fk**. In this case, 64and 36 percentages of each of A and B aggregates, respectively.
8. The line **fk** crosses the sieve lines, which has beenfoundearlier in step 3 above, in many points. These points give new blend mixedfrom two aggregate(Aand B) with proportion values(a=0.64 and b=0.36) when used resulting a blendgradation meets the specification limits.
9. All these points projected on the vertical left-side of Figure (4 **II**) representing the locations of sieves of the aggregates A and B mixed together . For

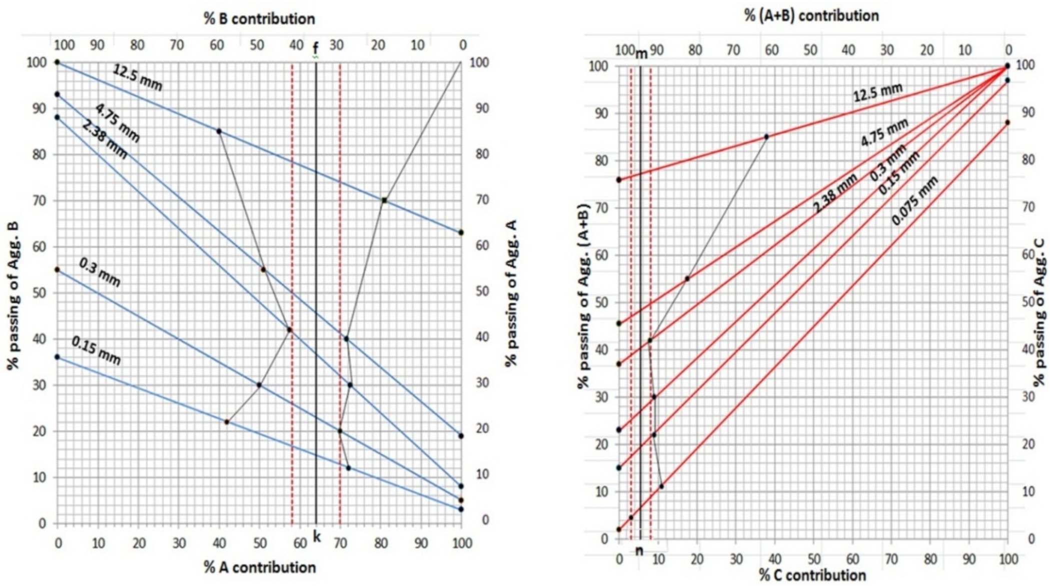
example, for sieve 12.5mm the value is 76, and for sieve 4.75mm is 45.5 and so on for other sieves.

10. The percents passing the various sizes for aggregate C are plotted on the verticalright-side of theFigure(4**II**) vertical scale (representing 100 percent aggregate C).

11. Byrepeateing same procedure from 1 to 8 on the of Figure(4**II**) to find the midpoint of the horizontal scale line which is the line**mn** from which the aggregate C contributes by 6% and aggregates A and B by 94%.

12. The final contribution of aggregates A and B,can be found by multiplying 94% by the values which found in step 7 (for A=64% and for B=36%) resulting that contribution of aggregate A whichis 64* 0.94=0.6 and for aggregate B is 36*0.94=0.34 , so the final values are; a=0.6, b=0.34, and c=0.06.

For more explinationssee References [15, 19, and 20]. Figure (4) shows aggregates of sample one and how they are mixed.



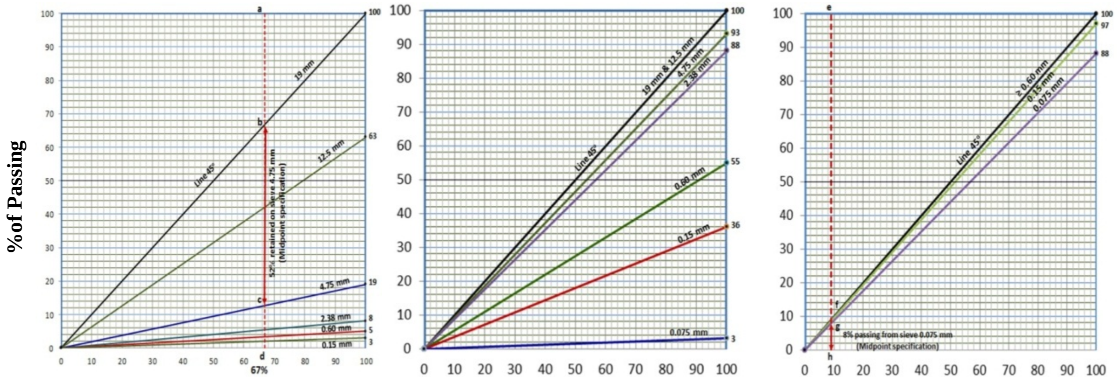
I **II**

Figure (4) Application of Asphalt Institute method on sample one aggregate gradation[15]

5) Wallace method: This method is well explained in Reference [21]. The main ideas of this method are:

a. Plotting each type of aggregate in a single drawing, so for three aggregate types, three drawings are needed. A line of 45^o representing the maximum size of each gradation (100%passing) mustbe drawn first, and then the remaining drawings should be plotted below it.

b. Interpretation of specifications and aggregate gradation of each sample is needed, and therefore understanding the percentage passing and retaining on a single sieve may accelerate the estimation of contribution values. Figure (5) explains this method for finding percentages of contribution of each aggregate type.



Aggregate A **Aggregate B** **Aggregate C**

Figure (5) Application of Wallace method on aggregate gradation of sample one[21]

MATLAB Application.

MATLAB is an integrated programming system, including graphical interfaces and a large number of specialized toolboxes used by engineers and scientists [22]. The program was applied in this research to find the blending values by using the data, representing values of sample one, listed in Table (2). The basic formulas applied to execute here in MATLAB program are shown in Equations 4, 5, and 6.

$X_i .a + Y_i .b + Z_i .c = Q_i$ …**(4)**

$$\begin{bmatrix} x1 & y1 & z1 \\ x2 & y2 & z2 \\ x3 & y3 & z3 \end{bmatrix} * \begin{Bmatrix} a \\ b \\ c \end{Bmatrix} = \begin{Bmatrix} Q1 \\ Q2 \\ Q3 \end{Bmatrix} \quad \ldots \textbf{(5)}$$

$$\begin{Bmatrix} a \\ b \\ c \end{Bmatrix} = \begin{bmatrix} x1 & y1 & z1 \\ x2 & y2 & z2 \\ x3 & y3 & z3 \end{bmatrix}^{-1} * \begin{Bmatrix} Q1 \\ Q2 \\ Q3 \end{Bmatrix} \quad \ldots \textbf{(6)}$$

Where

X_i = the percentages of materials retained on sieve 2.38mm (No.8) of aggregates A, B, and C respectively.

Y_i are the percentages of materials passing sieve 2.38mm (No.8) retained on sieve 0.075mm (No.200) of aggregates A, B, and C respectively.

Z_i are the percentages of materials passing sieve 0.075mm (No.200) of aggregates A, B, and C respectively.

Q_1 is the percentages of midpoint specification of materials retained on sieve 2.38mm (No.8).

Q_2 is the percentages of midpoint specification of materials passing sieve 2.38mm(No.8) retained on sieve 0.075mm (No.200).

Q_3 is the percentages of midpoint specification of materials passing sieve 0.075mm (No.200).

Table (2) Sample one values used to execute MATLAB program

Aggregate	%Retained on Sieve No.8	%Passing Sieve No.8 Retained on Sieve No.200	%Passing SieveNo.200
A	92	8	0
B	7	90	3
C	0	12	88
Midpoint of Specification	64	28	8

Excel sheet program

Excel sheet program was used for solving the ten samples to find the optimum values of proportions of blended aggregates. The found values (a, b, and c) give results in which the handled blends are acceptable and very close to the midpoints of specification values.

Methods, Results and Analysis

In this research, the data of ten samples were used and solved by seven methods to find the values of contribution of each aggregate type, which are a, b, and c . The total reading numbers were of more than 210 readings. They were found from five graphical methods and running MATLAB and Excel spreadsheet programs. Each individual application of the graphical methods gave 30 readings except Triangular method which gave 90 readings due to the ability of applying this method in three directions (each direction gives 30 readings).The readings were used to find the blending values and then the average of these was dependent.

The Excel spreadsheet gave optimum blending values of 30 readings for a, b, and c for each sample. The remaining thirty readings were found from MATLAB program. From all of the above methods the gained final results are listed in Table (3). All of the readings from the graphical and MATLAB methods were compared with optimum values.

Figure (6) shows a scatter diagram representing the relationship between Triangular and optimum values. From this figure the R^2 value, which is a statistical measure of how close the data is to the fitted regression line, is 0.9076, which indicates a good relationship between the two variables. The Triangle method is good and accurate but it was limited to using only two or three aggregate types to be blended. If the number of aggregates combined was more than three, then the method cannot be applied.

Figure (7) gives the best results because the value of R-squared was 0.946. This value indicates that the relationship between optimum and Equal Areas method values are close to each other. The Balanced-Areas(Rothfuchs) method, as shown from the value of the coefficient of determination (R^2), is a good method and can be applied for any number of aggregates to be blended. In this method, some difficulties appeared during computing the areas around the balanced line; therefore the AutoCAD program was used to find these areas instead of computing manually. AutoCAD was used to compute all of the balanced areas of all samples.

Figure (8) shows a scatter diagram that the Equal Distances method values are close to optimum values, and also gives a high coefficient of determination of 0.9174. This is the best method because it gives good results and is simple in application.Furthermore it does not need high skill for the designer and does not require a long time to complete it the analysis.,Finally, this method is applicable to any number of aggregates to be blended.

Figure (9) is a scatter diagram of Asphalt Institute and optimum values. The value of coefficient of determination of this scatter diagramis 0.7545 which indicates an acceptable relation, but when comparing with other R^2 values, this low value is an indication of some of the difficulties in applying this method.

The main difficulties clarified when two samples, sample No.4 & No.10 shown in Table (3), did not give any results, so the comparison was done by using the results of eight samples instead of ten.Furthermore the values obtained fromthe Asphalt Institute method are sometimes far away from optimum values,such as in the results of sample No.6. In this instancethe Asphalt Institute method gives a=0.29, b=0.56, and c=0.15, while the optimum values are a=0.43, b=0.27, and c=0.30. In general the Asphalt Institute method is useful and gives good results only when two types of aggregates are to be combined, but manifests difficulties when the number of aggregatesis three or more.

Figure (10) displays the results of Wallace and optimum results. The linear regression model of this scatter diagram gives a value of R-squared of 0.929 which is better than the other graphical methods except for the Equal Areas method. The Wallace method, sometimes, seems difficult becausethree graphs must be done for the three aggregate types and more if more types are used. The sieve analysis gradation of each aggregate must also be interpreted very well to ease the operation of finding values, and when the number of aggregates becomes more than three, the application of this method was difficult and it became a time consuming method. Figure (11) is a scatter diagram of MATLAB and optimum result values. For this diagram the value of R-squared was 0.932, which indicates a strong relationship between the values, although there are missed readings of sample No.4. The reason for missed data was due tosome values which are put in the equation (6) having values of zero, therefore no results were found for sample 4.

Table (3) Final blending percentages of all samples after applying all methods
Note: (*) no results can be found

	Percentage values	Method type					Excel Values (Optimum)	Source Values	MATLAB Results
		Triangle	Rothfuchs	Equal distances	Asphalt institute	Wallace			
		No.1	No.2	No.3	No.4	No.5			
Sample No.1	a	0.68	0.63	0.64	0.60	0.67	0.66	0.66	0.63
	b	0.24	0.30	0.26	0.34	0.24	0.27	0.28	0.26
	c	0.08	0.07	0.1	0.06	0.09	0.07	0.06	0.11
Sample No.2	a	0.68	0.62	0.52	0.60	0.65	0.7	0.65	0.68
	b	0.19	0.23	0.28	0.36	0.25	0.21	0.3	0.24
	c	0.13	0.15	0.20	0.04	0.1	0.09	0.05	0.08
Sample No.3	a	0.52	0.48	0.48	0.50	0.49	0.52	0.5	0.51
	b	0.44	0.47	0.43	0.47	0.46	0.44	0.47	0.46
	c	0.04	0.05	0.09	0.03	0.05	0.04	0.03	0.03
Sample No.4	a	0.39	0.50	0.50	*	0.57	0.52	0.52	*
	b	0.39	0.22	0.22	*	0.19	0.23	0.23	*
	c	0.22	0.28	0.28	*	0.24	0.25	0.25	*
Sample No.5	a	0.59	0.47	0.46	0.42	0.42	0.46	0.45	0.6
	b	0.25	0.44	0.32	0.49	0.41	0.4	0.4	0.22
	C	0.16	0.09	0.22	0.09	0.17	0.14	0.15	0.18
Sample No.6	a	0.39	0.4	0.42	0.29	0.41	0.43	0.41	0.41
	b	0.32	0.36	0.25	0.56	0.28	0.27	0.28	0.31
	c	0.29	0.24	0.33	0.15	0.31	0.3	0.31	0.28
Sample No.7	a	0.56	0.53	0.54	0.48	0.65	0.55	0.55	0.56
	b	0.19	0.25	0.22	0.37	0.25	0.21	0.2	0.19
	c	0.25	0.22	0.24	0.15	0.1	0.24	0.25	0.25
Sample No.8	a	0.41	0.49	0.4	0.38	0.52	0.4	0.45	0.42
	b	0.34	0.31	0.42	0.38	0.23	0.32	0.3	0.35
	c	0.25	0.2	0.18	0.24	0.25	0.28	0.25	0.23
Sample No.9	a	0.66	0.59	0.56	0.63	0.64	0.64	0.62	0.67
	b	0.32	0.36	0.34	0.34	0.28	0.34	0.35	0.31
	c	0.02	0.05	0.1	0.03	0.08	0.02	0.03	0.02
Sample No.10	a	0.56	0.55	0.54	*	0.59	0.59	0.59	0.57
	b	0.24	0.25	0.25	*	0.21	0.21	0.21	0.23
	c	0.2	0.2	0.21	*	0.2	0.2	0.2	0.2

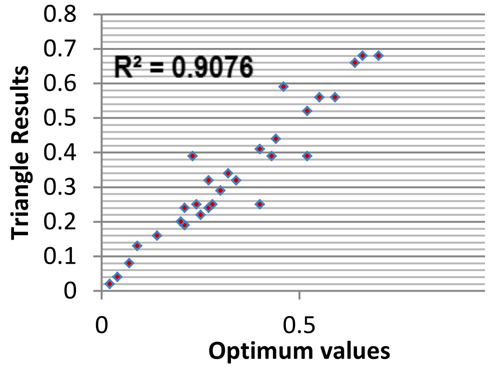


Figure (6) Relationship between Triangle and Optimum values

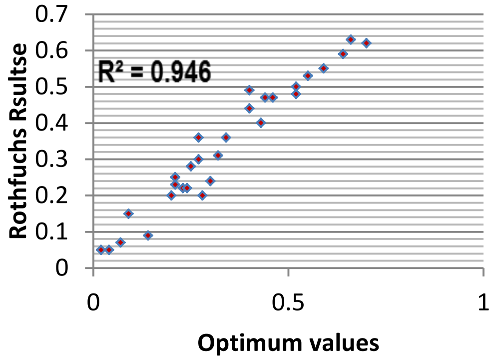


Figure (7) Relationship between Rothfuchs and Optimum Values

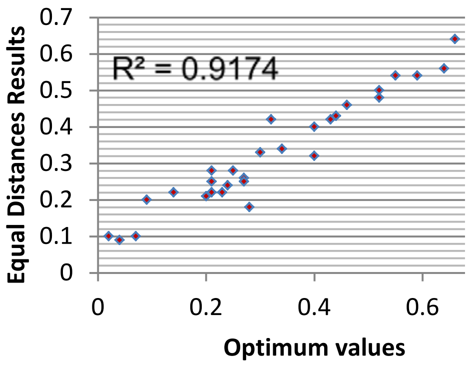


Figure (8) Relationship between Equal Distances and Optimum values

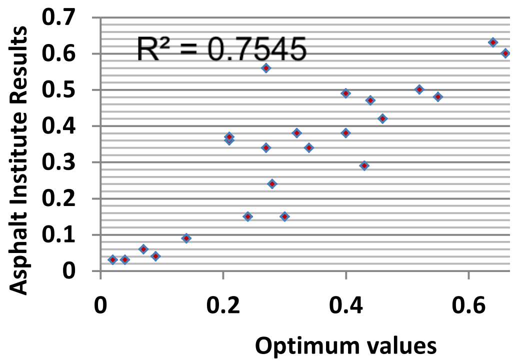


Figure (9) Relationship between Asphalt Institute and Optimum Values

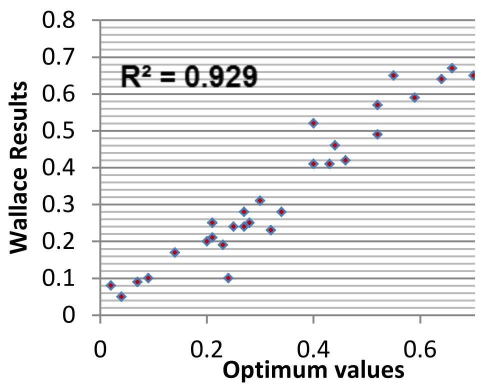


Figure (10) Relationship between Wallace and Optimum Values

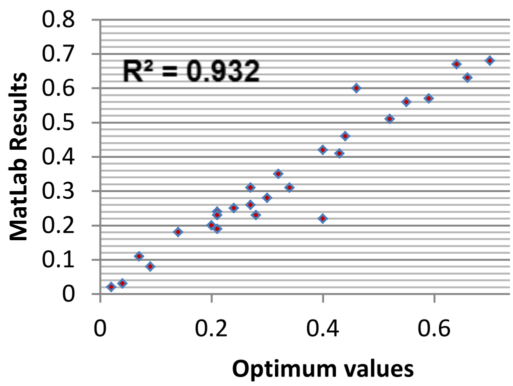


Figure (11) Relationship between MATLAB and Optimum Values

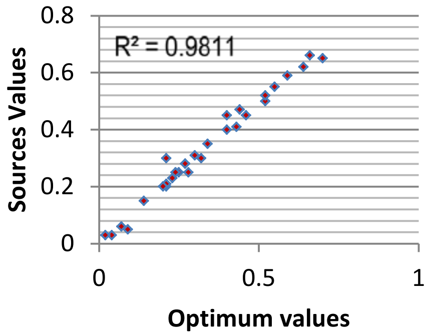


Figure (12) Relationship between Sources and Optimum Values

SPSS Results

In order to get clear comparison among the results of these methods, the SSPS program was used. In this research, the concentration on correlations would be only between the values of optimum method as controlled method and as a reference to others. The correlation matrix, which is shown in Table (4), represents the correlation among seven methods which were used to find a, b, and c.

Some samples give zero results in two methods so, in this table, the zero values were removed before running the SPSS program. .The values of person correlation (r) of the methods Rothfuchs(Balanced –areas), Wallace, Equal Distances, Triangular, and Asphalt Institute as correlated with optimum values were 0.973, 0.964, 0.958, 0.953, and 0.869 respectively. All of the values of person correlation values are strong and significant as p = 0.01 levels.

Table (4), shows the results of (r) values and their ranks, Rothfuchs as the highest followed by others while Asphalt Institute method as the lowest. In general, all graphical methods can be used to find tentative values of a, b, and c and after they have been applied, the designer uses the Trial and Error method to reach optimum values. The Rothfuchs method requires fewer iterations of the Trial and Error method than the Asphalt Institute method to approach to optimum aggregate mixing value. As such the Rothfuchs(Balanced- Areas) method is preferable to the latter.

For more accuracy among correlation of these methods Table (5) shows results of the SPSS program correlation matrix. In Table(5), all of the values of samples No.4 and No.10 were removed because they did not give any results when applying Asphalt Institute and MATLAB methods, as shown in Table(3). The later SPSS run was done to know the new rank of these methods after removing the results of these unusable samples. The coefficient of correlations of the Triangular, Rothfuchs(Balanced- Areas), Wallace, Equal Distances, and Asphalt Institute methods were 0.972, 0.970, 0.959, 0.952, and 0.869 respectively. From these, new ranks appeared with high significant as p value at 0.01 level. From the result of first one up to fourth, the(r) values did not more vary among them but still the Asphalt Institute method gave the lowest (r).In general the coefficient of correlation in the second SPSS run gave some different values than the first run. From the two tables the person correlations between the source and optimum indicates that they are closed to each other.

Table (4) Correlation matrix among different methods values with removing zeros values.

Correlations									
		Optimum values	Triangle	Rothfuchs	Equal Distances	Asphalt Institute	Wallace	MATLAB	Source Values
Optimum values	Pearson Correlation	1							
	Sig. (2-tailed)								
	N	30							
Triangle	Pearson Correlation	.953**	1						
	Sig. (2-tailed)	0							
	N	30	30						
Rothfuchs	Pearson Correlation	.973**	.927**	1					
	Sig. (2-tailed)	0	0						
	N	30	30	30					
Equal Distances	Pearson Correlation	.958**	.929**	.945**	1				
	Sig. (2-tailed)	0	0	0					
	N	30	30	30	30				
Asphalt Institute	Pearson Correlation	.869**	.836**	.916**	.812**	1			
	Sig. (2-tailed)	0	0	0	0				
	N	24	24	24	24	24			
Wallace	Pearson Correlation	.964**	.903**	.959**	.938**	.852**	1		
	Sig. (2-tailed)	0	0	0	0	0			
	N	30	30	30	30	24	30		
MATLAB	Pearson Correlation	.965**	.994**	.941**	.955**	.834**	.929**	1	
	Sig. (2-tailed)	0	0	0	0	0	0		
	N	27	27	27	27	24	27	27	
Source Values	Pearson Correlation	.991**	.940**	.975**	.960**	.883**	.969**	.961**	1
	Sig. (2-tailed)	0	0	0	0	0	0	0	
	N	30	30	30	30	24	30	27	30

**. Correlation is significant at the 0.01 level (2-tailed).

Table (5) Correlation matrix among different methods values without all values of samples No.4 &No.10

Correlations									
		Optimum values	Triangle	Rothfuchs	Equal Distances	Asphalt Institute	Wallace	MATLAB	Source Values
optimum values	Pearson Correlation	1							
	Sig. (2-tailed)								
	N	24							
Triangle	Pearson Correlation	.972**	1						
	Sig. (2-tailed)	0							
	N	24	24						
Rothfuchs	Pearson Correlation	.970**	.946**	1					
	Sig. (2-tailed)	0	0						
	N	24	24	24					
Equal Distances	Pearson Correlation	.952**	.956**	.936**	1				
	Sig. (2-tailed)	0	0	0					
	N	24	24	24	24				
Asphalt Institute	Pearson Correlation	.869**	.836**	.916**	.812**	1			
	Sig. (2-tailed)	0	0	0	0				
	N	24	24	24	24	24			
Wallace	Pearson Correlation	.959**	.929**	.955**	.926**	.852**	1		
	Sig. (2-tailed)	0	0	0	0	0			
	N	24	24	24	24	24	24		
Mat Lab	Pearson Correlation	.962**	.993**	.935**	.951**	.834**	.922**	1	
	Sig. (2-tailed)	0	0	0	0	0	0		
	N	24	24	24	24	24	24	24	
Source Values	Pearson Correlation	.989**	.959**	.973**	.954**	.883**	.964**	.957**	1
	Sig. (2-tailed)	0	0	0	0	0	0	0	
	N	24	24	24	24	24	24	24	24

**. Correlation is significant at the 0.01 level (2-tailed).

Conclusions

1. The Excel spreadsheet program(used in this research) is one that the designer can use it to support his experience to accelerate the operation of estimating values.

2. All graphical methods are used to find the tentative values of aggregate proportions and then these values are adjusted by Trial and error or by using Excel spreadsheet program to reach optimum values (designer experience).

3. The simplicity and complexity of any graphical method depends on:

a) Number of aggregates to be combined. More aggregate types are more complex to find the optimal aggregate blending percentages.

b) The range of the specification, i.e. the difference between lower and upper limits. For a wide rangeit is relatively easy to find proportions.

c) Number of sieves used in gradation. A larger number of sieves makes it more difficult to find percentages.

d) Scale and accuracy of used drawing.

In addition to these general conclusions, the following conclusions are found from the results of applying different graphical methods depending on their final rank:

I. Rothfuchs(Balanced-areas) method: This is ranked as the best method by this work,as it is simple, accurate, and can be used for any number of aggregates. It has one difficulty, which is the selection of a closest balanced line with minimum areas around it and computing these areas, so the AutoCAD program needs to be used to find exact areas to get the best results.

II. Wallace method: is an accurate method, can be applied to any number of aggregates, but needs a long time to complete. Additional features are;

a- The number of graphs is equal to number of aggregates so it becomes difficult when the number of aggregates is increased.

b- Needsconsiderable interpretation of specifications and sieve analysis, i.e. percentages of retained and passing of each sieve, because this method cannot be solved unless the interpretation sieve gradation is done, so the difficulty of this method is proportionate to the aggregate number.

III. Triangular method: an accurate method for two or three types of aggregates but cannot be used for more than three types of aggregates. It has been noticed that all of the sieve gradations must be changed to that in bottom of Table (1), i.e. percentage of retained on sieve No.8, percentage of passing sieve No.8 retained on sieve No.200, and the last is percentage passing sieve No.200.

IV. Equal Distances method: accurate, simple, easy, fast, and can be used for any number of aggregates.

V. Asphalt Institute method: Is the last in the rank but it is the most common method because it is easy, simple, and gives acceptable results for blending two types of aggregates. This method becomes difficult for combining three types of aggregates, and complex for four types and did not give accurate values for three aggregate types.

Recommendations

The main recommendations drawn from this research are:

1. It is strongly recommended to use theEqual Distances method in finding tentative percentages values of aggregate blending.

2. Due to the simplicity and accuracy of the Equal Distancesmethod, it is recommended for teaching to students in engineering colleges, and to engineers and designers in designing job mix formula.

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