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Research Article

Improving flexible pavement performance through suitable aggregate gradation

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Abstract: The objective of this study was to improve the performance of flexible pavement through suitable aggregate gradation. Thus, initially, the dynamic modulus of asphalt mixtures |E*| for different aggregate gradations were predicted, and suitable aggregate gradation was determined. Then the performance of three different pavement structures for two aggregate gradations (Mid and Suitable), using AASHTOWare Pavement ME Design 2.5. 5, were evaluated for local conditions of Izmir, Turkey. The analysis result revealed that using suitable values compared to middle values increased the |E*| and improved the rutting and fatigue resistance of all pavement structures for any traffic levels. The output of this study can be used as a guide for hot mixed asphalt mix design and pavement design based on Mechanistic-Empirical Pavement Design Guide as well.

Keywords: Flexible pavement, aggregate gradation, rutting, cracking.

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1. Introduction

Mineral aggregate blend forms a high portion of volume and weight of hot-mix asphalt (HMA) mixture, and aggregate is an enormously important component in an asphalt mixture. In addition to the physical and chemical characteristics and morphologies (shape, angularity, and texture), the aggregate particle size distribution (aggregate gradation) is the main factor influencing the asphalt mixture’s properties and performance. Therefore, the aggregate gradation plays a crucial role in HMA mixture properties and mixture performances (e.g., stability, stiffness, durability, permeability, workability, fatigue, and rutting resistance) as well as significantly influences rutting and fatigue resistance of pavements (Huang, 2004). In order to obtain satisfactorily aggregate gradation, mixtures are designed using a trial-and-error procedure. To decrease the number of trials, highway technical manuals propose aggregate gradations in restricted ranges (a lower and an upper limit) (General Directorate of Highways, 2013). Generally, mix-designers and researchers prefer to choose a gradation between these limits (particularly, middle values between lower and upper limits). As the variation of aggregate particle size distribution has a remarkable effect on mixture properties and pavement performance, choosing middle values maybe not necessarily a suitable value. In other word, selecting middle values of aggregate gradation rather than upper or lower values may not lead to higher rutting and fatigue resistance in pavement.

The evaluation of the impact of aggregate gradation on mixture properties and mixture performance is an interesting topic for researchers, therefore, in two decades, several research studies have been conducted (Ahmed and Attia, 2013; Chen and Liao, 2002; El-Basyouny and Mamlouk, 1999; Fang et al., 2019; Garcia et al., 2020; M., 2014; Stakston and Bahia, 2003).

The result of a study conducted by El-Basyouny and Mamlouk revealed that rutting depth is affected by both aggregate gradation and aggregate nominal size (El-Basyouny and Mamlouk, 1999). In another study, Stakston and Bahia found that aggregate gradation strongly influences the rutting resistance of mixtures, and a mixture made with high-quality materials would fail without suitable gradation (Stakston and Bahia, 2003). Chen and Liao found that rutting resistance of asphalt mixture was increased with a good determination for the amount of fine aggregate which passed through sieve 4.75mm (Chen and Liao, 2002). Although in some cases, the mixes with coarse gradations yielded good rutting performance (Ahmed and Attia, 2013; M., 2014). The study performed by Victor M. Garcia1 et al., revealed that increasing the coarse fraction increased VMA but did not significantly impact the strength and stability of the mix (Garcia et al., 2020). Fang. et al, in a review study, indicated that the aggregate gradation can influence almost all the performances of asphalt mixture (Fang et al., 2019).

Another study, which was conducted using the finite element method was determined that the stresses in the rigid pavements remain in the coating layer, while the stresses in the flexible pavements reach the base and sub-base (Serin, S. et al., 2021). In a separate study, conducted in India, two different groups of hybrid combination of fibers such as steel and basalt were cast with 3 different groups of coarse aggregate proportions of sizes 20 mm and 12.5 mm. The hybridization of fibers is assessed in this study under compression, tension, flexure and fracture. Stress-strain data were recorded under compression to validate the strain capacity of the mixtures. The results from the flexural toughness showcased the potential of hybrid fibers with greater energy absorption capacity ensuring the ductile property of the proposed hybrid fiber reinforced concrete (Jenifer, J. V. and Brindha, D. (2021).

Conventionally, the effect of mixture design factors on mixture properties and performance are evaluated in the laboratory environment, which in some cases may differ from the performance of the field-competed pavement. Therefore, it is important to evaluate the effect of mixture factors on pavement performance based on a mechanistic-empirical method. At the present, the Mechanistic-Empirical Pavement Design Guide (MEPDG) and its software (AASHTOWare Pavement ME Design, henceforth referred to as AASHTOWare) is the state-of-the-art pavement design method that calculates pavement responses (stress and strains) and predicts different pavement distresses (rutting, fatigue cracking, and thermal cracking) under the combination of traffic loading and climate factors into consideration of material properties. The possibility of using local data as design inputs in the AASHTOWare is one of the main advantages of this method. This method requires extensive detailed local data (material properties, traffic characteristics, and climate data) in three hierarchical input levels. In input Level 1, data are obtained through forensic study and lab works. In input level 2, design inputs are calculated using predictive formulas. In input Level 3, the MEPDG default data are used or extracted from local agency database. However, the inputs level is selected based on availability of local data, the level of sensitivity of inputs on pavement performance, road types, traffic level, and local agency decisions. In the MEPDG, one of the vital design inputs is the dynamic modulus of asphalt mixture. It is believed that dynamic modulus of HMA can cover the full viscoelastic behavior of asphalt mixtures.

In Level 2 input and Level 3 input, in the AASHTOWare, the dynamic modulus is predicted internally using Witczak's formula, therefore, aggregate gradation, air voids, effective binder content, and binder grade are required as design inputs (AASHTO, 2008, 2015, 2020). In Turkey, based on the Highway Technical Specifications-2013 (HTS-2013) different HMA mixture and various aggregate gradations are used. According to the HTS-2013, for each asphalt concrete (AC) layer (wearing course, binder course, and base course) in a pavement structure, specific mixture type and aggregate gradations are recommended. As previously conducted studies emphasize on significant effect of aggregate gradation on mixture properties and performance, the investigation of the influence of variation of different aggregate gradations on dynamic modulus of HMA and further on pavement performance based on the mechanistic-empirical pavement design guide (MEPDG) for local conditions is a strong need.

Therefore, the objective of this study was to improve the performance of flexible pavement through suitable aggregate gradation. To achieve the objective of the study, first the dynamic modulus of HMA mixtures for minimum, medium and maximum percent aggregate passing the sieves 19, 9.5, 4.75 and 0.075 mm were predicted and the suitable aggregate gradations were determined (in this study, the percent aggregate passing the sieves that leads to the maximum amount of dynamic modulus is called the suitable aggregate gradation), then the performance of three different pavement structures for two aggregate gradation (medium and suitable values) using AASHTOWare pavement ME Design 2.5.5 were evaluated for local conditions of Izmir, Turkey. The output of this study can be used as a guide for hot mixed asphalt mix design and pavement design based on Mechanistic-Empirical Pavement Design Guide as well.

2. Methodology

In this study, efforts were made to achieve the objectives in three steps. In the first step, local data (pavement structure, material properties, traffic characteristics, and climate data) were collected, analyzed, and converted to the AASHTOWare format. In this study, all prepared local data are in input Level 3. In the second step, dynamic modulus of different HMA mixtures used in wearing course, binder course, and base course were predicted and suitable aggregate gradation were determined. In third step, the performance of three different pavement structures for two aggregate gradations (mid and suitable values) using AASHTOWare 2.5.5 were evaluated. The analyses were performed for three traffic levels [5000, 10000, and 15000 average annual daily truck traffic (AADTT)] and three subgrade strengths [5, 10, 15 California Bearing Ratio (CBR)] at 90% reliability and 20-year design life.

2.1. *Local data preparation*

2.1.1. Pavement structure

Based on the Turkish Flexible Pavement Design Guide – 2008, three different pavement structures for three traffic levels and three subgrade types were selected (Table 1). The pavement layer thickness was designed based on Turkish Flexible Pavement Design Guide, which is based on the American Association of State Highway and Transportation Officials (AASHTO) 1993 method. Each pavement structure forms of three AC layer (wearing course, binder course, and base course), crushed stone base course, and subbase course. Generally, the overall thickness of pavement structure increases with increasing traffic level. Table 1 shows that the thickness of binder course, AC base course, and granular subbase course increases with traffic level while the thickness of wearing course and crushed stone base course is not sensitive to variation of traffic levels. Also, it can be looked at Table 1 that only the thickness of granular subbase courses changes according to variation of subgrade strength.

Table 1. Pavement structure.

Layers		AADTT		
		5000	10000	15000
AC wearing (mm)		50	50	50
AC binder course (mm)		80	100	100
AC base course (mm)		110	110	140
Crushed stone base course (mm)		200	200	200
Granular subbase course (mm)				
Subgrade, CBR %	5	300	300	350
	10	200	200	200
	15	200	200	200

2.1.2. Material properties

The material properties such as binder content, air void, binder grade, aggregate gradation, granular resilient modulus and subgrade CBR values were extracted from THS-2013 and shown in Table 2, and Table 3.

Table 2. HMA mixture properties.

Inputs	Mixture type		
	Wearing course	Binder course	Base course
Air voids, %	4	5	5.5
Effective binder content, %	10	8	8
Binder Penetration grade,	60/70	60/70	60/70
% Passing the sieve 19mm	100	90-100	60-90
% Passing the sieve 9.5mm	72-90	70-48	43-70
% Passing the sieve 4.75mm	42-52	52-30	30-55
% Passing the sieve 0.075mm	3-8	2-7	0-7

Table 3. HMA mixture properties

Layer type	Value
Base course, MPa	225
Subbase course, MPa	125
Subgrade, CBR %	5, 10, 15

2.1.3. Traffic data

The MEPDG requires detailed traffic data (e.g., vehicle classification, vehicle class distribution factors, traffic growth factors, monthly adjustment factors, axle load distribution factors, and axle number per truck). Local traffic data were extracted from the Transportation Information and Characteristics (General Directorate of Highways, 2017), the Highway Traffic Flow Characteristics (General Directorate of Highways, 2016) and the Parameters and the Features and Trends of Heavy Vehicle Traffic in Freight Transport on Highways surveyed between (2007-2009) (General Directorate of Highways, 2011) and (2010-2014) (General Directorate of Highways, 2014) (Tables 4, Table 5, and Table 6). The collected local traffic data showed, currently, in Turkey, vehicles are classified based on vehicle types into five groups: 1) Cars, 2) Medium-duty commercial vehicles, 3) Buses, 4) Trucks, and 5) Trailers (General Directorate of Highways, 2008).

Based on the MEPDG, trucks are classified based on truck types, axle types (single, tandem, tridem, and quad) and axle numbers (two, three, four, five and six), therefore, the existing vehicle classification is not suitable for direct use as design input in the AASHTOWare 2.5.5. In order to develop a new truck classification, vehicle class 1 (Cars) was removed from the new truck classification, class 2 was merged in busses and trucks (because the medium-duty commercial vehicles formed from 70% buses 30% trucks) and vehicle class 3 and 4 were divided into three sub-classes, respectively, based on axle number, axle types and truck types. Finally, observed vehicles were aggregated into seven classes (in AASHTOWare class 4 to 10). The truck classes 11, 12, and 13 were not observed in the state roads in Izmir, Turkey (Table 4). [Times New Roman 10]. Present quotes and bibliographic references in accordance with the Publication Manual of the American Psychological Association (APA) 6TH Edition. Figures, images, photos and diagrams, Tables, Equations. Figures, images, photos, tables and diagrams: please declare explicitly in the description if some element is from another source. Indent first line of each paragraph - left 0.42 cm. Paragraph spacing multiple at 1.08 cm.

Table 4. Vehicle class distribution factors and truck growth rate

Vehicle class	Distribution (%)	Growth Rate (%)	Growth function
4	15.82	5	Linear
5	33.01	5	Linear
6	16.59	3	Linear
7	10.08	3	Linear
8	0.33	3	Linear
9	24.10	3	Linear
10	0.07	3	Linear
Total	100		-

Table 5. Number of axles per truck

Vehicle class	Single	Tandem	Tridem	Quad
4	1.96	0.04	0.00	0
5	2.00	0.00	0.00	0
6	1.00	1.00	0.00	0
7	1.33	0.33	0.68	0
8	2.00	1.00	0.00	0
9	1.99	0.03	0.99	0
10	1.00	1.00	1.00	0
11	0	0	0	0
12	0	0	0	0
13	0	0	0	0

Table 6. Trucks monthly adjustment factors.

Month	Trucks classes									
	4	5	6	7	8	9	10	11	12	13
Jan	0.83	0.84	0.84	0.84	0.8	0.8	0.8	0	0	0
Feb	0.79	0.8	0.8	0.8	0.77	0.77	0.77	0	0	0
Mar	0.88	0.96	0.96	0.96	0.94	0.94	0.94	0	0	0
Apr	0.9	0.99	0.99	0.99	0.96	0.96	0.96	0	0	0
May	1.03	1.07	1.07	1.07	1.05	1.05	1.05	0	0	0
Jun	1.07	1.07	1.07	1.07	1.05	1.05	1.05	0	0	0
Jul	1.25	1.1	1.1	1.1	1.13	1.13	1.13	0	0	0
Aug	1.28	1.08	1.08	1.08	1.12	1.12	1.12	0	0	0
Sep	1.05	1.03	1.03	1.03	1.07	1.07	1.07	0	0	0
Oct	1.04	1.08	1.08	1.08	1.12	1.12	1.12	0	0	0
Nov	0.92	0.99	0.99	0.99	1.04	1.04	1.04	0	0	0
Dec	0.95	0.99	0.99	0.99	0.95	0.95	0.95	0	0	0
Total	12	12	12	12	12	12	12	0	0	0

2.1.4. Climate data

Five-year hourly climate data (temperature, windspeed, sunshine, precipitation, and humidity) of Izmir region was obtained from the Turkish State Meteorological Service in a text file. The obtained data were checked and many missing data in hours, days, weeks and months were found. The maintenance of the weather stations, malfunction, or extreme weather can be the reason of missing data. The missing data were calculated as the average value of before and after the missing data points. Because each 5-year weather factor consists of tens of thousands of rows, identifying the missing data one by one is a time-consuming process. Therefore, an excel model was developed that can automatically identify and interpolate the missing data. Also, it was found that in Turkey, cloud cover measures in Okta unit, while AASHTOWare requires sunshine percentage as input. In Okta unit, sky is divided into eight equal parts, which 8-Okta indicates to the completely cloudy sky and 1-Okta shows a clear sky. Thus, at first, cloud cover from Okta unit was changed to percent unit and then cloud cover was converted to sunshine. Finally, the climate data were converted to the text file with ".hcd" extension, which can be used in AASHTOWare 2.5.5. Each climatic file consists of date (YYYY/mm/dd/hr), air temperature (°C), precipitation (mm), wind speed (m/hr), sunshine (%), and humidity (%).

2.1.5. Prediction of dynamic modulus and determination of suitable aggregate gradation

Based on the HTS-2013, for each AC layer, a specific HMA mixture with different design factors are suggested (Table 2). In the AASHTOWare, in Level 3 design input, the dynamic modulus of asphaltic mixtures is predicted using Witczak's formula (Equation 1) (ARA, Inc., 2004).

$$log(E*) = 3.750063 + 0.02932\rho_{200} - 0.001767(\rho_{200})^2 - 0.002841\rho_4 - 0.05809V_a - 0.802208\left(\frac{V_{beff}}{V_{beff} + V_a}\right) + \frac{3.871977 - 0.0021\rho_4 + 0.003958\rho_{38} - 0.000017(\rho_{38})^2 + 0.005470\rho_{34}}{1 + e^{(-0.603313 - 0.313351\,log(f) - 0.393532\,log(\eta))}} \quad (1)$$

where:

$E*$ = dynamic modulus of mix, 10^5 psi
η = viscosity of binder, 10^6 poise
f = loading frequency, hz
ρ_{200} = % passing the 0.075mm sieve
ρ_4 = % retained on 4.75mm sieve
ρ_{38} = % retained on 9.5mm sieve
ρ_{34} = % retained on 19mm sieve
V_a = air void, % by volume
V_{beff} = effective binder content, %

The η is calculating using Equation 2.

$$log\,\lambda = 10.5012 - 2.2601\,log(Pen) + 0.00389(log(Pen))^2 \quad (2)$$

In order to determine the impact of variation of aggregate gradation on dynamic modulus of asphalt mixtures used in wearing course, binder course, and base course, the percent aggregate passing the sieves (e.g., 19, 9.5, 4.75, and 0.075mm) were categorized into three levels of minimum (Min), middle (Mid), and maximum (Max), which are illustrated in Table 7. The dynamic modulus of each HMA mixtures was predicted five different loading time (0.1, 1, 5, 10, and 25 Hz) for asphalt penetration Pe 60. In this study, for all analysis, the variation of aggregate gradation was remained within restricted zone specified by THS-2013.

Table 7. Aggregate gradation.

Sieves (mm)	Passing level	Wearing course (%)	Binder course (%)	AC Base course (%)
19	Min	100	80	70
	Mid	100	90	80
	Max	100	100	90
9.5	Min	72	48	55
	Mid	81	59	65
	Max	90	70	75
4.75	Min	42	30	42
	Mid	47	41	52
	Max	52	52	62
0.075	Min	3	2	1
	Mid	5.5	4.5	4.5
	Max	8	7	7

After the predicting of dynamic modulus for different aggregate gradation, the percent passing the sieves which led to maximum dynamic modulus were aggregated in new aggregate classification. In this study, the new aggregate gradation is called suitable aggregate gradation.

2.1.6. Evaluation of effect of aggregate gradation on pavement performance

In this step, the performance of three different pavement structures was evaluated for Mid and Suitable aggregate gradations using AASHTOWare 2.5.5. For each aggregate variable, the AASHTOWare 2.5.5 was run nine times to cover all combinations of three traffic levels and three subgrade types. The pavement distresses [e.g., total rutting, rutting within the AC layers (AC rutting), alligator cracking, and longitudinal cracking] were predicted for 20-year design life at a 90% reliability level.

3. Results and discussions

The results of analysis of the effect of aggregate gradations on predicted dynamic modulus and on pavement performance are discussed as follows.

3.1. Prediction of dynamic modulus and determination of suitable aggregate gradation

The numerical analysis results revealed that the variation of aggregate gradations have profound effects on dynamic modulus of HMA mixtures values, even within restricted zones. The analysis results shown that increasing percent of aggregate passing the sieves 0.075 and 4.75mm increased the dynamic modulus, and for maximum percent passing the sieves 0.075 and 4.75mm, maximum dynamic modulus was predicted. The predicted dynamic modulus of HMA mixtures used in wearing course, binder course and base course are illustrated in Figure 1, Figure 2, and Figure 3, respectively. Conversely, results demonstrated that increasing percent of aggregate passing the sieves 9.5 and 19 mm in HMA mixtures, decreased the dynamic modulus. The maximum dynamic modulus of all mixtures was achieved for minimum percent of aggregate passing through the sieves 9.5 and 19 mm (Figure 4, Figure 5, and Figure 6).

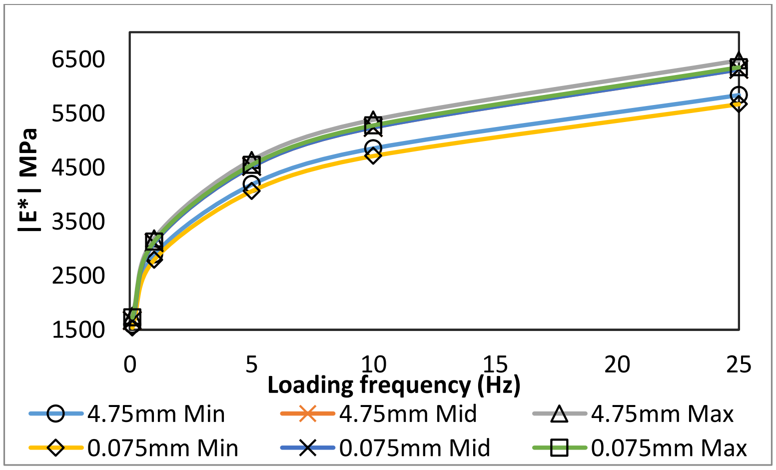

Figure 1. Predicted dynamic modulus of wearing course mixture for percent passing the sieves 0.075 and 4.75 mm.

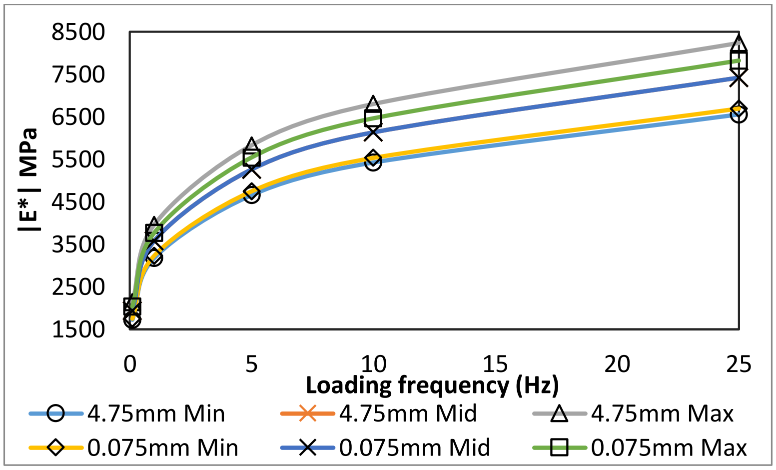

Figure 2. Predicted dynamic modulus of binder course mixture for percent passing the sieves 0.075 and 4.75 mm.

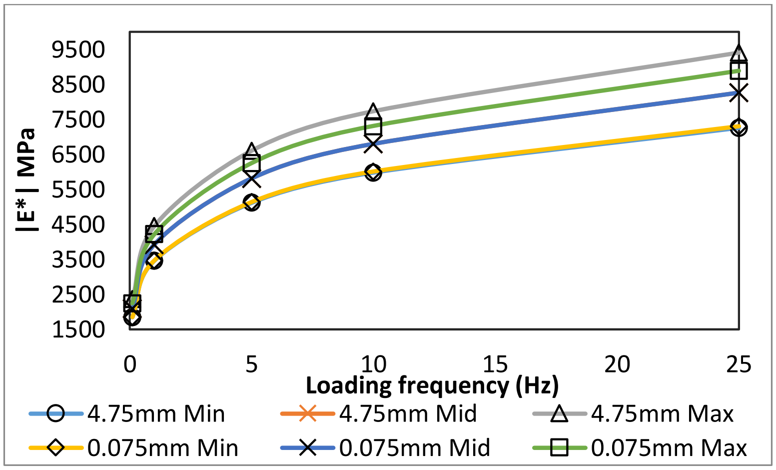

Figure 3. Predicted dynamic modulus of base course mixture for percent passing the sieves 0.075 and 4.75 mm.

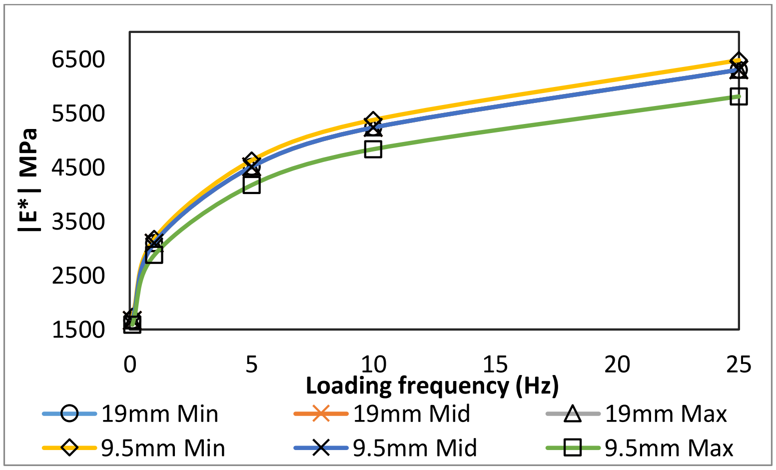

Figure 4. Predicted dynamic modulus of wearing course mixture for percent passing the sieves 9.5 and 19 mm.

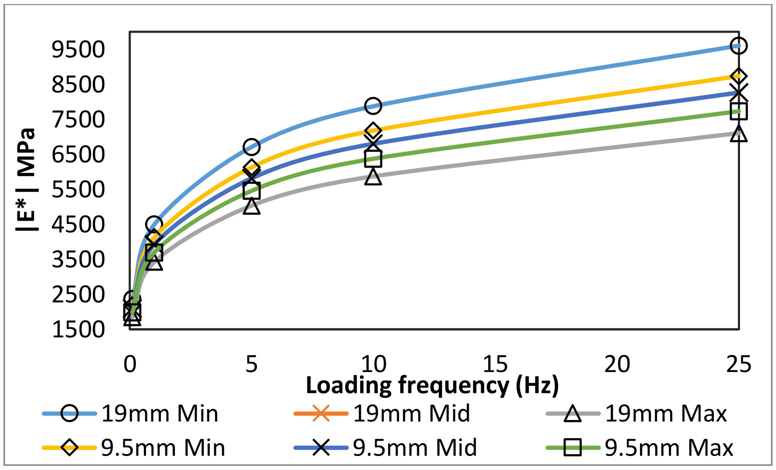

Figure 5. Predicted dynamic modulus of binder course mixture for percent passing the sieves 9.5 and 19 mm.

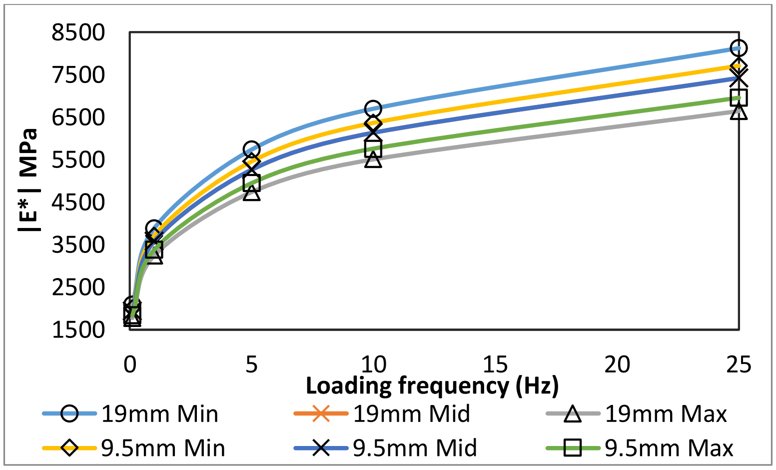

Figure 6. Predicted dynamic modulus of base course mixture for percent passing the sieves 9.5 and 19 mm.

According to the results, the maximum dynamic modulus of all HMA mixtures used in wearing course, binder course, and base course were achieved for maximum percent of aggregate passing through the sieves 0.075 and 4.75 mm and for minimum percent of aggregate passing through the sieves 9.5 and 19 mm. Therefore, the maximum percent of aggregate passing the sieves 0.075 and 4.75mm and the minimum percent of aggregate passing the sieves 9.5 mm and 19 mm were aggregated in new classification, and named suitable aggregate gradation. In this study, the suitable aggregate gradation is a gradation that maximum possible dynamic modulus of HMA mixtures is achieved for those values (Table 8).

Table 8. Suitable aggregate gradation.

Sieves (mm)	Wearing course	Binder course	AC Base course
% passing the sieve 19 mm	100	80	70
% passing the sieve 9.5 mm	72	48	55
% passing the sieves 4.75 mm	52	52	62
% passing the sieves 0.075 mm	8	7	6

In order to verify the suitable aggregate gradation, the dynamic modulus of HMA mixtures were predicted for suitable values (Table 8) and mid values (Table 7). Results shown that using suitable values compared to mid values resulted in an increase by 14, 30, and 38% in dynamic modulus of HMA mixtures used in wearing cosure, binder course, and base course, respectively, which are illustrated in Figure 7, Figure 8, and Figure 9.

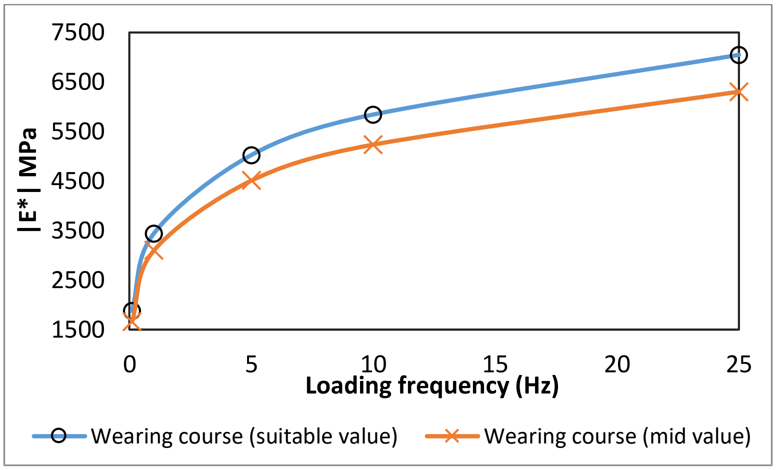

Figure 7. Dynamic modulus of wearing course mixture for suitable and mid values.

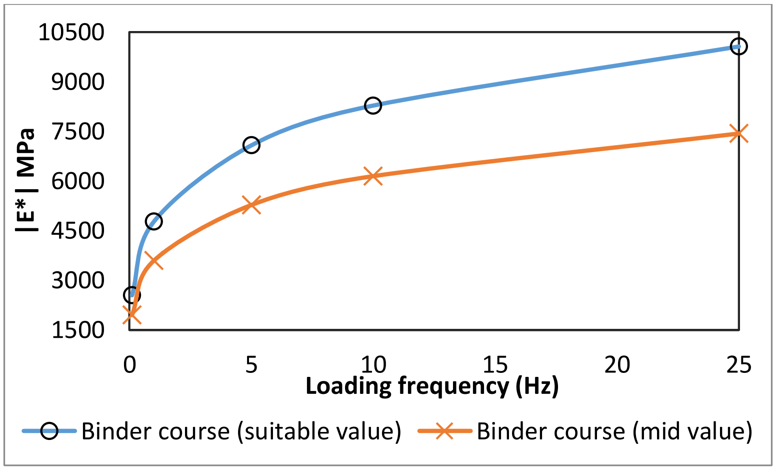

Figure 8. Dynamic modulus of binder course mixture for suitable and mid values.

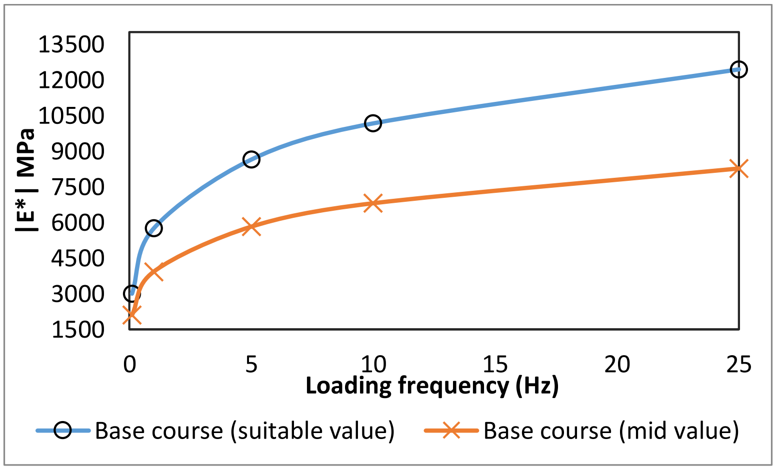

Figure 9. Dynamic modulus of base course mixture for suitable and mid values.

3.2. The effect of aggregate gradation types on pavement performance

The analysis results manifested that using suitable value compared to mid values resulted in higher rutting and fatigue resistance in flexible pavements for all traffic levels and any subgrade types.

3.2.1. Evaluation of rutting resistance

The study results demonstrated that total rutting and AC rutting depth in all pavement structures for all traffic levels and subgrade types are lower when suitable aggregate gradations are used compared to mid values. Figure 10 and Figure 11 show that the average total rutting and AC rutting in the presence of suitable values compared to mid values are lower by 5.95 and 9.72%, respectively. The comparison of Figure 7, Figure 8, and Figure 9 with Figure 10 and Figure 11 indicate that using mixtures with higher dynamic modulus results in higher rutting resistance in pavement.

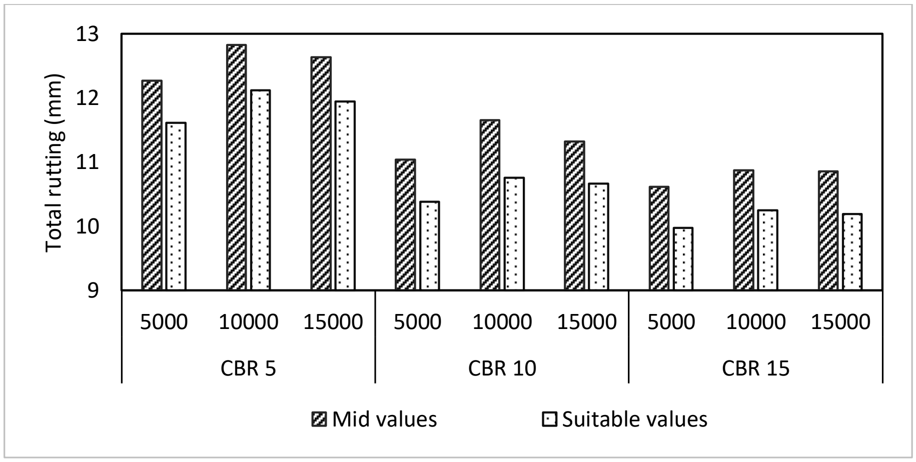

Figure 10. Comparison of total rutting for suitable and mid values.

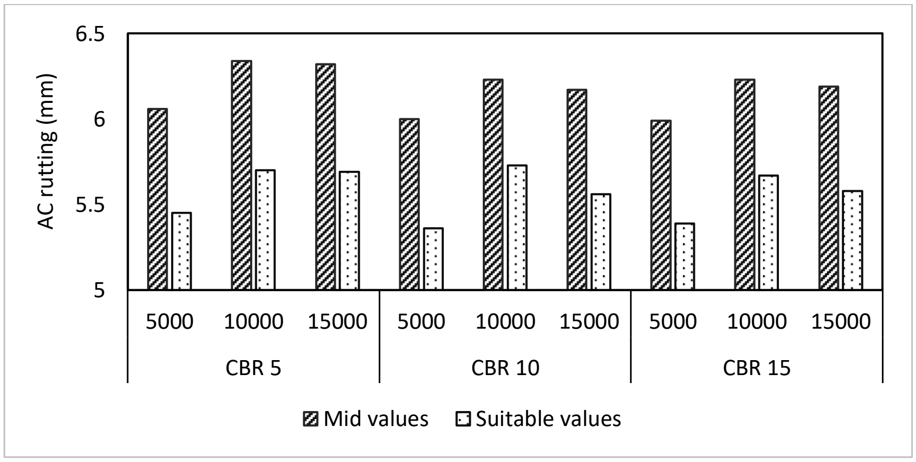

Figure 11. Comparison of AC rutting for suitable and mid values.

The rutting resistance may improve by increasing percent retained on sieves 19 and 9.5 mm increased the coarser aggregate percentage in the mixture. This increase provides a stable stone-to-stone skeleton held together by a higher percent of fine particles (percent passing through the sieves 4.75 and 0.075 mm) and asphalt binder. Although the variation of aggregate particle distribution in the suitable aggregate gradation is within the restricted zone of a dense-graded aggregate blend, its characteristics are close to stone mastic asphalt (SMA). In other hand, the comparison of dynamic modulus of danse-graded asphalt and stone SMA show that dynamic modulus of dense-graded asphalt mixtures is higher than SMA, in contrast the dynamic modulus of suitable aggregate gradation is higher than middle values (Cross, Gibbe, and Aryal 2011). Here, it should be noted that the lower dynamic modulus in SMA compared to dense-graded asphalt is caused by the existence of higher effective binder content in SMA but may not be due to the distribution of aggregate particles.

3.2.2. Evaluation of fatigue resistance

In this study, based on the MEPDG, the fatigue resistance of pavement in terms of two types of fatigue cracks [alligator cracking and top-down (longitudinal) cracking] were assessed for variation of aggregate gradation. Analysis results revealed that the for all traffic level and subgrade types, the use of suitable values rather than mid values resulted in higher fatigue resistance in flexible pavements. The magnitude of alligator cracking and longitudinal cracking decreased by 21.23 and 14.76% when suitable aggregate gradations are used rather than mid aggregate gradation (Figure 12 and Figure 13).

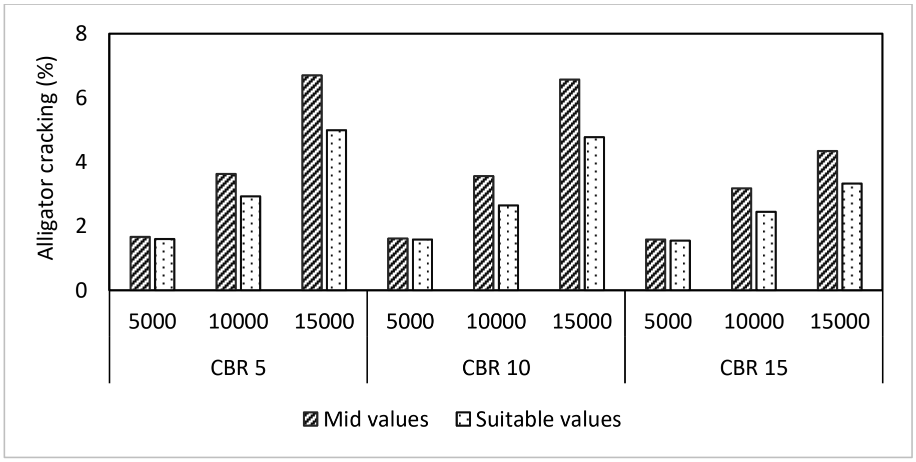

Figure 12. Comparison of alligator cracking for suitable and mid values.

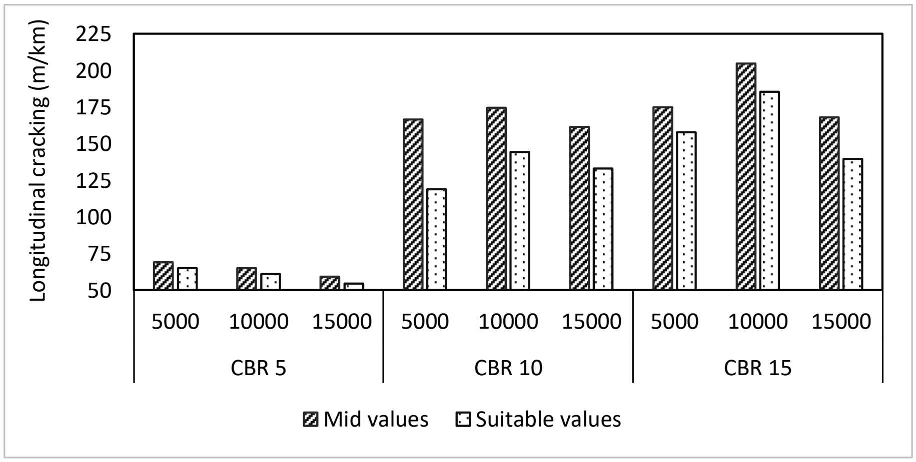

Figure 13. Comparison of longitudinal cracking for suitable and mid values.

4. Conclusions and comments

This study was conducted to improve the performance of flexible pavement through suitable aggregate gradation. To achieve the objectives, first the dynamic modulus of HMA mixtures for minimum, medium and maximum percent aggregate passing the sieves 19, 9.5, 4.75 and 0.075 mm were predicted and the suitable aggregate gradations were determined, then the performance of three different pavement structures for two aggregate gradations (middle and suitable values) using AASHTOWare Pavement ME Design 2.5.5 were evaluated for local conditions of Izmir, Turkey. Based on the analysis results, the conclusion is drawn as follows:

1. The predicted dynamic modulus of HMA mixtures is affected from variation of aggregate gradation, even in restricted zones;
2. Increasing percent of aggregate passing through the sieves 0.075 and 4.75 mm increase dynamic modulus of HMA mixture;
3. Decreasing percent of aggregate passing the sieves 9.5 and 19mm increase the dynamic modulus of HMA mixture;
4. Using suitable aggregate gradation rather than middle aggregate gradation, the dynamic modulus of HMA mixtures used in wearing course, binder course, and base course are increasing by 14, 30, and 38%, respectively;
5. The overall pavement rutting resistance and fatigue crack resistance are improved using suitable values compared to middle percent of aggregate passing the sieves. Using suitable values rather than middle values, total rutting and AC rutting depth in flexible pavement decreased by 5.95 and 9.72%, respectively. The magnitude of alligator cracking and longitudinal decreased by 21.23 and 14.76, respectively, using suitable values compared to middle values.

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