Statistical Analysis of Component Deviation from Job Mix Formula in Hot Mix Asphalt

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Abstract-The main objective of this research is to find out the effect of deviation in the aggregate gradients of asphalt mixtures from the Job Mix Formula (JMF) on the general mixture performance. Three road layers were worked on (wearing layer, binder layer, and base layer) and statistical analysis was performed for the data of completed projects in Baghdad city and the sieve that carried the largest number of deviations for each layer was identified. No.8 sieve (2.36mm), No.50 sieve (0.3mm), and 3/8" sieve (9.5mm) had the largest number of deviations in the wearing layer, the binder layer, and the base layer respectively. After that, a mixture called Mix 1, was made. This mixture was selected from a number of completed mixtures, and it represents the worst mixture. Mix 1 was compared with two other mixtures, Mix 2 and Mix 3, Mix 2 representing the middle of JMF for the gradients of aggregates, and Mix 3 is the same as Mix 1 except for the sieve that contains the largest number of deviations, so the gradient of aggregates for it is the middle of JMF. Fifteen Marshall specimens were made for each mixture and for each layer in order to know the differences in Marshall properties between the mixtures. Also, 6 specimens were made for each mixture (the total is 18 specimens for each layer) to check the indirect tensile strength, for the purpose of knowing mixtures susceptibility to moisture. Finally, 1 specimen was made for each mixture for repeated load test for the purpose of knowing the performance of the mixtures with respect to permanent deformation. The tests showed that the performance of Mix 2 and Mix 3 was improved in comparison with Mix 1. The deviation of the aggregate gradients in specific sieves may be higher than the limits of the JMF or it may be less, and in both cases, the implementation of a mixture like Mix 1 for the streets is bad for the performance of the road and failures occur due to the wrong implementation of the JMF. On the other hand, there are much better mixtures in all respects such as Mix 2 and Mix 3, and if they are implemented on the streets, they will certainly have much better.

Keywords-hot mix asphalt; JMF; deviation; aggregate gradations

I. INTRODUCTION

Road construction industry faces the challenge of designing and constructing high-performance asphalt materials to meet the ever-growing demand of increasing traffic volumes and axle loadings. Quality control over the production of hot asphalt compounds is a significant issue. When the asphalt components are manufactured to have high performance under weather and road conditions, this increases asphalt pavement life and consequently reduces additional maintenance and rehabilitation costs.

One of the most important issues that affect pavement design is the occurrence of defects. The reasons for these defects may be the quality of the used materials, laboratory equipment, unqualified staff, the lack and delay of necessary maintenance after the implementation of the pavement, wrong construction, or a flaw or wrong execution of the JMF resulting in aggregate gradients that do not conform to JMF contain deviations. Generally, the deviations in aggregate gradations are not accidental, but are caused by external factors [1]. The method to verify that the produced mix complies with the project specifications is the JMF or dense gradation mix submittal. A successful mix design should meet the suggested proportion of aggregates and asphalt binder. This suggested mixture also includes the type of asphalt binder, the aggregate gradation, and the permissible specification bands for inherent material and production variability. The mix designer is free to select a specific JMF gradation, and the manufacturer is expected to produce the mix according to this JMF gradation closely [2]. The Iraqi standard specifications for roads and bridges, SCRB R/9 2003, allowed some tolerances in JMF with regard to the following properties: coarse aggregate gradients, fine aggregate gradients, filler content, asphalt concrete content, and mixing temperature (Table I) [3]. The characteristics of the asphalt mixture's components have a significant and obvious impact on the performance of the pavement, especially the aggregates that make up a significant portion of the asphalt mixture. Aggregates are the largest and most important volumetric component of the asphalt mixture and its performance and are the basis of the homogeneous and solid texture of the asphalt mixture.

In addition to serving as the base for the design of asphalt mixtures, aggregates play a significant role in determining the quality of the road, the loads applied on it, and the nature of road layers. The type and viscosity of the asphalt used are impacted by the gradient of the aggregates and internal friction. The fundamental concept of choosing the aggregate quality and

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size is to get the highest consistency and homogeneity of the asphalt mixture, creating the perfect layer to receive and distribute the load of wheels and vehicles on the sub base without failures [4-6].

TABLE I. ALLOWED TOLERANCES FROM JMF [3]

Sieve size	Tolerance
Aggregate materials passing through sieve 4.75mm (No.4) or larger	±6%
Aggregate materials passing through sieve 2.36mm (No.8) to sieve 0.3mm (No.50)	±4%
Filler passing through sieve 0.075mm (No.200)	±1.5%
Asphalt	±0.3%
Mixing temperature	±15°C

Aggregate gradation, which is measured by sieve analysis, is the distribution of aggregate particle size. While aggregates of varying size made the mixture have fewer voids, the aggregates that have no variety in sizes make the compacted mass to have more voids due to the uniformity of the particles. Aggregate gradation significantly affects Hot Mix Asphalt (HMA) properties. The component content in the HMA mixture has been shown to have an impact on the mixture's structure and properties, which in turn affects the dependability and durability of the pavement [7]. It is concluded that the deviations related to the gradient of the asphalt mixture aggregates are considered to be effective and common deviations, which requires taking appropriate procedures to avoid these failures, including doing the correct JMF in a manner appropriate to the use of the intended layer in addition to the use of materials that successfully pass laboratory testing and ensure the correct implementation of the required thickness and compaction, thus, improving the quality and performance of the implemented road in a way that meets its purpose [8].

In order to find some performance requirements, designers are interested in aggregate gradation. For good permanent deformation resistance, Superpave defines the "Restricted Zone" within the gradation of aggregates and recommends that the limited area should not be violated. Depending on the nominal maximum particle size, the restricted zone is between the mid-size particles (4.75 or 2.36mm), and the 0.3mm at the maximum dense line [9-11]. Aggregate gradation determines how well an asphalt pavement performs. Any changes in aggregate gradation cause changes in many factors, such as directions and contact points, which in turn affect the performance of asphalt pavements [12]. Authors in [13] showed the use of 4 different aggregate gradations and the wheel tracking test showed that they were superior to fine aggregates regarding permanent deformation. Authors in [14] showed that aggregate gradation was a significant factor of the perfect mixture. With three grades and various percentages, they produced a hot and a warm mix of asphalt from a single source. The test results showed that the aggregate gradations had a variety of effects on the introduced mixtures' rutting resistance, particularly their sensitivity to moisture. Authors in [15] examined the way aggregate gradation affects the different characteristics of asphalt concrete mixtures. The effects of different aggregate types and gradations on the mixing properties have been investigated for blends with fine, medium, and coarse aggregate gradations. The mixtures' asphalt content remained constant at the job mix design content. They looked at the properties of Marshall stability, Marshall flow, unit weight, air voids, and mineral aggregates. Analysis of the different aggregate types made clear that the fine-coarse and coarse-fine variations had the greatest impact on the mix. Authors in [16] estimated the effect of asphalt and aggregate gradation type on HMA found in asphalt concrete mixtures. Additionally, the effect of the aggregate characteristics on the Marshall mix properties was investigated. Finally, an estimation of the relationship between rutting potential and HMA mixing was made. The study showed that characteristic mineral aggregates had a significant influence on the construction of local highways, giving the possibility to develop resistance to various externally applied loads and environmental conditions. Furthermore, it illustrated how aggregate properties have a long-term impact on the way hot-mix asphalt is deformed.

Many studies have been conducted to identify the effect of aggregate gradation on moisture susceptibility and permanent deformation of HMA. Rutting has recently taken over as the main mode of flexible pavement failure as a result of increased truck tire pressure and the lack of maintenance [17]. Rutting is mainly brought on by the accumulation of permanent deformations in the pavement or its layers. Heavy axle loads and high tire pressure contribute significantly to rutting in the flexible pavement surface layer. High tire pressure increases stress and reduces the area of contact between the tire and the pavement, which aggravates deformation in flexible pavements. Additionally, the pavements' top layer is significantly impacted by environmental conditions [18]. The asphalt mixtures used in road construction must be resistant to cracking and permanent deformations. They are composed of voids, aggregates, and binder. To obtain relevant properties that affect the way the asphalt behaves, appropriate materials must first be chosen in advance, and their proportions in the asphalt mixture must be determined. It's essential to know how asphalt mixtures are built in, in addition to how they are produced [6]. It is widely accepted that coarser gradation results in an HMA mixture that is more rut resistant. However, some studies have discovered that mixtures with finer gradations have lower rut potential [19]. Authors in [20] observed that, a significant contributing factor to the asphalt binder film's loss of adhesion may be the fine aggregates. They also noted that the presence of crushed sand may reduce moisture damage and that maximum aggregate size and mixture gradation have a significant impact on rutting resistance.

II. DATA USED AND MOST COMMON DEVIATIONS

For the purpose of knowing the sieve that carries the largest number of deviations in the aggregate gradients (the most frequent) and for the three considered layers (wearing, binder, and base layer) a data set was acquired from road projects implemented in Baghdad governorate. The data were randomly selected. Data were taken from 140 wearing layer specimens, 33 binder layer specimens, and 30 base layer specimens. The percentage of passing through each sieve can be easily plotted for each sieve and the conclusion is that the largest number of deviations in the aggregate gradients from JMF of wearing layer were sieve No.8 (2.36mm) for the wearing layer, No.50

(0.3mm) for the binder layer, and sieve 3/8" (9.5mm) for the base layer.

III. SELECTION OF AGGREGATE GRADATIONS

The sieve that has the largest number of deviations in aggregate gradations was determined for each considered layer. Figures 1-3 show the aggregate gradients for the worst implemented chosen mixture, and the amount of its deviation from Iraqi specification for roads and bridges (SCRB) and JMF. This mixture was called Mix 1. The performance of this mixture (Mix 1) was compared with mixtures without or less errors and deviations, in order to determine how bad these mixtures are being implemented. Another mixture, called Mix 2, was made. Its aggregate gradients represent the midpoint of the JMF for Mix 1. A third mixture, called Mix 3, was prepared with the same gradations of aggregates as Mix1, except for the sieve containing the largest number of deviations (the sieve that deviates from the JMF). So we have:

- Mix 1: as it is.
- Mix 2: mean of JMF.
- Mix 3: as it is, mid for deviated sieve.

The above were implemented on all layers (wearing, binder and base). Figures 1-3 show the gradations of aggregates for each mixture and for each layer.

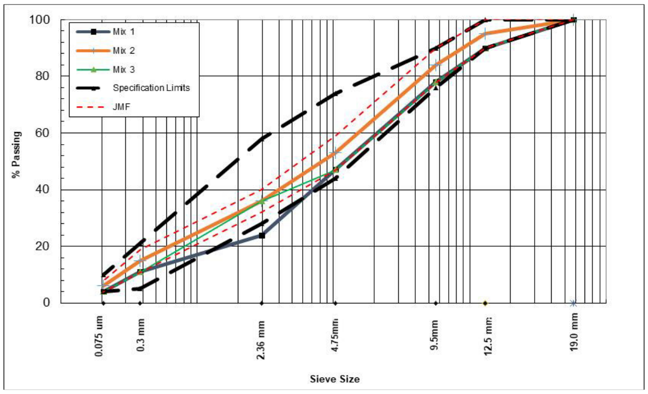

Fig. 1. Wearing layer aggregate gradients.

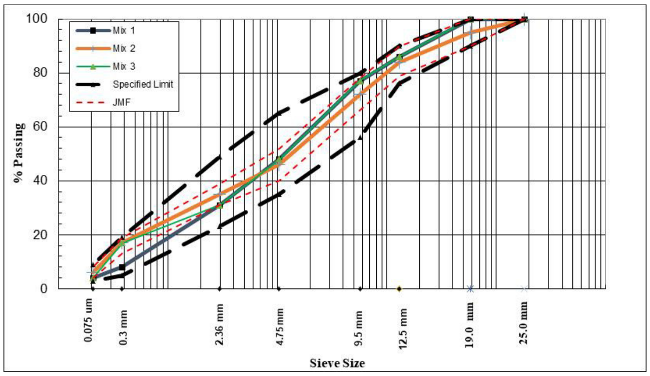

Fig. 2. Binder layer aggregate gradients.

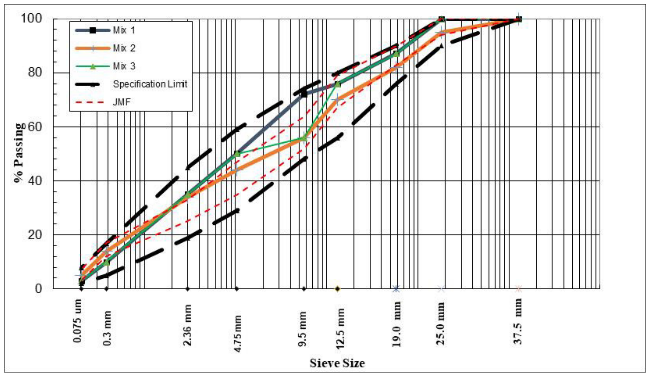

Fig. 3. Base layer aggregate gradients.

IV. MATERIAL CHARACTERIZATION

A. *Aggregates*

Crushed quartz was used as aggregates in this research. In the city of Baghdad, this aggregate type is frequently used in asphalt mixtures. Routine tests were performed on the aggregates to assess their physical characteristics. Table II provides a summary of the results along with the specification limits established by the SCRB. The test results indicate that the selected aggregates meet the SCRB specifications.

TABLE II. PHYSICAL PROPERTIES OF AGGREGATES

Property	Coarse aggregates	Fine aggregates	SCRB
Bulk specific gravity (ASTMC127 and C128)	2.646	2.63	……
Apparent specific gravity (ASTMC127 and C128)	2.656	2.667	……
Percent water absorption (ASTM C127 and C128)	0.14	0.523	…...
Percent wear (Los-Angeles Abrasion) (ASTM C131)	19.69		30 Max
Fractured pieces (%)	98		90 min
Sand Equivalent(ASTM D 2419)		55	45 min Superpave (SP-2)
Soundness loss by sodium sulfate solution,%(C-88)	3.4		12 Max

TABLE III. PHYSICAL PROPERTIES OF AC 40/50

Tests	Unit	40/50 AC specification	SCRB specification
Penetration at 25°C, 100gm, 5sec (ASTM-D5)	0.1mm	45	40-50
Softening point R&B (ASTM-D36)	°C	48	…..
Specific gravity at 25°C (ASTM-D70)	......	1.04	…..
Flash point (ASTM-D92)	°C	290	Min. 232
Ductility (ASTM-D113)	cm	132	Min. 100
Residue from thin film oven test (ASTM-D1754)			
Retained penetration ,% of original (ASTM-D5)	0.1mm	59	Min. 55
Ductility at 25°C, 5cm/min, (ASTM-D113)	cm	90	Min. 25

B. Asphalt Cement

The penetration grade (40/50) of asphalt cement, which is frequently used in paving construction projects in Iraq, was considered in this study. For the purpose of determining the fundamental physical characteristics of asphalt cement, a number of ASTM tests were carried out. The asphalt cement used in this study complies with the necessary (SCRB/R9 2003 Revision) specification, as shown in Table III.

C. Filler

The filler is a non-plastic material passing through sieve No.200 (0.075mm). The filler used in this work is limestone dust. Its physical properties are presented in Table IV.

TABLE IV. PHYSICAL PROPERTIES OF MINERAL FILLER.

Property	Test result
Specific gravity	2.78
Passing sieve No.200 (0.075mm)	85

V. SPECIMEN PREPARATION AND TESTING PROCEDURE

To evaluate the performance of the three mixtures, three types of tests were performed, the Marshall test (ASTM D6926-2010a) in order to obtain the optimum asphalt content, density, stability, flow, and other properties, indirect tensile strength test (ASTM- D-4867-96) in order to evaluate the moisture sensitivity of the mixes, and finally the repeated load test for permanent deformation evaluation.

A. Marshall Test

In Marshall design there are two kinds of test: stability-flow tests and density voids tests. The Marshall method (ASTM D6927) is used to determine the optimum asphalt content of the HMA pavement. For the purpose of calculating the optimum asphalt content, 5 different percentage values 4, 4.3, 4.6, 4.9 and 5.2%, were used for asphalt cement (binder course), while 3.4, 3.7, 4, 4.3, and 4.6% were used for base course, and 4.3, 4.6, 4.9, 5.2, and 5.5% were used for the wearing course. Three specimens were prepared for each ratio. Therefore, 15 specimens were prepared for each mix, i.e. 45 specimens for each layer (to a total of 135 specimens for the three layers). The aggregate gradations for all mixtures (Mix 1, Mix 2, Mix 3) and for all layers were as explained above and the Marshall specimens were made after the calculation of the optimum asphalt content for each mixture. The Marshall test steps have been performed.

B. Indirect Tensile Strength Test

To assess the moisture sensitivity of mixes, Indirect Tensile Tests (ITSs), according to ASTM- D-4867-96 were performed for each mix: two subsets, 3 specimens each were compacted with blow range between 30 to 50 for wearing course, binder course, and base course. So, 6 specimens were prepared for each mixture and for each layer, to a total of 54 specimens. The first subset was tested in a dry condition (soaked in water for 2hr at 25^{o}C). The second subset was tested in wet condition, i.e. it was inundated for 24hr at 60^{o}C followed by 25^{o}C for 2hr in water bath. The Marshall device applies a compressive load to a cylindrical specimen through two diametrically opposed rigid strips consisting of 10×10mm (0.39×0.39in) rectangular steel bars of 102mm (4in) diameter specimens to induce tensile stress along the diametric vertical axis of the test specimen. A series of splitting tensile strength tests were conducted at a constant strain rate of 2in/min vertically until vertical cracks appeared and the sample failed. The peak compressive load was recorded and used to calculate the tensile strength of the specimen using (1):

$$S_t = 2\,P_u/\,\pi tD \quad (1)$$

where S_t is the tensile strength (Psi), P_u is the max. load (lb), t is specimen's height immediately before tensile test (in), and D is specimen's diameter (in.).

The Tensile Strength Ratio (TSR, %) was calculated by:

$$TSR = (S_{tm}/S_{td}) \times 100 \quad (2)$$

where S_{tm} is the average tensile strength of the moisture conditioned subset (Psi) and S_{td} is the average tensile strength of the dry subset (Psi).

C. Repeated Load Test

A total of 9 cylindrical specimens (1 specimen for each mix for the 3 layers) were fabricated to investigate the effect of deviation in the gradation of aggregates on permanent deformation of asphalt concrete mixture at 40^{o}C. The cylindrical specimens produced for this study had initial dimensions of 101.6mm (4in) diameter × 152.4mm (6in) height. The tests were performed at single stress level of 20Psi (138kPa). Repeated compressive loading for 10,000 repetitions was conducted with a loading cycle of 60 cycles per minute in duration and consisting of a 0.1s load period followed by a 0.9s rest period (the 0.1s load duration was selected in order to simulate the loading of truck moving at the highway with a speed of 50km/hr). This test was applied to determine the permanent deformation characteristics of paving materials. Permanent axial deformation was recorded throughout the test using Linear Variable Differential Transducer (LVDT) to measure the deformation in the upper face of the sample via a data acquisition system. A Pneumatic Repeated Load System (PRLS) apparatus manufactured under the auspices of University of Baghdad's Civil Engineering Department was used to calculate the permanent strain values [21]. The values of the permanent strain were obtained at 1, 2, 10, 100, 500, 1000, 2000, 3000, 4000, 5000, 6000, 7000, 8000, 9000, and 10000 load repetitions. The permanent strain (Ɛp) was calculated by:

$$\mathcal{E}p = \frac{P_d \times 10^6}{h} \quad (3)$$

where Ɛp is the axial permanent microstrain, P_d is the axial permanent deformation, andh is the specimen's height.

Authors in [22, 23] suggested a log-log relationship between Ɛp and N, as in (4):

$$\mathcal{E}p = aN^b \quad (4)$$

where N is the number of load repetitions, and a and b are positive regression constants. As depicted in Figure 4, the parameter a is the intercept with the permanent strain axis, and b is the slope of the linear portion of the logarithmic relationship.

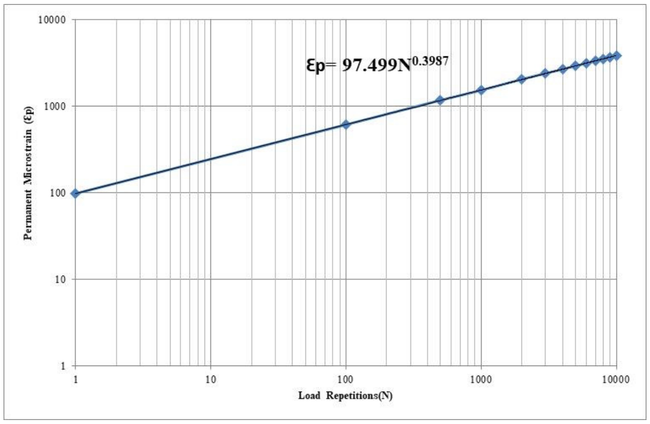

Fig. 4. Log-log relationship between permanent microstrain and number of load repetitions.

VI. RESULTS AND DISCUSSION

As mentioned above, Mix 1 is the mixture that has already been implemented in some of the streets of the city of Baghdad. This mixture shows some deviations in the gradients of the aggregates from the mixing equation and for the 3 layers of the road. These deviations surely did not occur intentionally, but due to defects in the JMF specified for each project, implementation errors, or errors of weighing and determining the exact amount of aggregate required for each sieve and for each mixture. Some of these deviations were beyond the upper limits of the mixing equation and even exceeded the amount of tolerance specified according to the SCRB. On the other hand, some of the deviations were less than the minimum limit of the mixing equation. Both cases can cause defects in the mixture.

The occurrence of defects in the aggregate gradients prescribed for a particular road, means an increase or decrease of fine or coarse materials in the mixture, leading to problems in the mixture and weakened performance of the road, making it prone to failures. This was made clear from the test results. To clarify the difference between the performance of the 3 mixtures, the results of each test and for each layer, will be discussed.

For the wearing course, the deviated sieve is sieve No. 8 (2.36mm). For Mix 1, the passing percentage of aggregates for this sieve is 24%, which is outside the lower limit of JMF (it is even outside the tolerance limit ±4) and is also less than the lower limit of Iraqi standard specifications, which is 28%.

For binder course, in Mix 1, the value of the aggregates that passed through the sieve No. 50 is 8%, which is less than the lower limit of the JMF and its tolerance limit, but within the limits of the Iraqi specification, as the percentage of passing through sieve No. 50 of binder course according to it must be within 5-19%.

For base course, in Mix 1, the transit ratio of aggregates to a 3/8" sieve was 72%, which is outside the upper limits of the mixing equation, and the tolerance limits of the mixing equation, but it is within the limits of SCRB, as the value of aggregates for this sieve and the base layer according to the SCRB is from 48 to 74%.

Mix 2 is the best (ideal) mixture. Figures 5-11 show how the properties of Mix 2 and Mix 3 were significantly improved in comparison to Mix 1. The values of stability, flow, and density of the asphalt mixture improved. Also, an increase in the ITR value was observed, which means more moisture resistance. A decrease in the values of slope and intercept was also noticed for Mix 2 and Mix 3 compared to Mix 1 for all the considered layers of the road (wearing, binder and base). The higher the value of the intercept, the larger is the strain and hence the larger the potential for permanent deformation [24], while slope b represents the rate of change in the permanent strain as a function number of loading cycles (N) in the log-log scale. High-slope values of a mix indicate an increase in the material deformation rate, hence less resistance against rutting. A mix with a low slope value is preferable as it prevents the occurrence of the rutting distress mechanism [25].

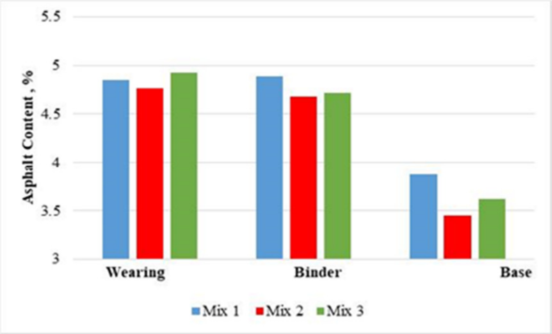

Fig. 5. Tests results of asphalt concrete percentage for each layer.

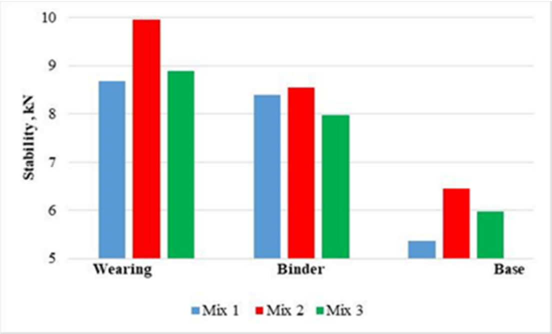

Fig. 6. Tests results of Marshall stability for each layer.

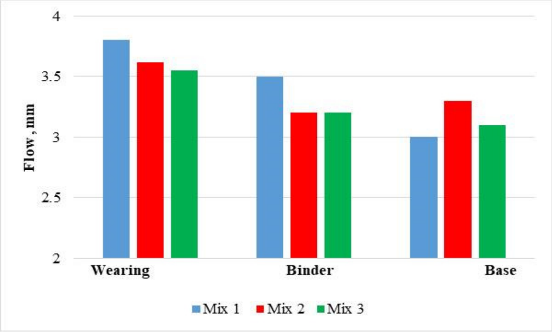

Fig. 7. Tests results of Marshall flow for each layer.

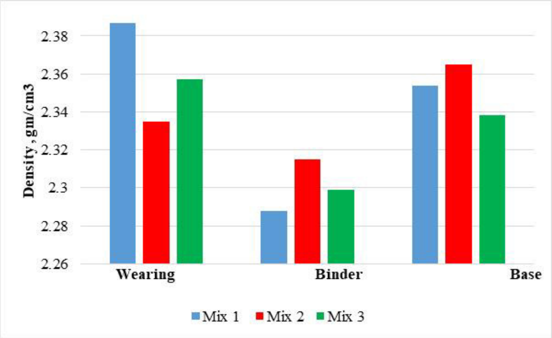

Fig. 8. Tests results of Marshall desity for each layer.

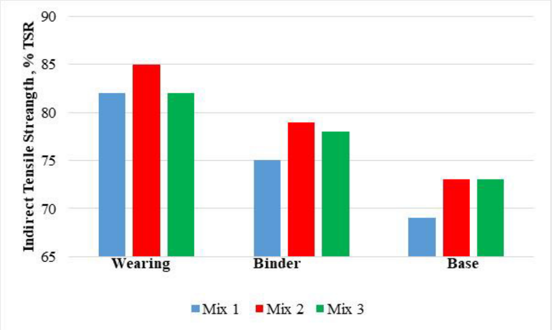

Fig. 9. Tests results of indirect TSR for each layer.

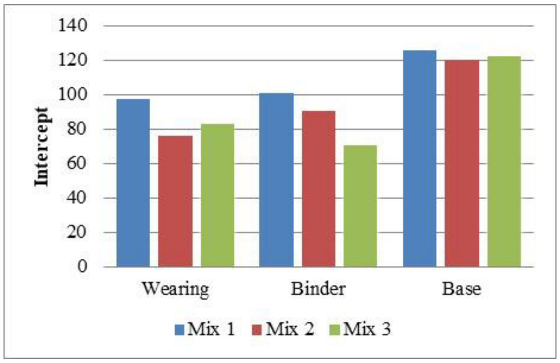

Fig. 10. Intercept value from log-log relationship between microstrain and load repetition for each layer.

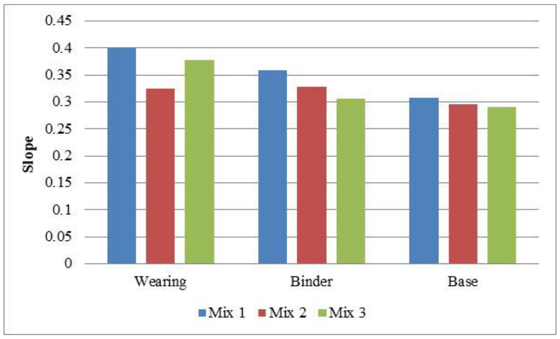

Fig. 11. Slope value from log-log relationship between microstrain and load repetition for each layer.

VII. CONCLUSION

In this research, three types of mixtures and three pavement layers were studied. The first mixture is already implemented in some of the road projects in the city of Baghdad, and it shows deviations in the aggregate gradients from the mixing equations, suffering from weak performance and noticeable failures in some roads. Knowing the importance of adjusting the aggregate gradients in the asphalt mixture according to the specifications, noticeable performance improvement was noticed when Mix 2 and Mix 3 were produced (correcting deviant aggregate gradients according to the mixing equations). Even if it is difficult to implement Mix 2 (which represents the gradients of aggregates at the mean values of the mixing equation), it is possible to implement Mix 3, which is closer to the reality of implementation, and all its properties are better than Mix 1, guaranteeing an improvement in road performance, fewer failures, and greater durability.

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