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Recommended Combination of the Bailey Parameters in Superpave Gradation Design for Japanese Airfield Pavements

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Abstract: The objective of this study is to investigate the necessary Bailey parameters to obtain satisfactory performance of Superpave mixtures for Tokyo International Airport (HND) pavements. The experimental work, which included 22 designed blends, was divided into three parts. Part 1 and Part 2 examined the effect of the Bailey parameters on voids in mineral aggregate (VMA) and rutting resistance. Based on the Part 1 and Part 2 findings, an optimization task was conducted in Part 3. Three performance related tests, namely the asphalt pavement analyzer (APA) test, wheel tracking test (WTT) and fatigue bending test were carried out to evaluate the performance of mixtures in Part 3. The test results indicated the Superpave coarse graded mixture with mid values of all Bailey ratios met the Superpave criteria and had higher resistance to rutting and cracking. The Superpave fine graded mixtures have to be designed with a lower coarse aggregate (CA) ratio and with the mid values of fine aggregate (FA) ratios to ensure adequate volumetric properties and high resistance to rutting and cracking. A comparison was made between the blends designed with and without the Bailey method. The results indicate that the blends designed with the Bailey method have provided significant improvement over those designed by the conventional Superpave method. It is recommended that the Bailey method be directly applied in a mixture design to save design time and effort.

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Key words*: Airport pavement; Asphalt mixture; Bailey method; Rut test; Superpave.*

Introduction

In Japan, the hot mix asphalt (HMA) mixture for airport pavements has been designed using the Marshall mix design method. For practicality, the mean values of the recommended gradation bands are the de facto standard for job mix formula. Over the past few years, rutting has been a frequent problem on asphalt pavements of the busy airports, especially in Tokyo International Airport (HND) [1]. It seems that the current Marshall fine graded mixture cannot withstand the traffic. The airport authority intends to apply the Superpave mixture, if suitable.

In 2008, Kai et al. gave a very preliminary review of the possibility of applying Superpave mixtures for airport pavements in Japan [2]. Four HMA mixtures with different nominal maximum particle size (NMPS) of 13 mm, 19 mm, 30 mm and 40 mm were designed. The mixtures had medium gradation in the specific ranges following the Japanese Marshall job-mix gradation bands. The selected numbers of gyrations (N_{des}) was 143. The test results indicated that the Superpave mixtures had rutting resistance superior to the Marshall mixtures. They further investigated the performance of 19 mm NMPS Superpave mixtures [3]. Three gradations within the Superpave control points, namely the fine, medium, and coarse graded, were designed. Only the coarse graded mixture met all the Superpave criteria. The fine and medium graded mixture could not meet the requirement of dust binder ratio. Four performance related tests, namely wheel track test (WTT), four point cyclic bending test, steered wheel tracking test, and three point static bending test, were carried out. The test results illustrated that the coarse graded mixture had higher resistance to rutting and cracking than the conventional Marshall fine graded mixture. Their study has shown the benefits of applying the Superpave mixture for airport pavements. Their study also indicated that in order to comply with all Superpave mix design criteria, time and effort are required for gradations trials.

It is well known that aggregate gradation greatly influences the mixture properties and performance. However, there are no specific guidelines in the Superpave mix design to ensure adequate volumetric parameters and satisfactory performance. Although the desired asphalt mixture volumetric properties can be obtained through the gradation adjustments, the performance of the mixture is still subject to verification. In this study, the authors deploy the Bailey method of aggregate gradation design in the Superpave mixture design for airport pavements in Japan. The Bailey method is a method of aggregate gradation design and an analysis for developing the aggregate structure in the asphalt mixture [4]. The Bailey method is chosen in this study because it links the aggregate gradation to voids in mineral aggregate (VMA) and voids estimation. This will reduce the trials to obtain the optimum gradation, thus resulting in considerable savings in time and effort during mix design.

Objective of the Study

Based on the literature search and reviews of information relevant to the use of the Bailey method in mixtures design, six out of eleven studies have proven that the Bailey method is effective to alter the VMA of mixture [5-10]. However, no relationship between the Bailey method and HMA mixture performance has been established. Although the recommended limits of Bailey ratios are given, very

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little is known on the necessary combinations of Bailey parameters that lead to a mixture that performs well. This study conducted a laboratory investigation with the objective to determine the desirable combinations of Bailey parameters for job mix gradations, in order to produce a mixture that provides high resistance to rutting and cracking in pavement.

Experimental

The Bailey Method Parameters

The parameters of Bailey method are briefly described here so that the readers become familiar with the terminology. The Bailey method has four parameters, namely the chosen unit weight of coarse aggregate (CACUW), the coarse aggregate ratio (CA), fine aggregate ratio of coarse portion (FA_c) and fine aggregate ratio of the fine portion (FA_f). The CACUW is the volume of coarse aggregates in the blend. It indicates how much void space must be filled by the fine aggregates, and determines the level of the aggregate interlock of the mixture. For a dense graded mixture, the CACUW refers to a percentage of loose unit weight of coarse aggregate (CALUW). The (loose unit weight) LUW represents the state of the aggregates that fill a unit volume when no compaction effort has been applied. It indicates the volume of the voids when the aggregates are just in contact with each other. This is considered as the lower limit of the coarse aggregate interlock.

The Bailey method has four control sieves to split the aggregates into coarse and fine aggregates, namely half sieve (HS), primary control sieve (PCS), secondary control sieve (SCS) and tertiary control sieve (TSC). The control sieve is dependent on the NMPS of the mixture. HS is defined as one half of the NMPS. The PCS is defined as the sieve that is closest to 0.22 of the NMPS. The value of 0.22 is an average ratio of the gap between the packing of any three different shaped particles that contain an unknown number of round and/or flat faces. The Bailey method uses 0.22 to further separate the fine fraction. The SCS is defined as the sieve closest to 0.22 of the PCS. It splits the fine aggregates into coarse sand and fine sand. Within the fine fraction, the aggregate larger than the SCS is considered as the coarse part of the fine fraction and smaller aggregate is considered as fine part of fine fraction. The fine sand is further evaluated by the TCS. The TCS is defined as the sieve closest to 0.22 of the SCS. The TCS splits the fine sand into the coarse part of the fine sand and fine part of fine sand.

The CA ratio is the percent passing the HS minus the percent passing the PCS and divided by 100% minus percent of HS. The FA_c is equal to the percent passing the SCS divided by the percent passing the PCS. The FA_f is equal to the percent passing the TCS divided by percent passing the SCS. The CA ratio is used to design and evaluate the packing of the coarse fraction and the resulting voids structure. FA_c ratio and FA_f ratio are used to design and evaluate coarse part of fine fraction (below PCS) and the fine part of fine fraction, respectively. To analyze the aggregate packing of the fine graded mixture, three new Bailey ratios are introduced, namely new CA ratio, new FA_c ratio, and new FA_f ratio. The new Bailey ratios control the gradation curve below the original PCS as a blend by itself [4].

The general effect of Bailey parameters on VMA is presented in Table 1. To increase the VMA of a coarser grade mixture, the designer can 1) increase the CALUW, 2) increase the CA ratio or 3) decrease the FA ratios. To increase the VMA of a fine graded mixture, the designer can 1) decrease the CALUW, 2) increase the new CA ratio, or 3) decrease the new FA ratios. The original CA ratio gives an indication of segregation and FA ratios indicate the coarseness and fineness of the blend. According to the Bailey principles, each parameter acts individually to change the VMA.

The definition for the coarse and fine graded mixture in the Bailey method is different from the Superpave method. The Bailey method defines the types of mixture based on the volume of the coarse aggregate in the mixture; the portion of the aggregate structure that carries the load and controls VMA. For example, the gradation with 90% of CALUW generally falls below the maximum density line (MDL) on the 0.45 power chart. This blend is referred as a fine graded mixture from the Bailey point of view, but it is considered as a Superpave coarse graded mixture. This study defines the coarse and fine graded mixture according to the Superpave method. Gradations that pass above the PCS are commonly called fine-graded mixtures, whereas those passing below are called coarse-graded mixtures.

Materials

Mixtures with different aggregates types, different NMPS, different aggregate interlocks (aggregate structure), different gradations curves and different compaction levels have different volumetric properties, and performances. The first step was to select the source materials for the study to minimize the differences. The 19 mm NMPS wearing course mixture of the Tokyo International Airport (HND) pavement was chosen in this case study because the pavements had severe rutting in wearing course layer. The same granular materials and asphalt binder as the HND mixture were utilized in the laboratory study. Table 2 shows the properties of the granular materials. For the asphalt binder, straight asphalt of Pen 60-80 was used. The properties of asphalt binder are shown in Table 3.

Outline of the Research Plan

Table 1. The General Effects of Bailey Parameters on VMA.

Parameters	To Increase VMA	To Decrease VMA
CALUW	Increase (for Coarse Graded Mixture) Decrease (for Fine Graded Mixture)	Decrease (for Coarse Graded Mixture) Increase (for Fine Graded Mixture)
CA/ New CA	Increase Ratio	Decrease Ratio
FA_c/ New FA_c	Decrease Ratio	Increase Ratio
FA_f/ New FA_f	Decrease Ratio	Increase Ratio

Table 2. The Properties of Granular Materials for Job Mix.

Item	Criteria	19 mm Crushed Sandstone	13 mm Crushed Sandstone	4.75 mm Crushed Sandstone	Screening	Coarse Sand	Fine Sand	Filler Hydrated Lime
Saturated Surface Density (g/cm^3)	>2.45	2.739	2.741	2.717	2.729	2.647	2.706	N/a
Water Absorption (%)	< 3.0	0.40	0.66	0.87	1.96	1.73	2.10	0.15
Los Angeles Value (%)	< 35	12.5	-	-			-	
Soundness (%)	<12	4.8	2.8	3.3			-	
Flat and Elongated (%)	<15	0.8	3.3	-			-	
Sand Equivalent (%)	>45		-				59	

Table 3. The Properties of Asphalt Binder for Job Mix.

Grade	Penetration (25℃) (1/10mm)	Softening Point (℃)	Ductility (15℃) (cm)	Solubility (%)	Flash Point (℃)	Loss on Heating (%)	Retained Penetration after Thin Film Oven Tst (%)	Penetration Ratio after Evaporation (%)	Density (15℃) (g/cm^3)	Kinematic Viscosity (cst)			Mixing Temperature ℃	Compaction Temperature ℃
60/80	60 −80	44.0 - 52.0	> 100	>99.0	> 260	< 0.6	> 55	< 110	<1.000	120℃	150℃	180℃	N/a	N/a
Test Value	74	50.5	100	99.93	324	0.06	60.8	100	1.034	1010	233	82.8	154−160	142−147

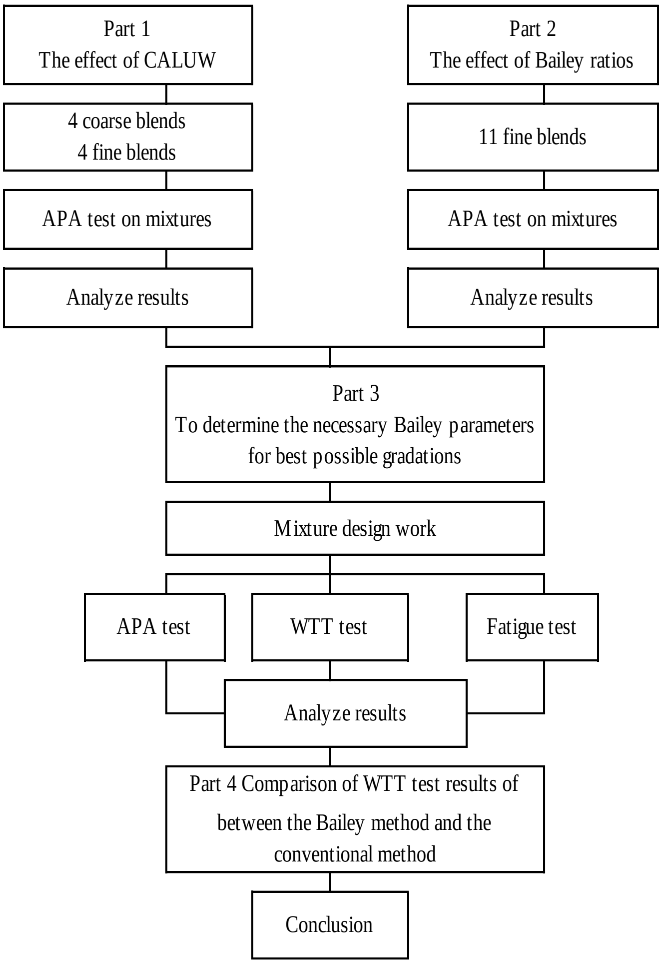

Fig. 1. Overall Research Approach.

The overall research approach is illustrated in Fig. 1. The Figure shows that the research was divided into four parts to obtain the information on the effect of Bailey parameters. Part 1 was to investigate the effect of CALUW on VMA and rutting performance. Part 2 was to investigate the effect of Bailey ratios within the Japanese preferred gradation bands. Part 3 was to extend the Part 1 and Part 2 research findings to conduct an optimization task by searching the appropriate combination of the Bailey parameters to obtain a mixture that performs well for HND pavements. Part 4 compared the mixture performances between gradation blends that were designed both with and without the Bailey method. This was to ascertain whether the Bailey method could significantly improve the job mix gradation.

All gradation blends in the study were designed within the recommended limits of the Bailey ratios and Superpave control points. All the specimens were compacted with N_{des} of 105 which represented the traffic level of HND [11]. The specimens were prepared following the Superpave mix design procedure to determine the optimum asphalt content (OAC) at 4 % air voids and tested for performance [12]. The experimental works and results obtained for the three parts are described as follows.

Part 1 Experiment Work

The primary purpose of Part 1 experiment was to determine which CALUW could produce a mixture with high rutting resistance while maintaining the volumetric properties. Eight blends with different CALUW ranging from 60% to 105% were designed. The gradation blends were designed to have a 5% interval at the percent passing 2.36 mm sieve. Fig. 2 shows the gradation Blends with different CALUW. Blends C1 to C4 were Superpave coarse gradations and blends F1 to F4 were Superpave fine gradations. C2 was the baseline design with CALUW of 100%. The CALUW for subsequent blends was changed from blend C2. The Bailey ratios of each blend followed the change due to the CALUW. Asphalt pavement analyzer (APA) was used to evaluate the rutting potentials of the mixtures. APA was used to perform the test according to

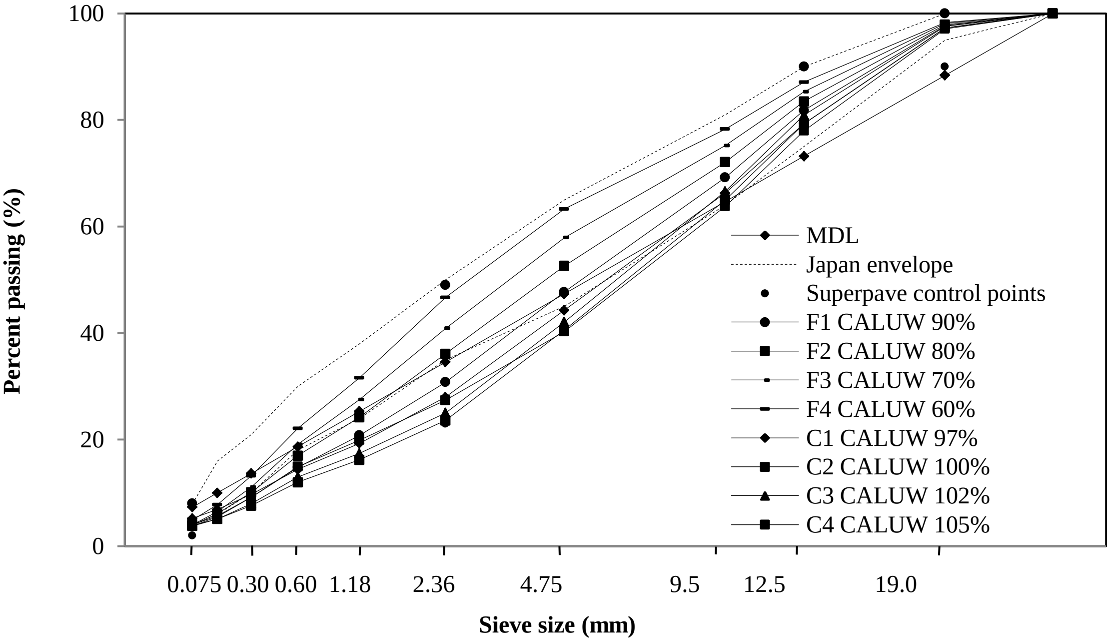

Fig. 2. The Gradation Blends in Part 1 Work.

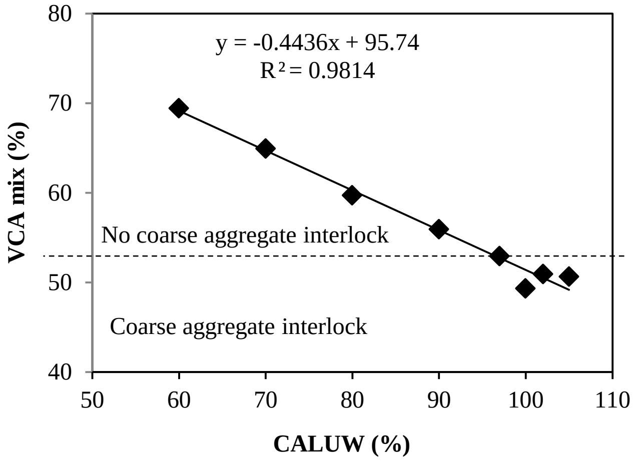

Fig. 3. The Relationship between the CALUW and VCA$_{mix}$.

Fig. 4. Blend C2 Specimens.

Fig. 5. Blend F4 Specimens.

AASHTO TP63-03. The specimens were preheated for six hours at a temperature of 60℃. The 60℃ is the standard testing temperature for Japanese rutting potential assessment.

The Bailey method identifies the existence of aggregate interlock at 100% of CALUW. Fig. 3 shows the CALUW versus voids in the coarse aggregate (VCA) of the mixture. The figure shows that the aggregate interlock occurred when the VCA of the mixture was less than 52%. The mixture with the VCA mix more than 52% had no coarse aggregate interlock. Fig. 4 shows the photo of Blend C2 at 100% of CALUW. The coarse aggregates were touching. Fig. 5 shows the photo of blend F4 at 60% of CALUW. The coarse aggregates were floating within the fine aggregate structure.

Table 4 shows the results of the combination of Bailey parameters, the VMA, and the rutting performance of the compacted specimens. The VMA value ranges from 13% to 15.7% and the rut depth ranges from 3.0 mm to 6.5 mm. Fig. 6 shows the effect of the CALUW on

Table 4. Combination of Bailey Parameters, VMA and Rut Depth of the Compacted Specimens.

Sieve Size (mm)	Blend	%CALUW	CA	FA_c	FA_f	New CA	New FA_c	New FA_f	VMA (%)	Rut Depth (mm)
Recommended Limits		N/a	0.60-0.75	0.35-0.50	0.35-0.50	0.60-1.00	0.35-0.5	0.35-0.50	>13.0	N/a
Fine Gradations	F1	90	0.70	0.44	0.44	0.60	0.44	0.43	14.1	3.2
	F2	80	0.70	0.46	0.42	0.72	0.42	0.39	13.0	3.4
	F3	70	0.70	0.47	0.4	0.79	0.40	0.36	14.0	3.0
	F4	60	0.69	0.50	0.42	0.91	0.42	0.37	14.1	6.0
Coarse Gradations	C1	97	0.65	0.44	0.50	0.53	0.50	0.54	14.2	3.6
	C2	100	0.65	0.49	0.46	0.58	0.46	0.41	14.0	3.1
	C3	102	0.73	0.41	0.46	0.44	0.46	0.49	14.1	4.9
	C4	105	0.70	0.40	0.47	0.44	0.47	0.5	15.7	6.5

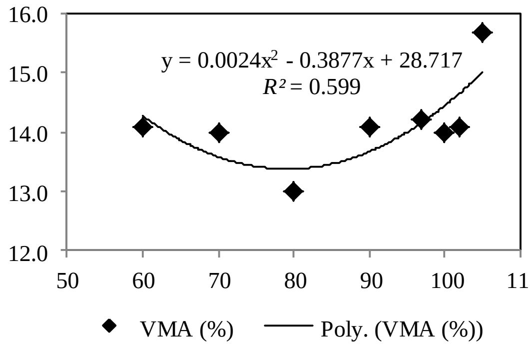

Fig. 6. The Effect of the CALUW on VMA.

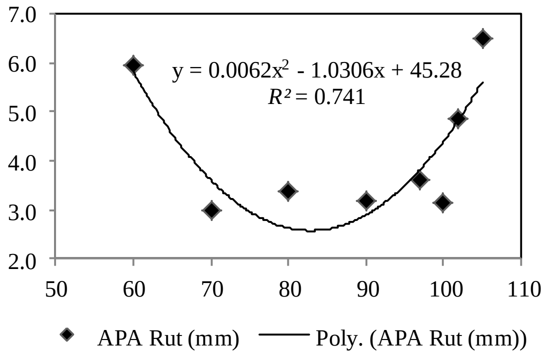

Fig. 7. The Effect of the CALUW on Rut Depth.

the VMA. The VMA increased when the CALUW increased towards the coarse graded mixture. This was because there was an increase in the coarse particles in the blend. The VMA also increased when the CALUW decreased towards the fine graded mixture. This was due to an increase in the fine particles in the blend. The trend line indicated that the VMA for the coarse graded mixture (right) was higher than the fine graded mixture (left). This was because the coarse graded mixtures would have larger void space between the coarse aggregate particles. The central portion of the curve, from 70% of CALUW to 90% of CALUW, had the lowest VMA. This corresponded to the densest gradation. The VMA data was in agreement with the Bailey principles. Fig. 7 shows the effect of the CALUW on the rut depth. It had a high coefficient of determination (R^2) value. The trend line indicated that the mixtures between the 70% and 90% CALUW had low rut depth. Both the coarsest and the finest blends had higher rut depth.

Part 2 Experimental Work

Part 2 of the experiment investigated the effects of the Bailey ratios within the Japanese Marshall Gradation Bands. The CALUW of the Japanese preferred gradation band is between the 70% and 80% of CALUW. 70% of CALUW was chosen because it produced the asphalt mixture that is finer than the current Marshall mixture. It is important to determine whether 1) the mixture properties would comply with Superpave mix design criteria and 2) the rutting resistance would be better than the current Marshall mixture. Eleven blends were designed to examine whether the recommended limits of Bailey ratios were appropriate for use. Fig. 8 shows the gradation blends of the Part 2 work. Blend M1 was the baseline blend. It had a the lower recommended limit of CA ratio (0.60) combined with upper recommended limit of FA ratios (0.50), and lower recommended limit of new CA ratio (0.60) combined with the upper recommended limits of new FA ratios (0.50), so that the mixture would have the lowest VMA in this study. The Bailey ratios for the subsequent blends were changed from blend M1. With this arrangement, their relative sensitivity to change in VMA values of each mixture could be seen clearly. Blends M2, M3, M6, and M7 were the blends with the change of the upper and lower limits of recommended Bailey ratios. Blends M4, M5 M8 and M11 were the blends with the change of FA ratios and new FA ratios. M9 and M10 were the blends with the change of all ratios. M10 had the mid values of the six Bailey recommended limits. The APA test was used to evaluate the rutting resistance performance of the mixture.

Table 5 shows the results of the Bailey ratios, the VMA, and rut depth of the compacted specimens. The mixtures had the VMA values ranging from 11% to 14.8% and the rut depth ranging from 2.4 mm to 4.3 mm. Out of the 11 blends, only two blends, namely blends M10 and M11 met all the volumetric criteria. Blend M10 with the mid values of all ratios had adequate VMA value of 14% and low rut depth value of 2.9 mm. It can be considered as the best job mix formula for the Part 2 experiment. Two blends, namely M5 and M8, met the VMA requirement but they could not meet the dust binder ratio requirement. Seven blends did not meet the minimum VMA requirement.

The experimental results showed that: 1) It was not recommended to design the aggregate gradation using the combination of all upper

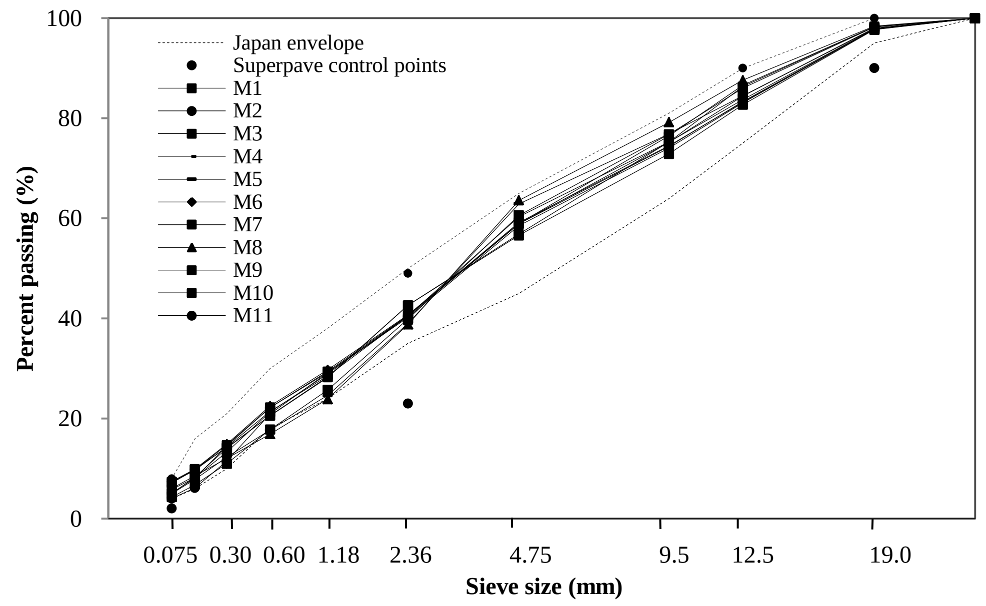

Fig. 8. The Gradation Blends of Part 2 Work.

Table 5. The Bailey Ratios, VMA and Rut Depth of the Gradations Blends.

Sample	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	Recommended Limits
CA	0.60	0.61	0.60	0.61	0.61	0.75	0.75	0.75	0.66	0.70	0.60	0.6-0.75
FA_c	0.50	0.50	0.50	0.47	0.39	0.50	0.50	0.38	0.49	0.42	0.50	0.35-0.50
FA_f	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.46	0.43	0.40	0.35-0.50
New CA	0.60	0.61	1.02	0.61	0.60	0.60	1.01	0.60	0.64	0.69	0.61	0.60-1.00
New FA_c	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.50	0.46	0.43	0.40	0.35-0.50
New FA_f	0.50	0.35	0.35	0.50	0.41	0.50	0.50	0.50	0.44	0.39	0.35	0.35-0.50
VMA (%)	11.0	11.9	12.5	12.0	13.2	10.8	11.3	14.8	11.4	14.3	13.0	>13.0
VFA (%)	64.9	67.9	66.5	66.0	69.1	62.0	64.6	71.3	64.5	73.1	64.9	65-75
Dust Binder Ratio	2.4	1.5	1.4	2.1	1.3	2.6	2.3	1.3	1.8	0.9	1.0	0.6-1.2
Rut Depth (mm)	3.1	3.2	4.3	3.1	3.2	3.0	2.4	4.4	2.7	2.9	3.7	N/a

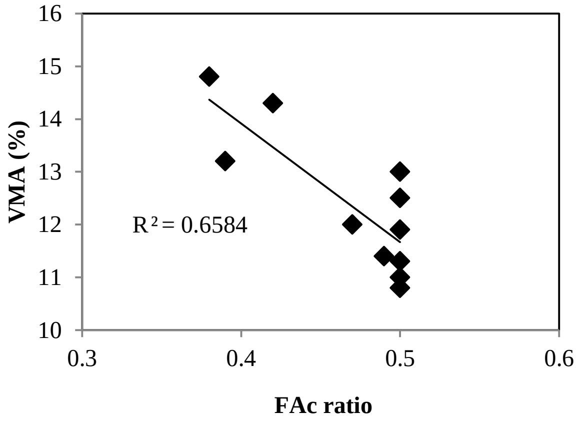

Fig. 9. The Effect of FA_c on VMA.

and lower recommended limits of the Bailey ratios because the gradations could not meet the minimum VMA requirement. 2) According to the Bailey principle, an increase in the CA ratio will increase the VMA. However, blend M6 indicated that an increase in the CA ratio had caused a slight decrease in VMA. This deviation was true because the fine graded mixture with a higher CA ratio contained fewer coarse aggregates in coarse fraction than that with a lower CA ratio. Thus, the combination of a high CA ratio with high FA ratios was not recommended for fine graded mixture. 3) Comparing the data of blends M2 with M3 and M6 with M7, both results showed that an increase in the new CA ratio increased the VMA. This was in the agreement with the Bailey principle. 4) Among all Bailey ratios, the FA_c ratio greatly affected the VMA of the mixture. Fig. 9 shows the effect of the FA_c ratio on the VMA. A reasonable high correlation coefficient, r = 0.88 was obtained between the FA_c ratio and VMA. The trend line showed that the VMA increased with decreasing the FA_c ratio. As the FA ratio increased towards 0.5 (the upper recommended limit of FA ratio), the VMA started to increase. The change of VMA value was in agreement with the Bailey principle. Fig. 10 shows the effect of the FA_c ratio on rut depth. The relationship between FA_c ratio and rutting resistance was weak. The r value was -0.29. There does appear that rut depth decreased as the FA_c ratio decreased. As the FA_c ratio started to increase towards 0.50, the rut depth started to increase.

Fig. 11 illustrates the relationship between VMA and rut depth. An r value of 0.66 was obtained between the VMA and rut depth due to the effect of CALUW in Part 1 experiment. An r value of

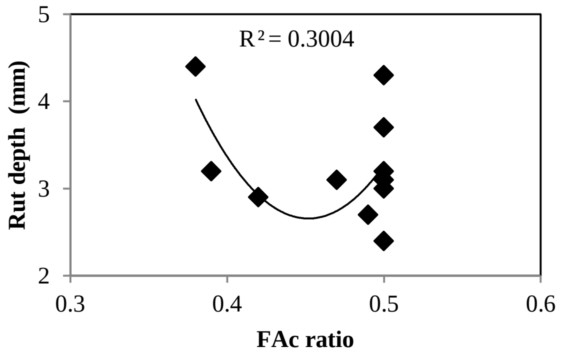

Fig. 10. The Effect of FA_c on Rut Depth.

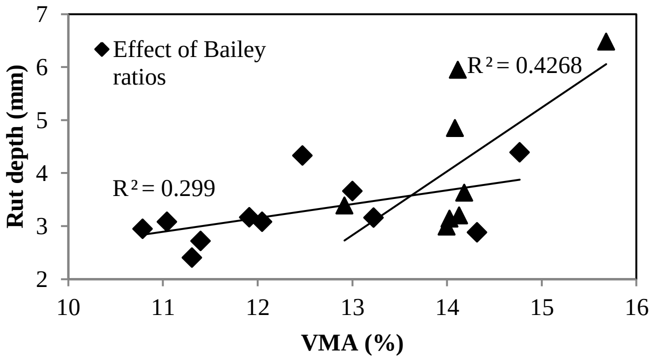

Fig. 11. The Relationship between the VMA and Rut Depth.

0.56 was obtained between the VMA and rut depth due to the effect of Bailey ratios in Part 2 experiment. The values indicate a moderate positive relationship between the VMA and rut depth. There does appear to be a trend line that an increase in rut depth occurs with an increase in VMA. The effect of Bailey ratios seemed to have less influence on mixture performance when compared with the effect of CALUW. The R^2 value was weak. The data was acceptable because the mixtures had the same aggregate interlock. It was difficult to predict the rut depth based on each Bailey ratio. For example, if the job mix formula has the same Bailey ratios but with a different percent of CALUW, the mixture properties and performance would be varied. This was why most of research findings cannot determine the correlation between the Bailey ratios and rutting resistance [6, 7]. The effects of the Bailey ratios on VMA and rut depth must be compared based on a same percent of CALUW and shall be evaluated in a total aggregate packing. Part 2 of the experiment indicated that the Bailey ratios seemed to have a stronger influence to control the VMA than the CALUW. At the same percent of CALUW, the changes in VMA had 4% difference while maintaining the same range of rut depth. Thus, there is a possibility that we can specify the desirable rut depth value with the requirement of volumetric properties. Further research is required to determine a consistent manner and practical improvement.

Part 3 Experiment Work

Part 3 of the experiment was aimed to create a basic concept of combining the Bailey parameters for obtaining a high rutting and cracking resistance mixture. Based on the Part 1 finding, the CALUW should be between 70% and 90% in order to obtain a high rutting resistance mixture. Part 2 findings were: 1) The mixture with all mid values of Bailey ratios seemed to be the best job mix formula. 2) FA ratios greatly influenced the VMA and rut depth. To minimize the VMA change due to the FA ratios, the Part 3 experiment fixed the FA ratios at the mid values of the recommended limits. CA ratio seems to be the second highest influence factor for rut depth. Thus, Part 3 examined the effect of the CA ratio on mixture performance. Three new gradations, namely blend CUW80, CUW90, and CUW100 with 80%, 90%, and 100% of CALUW, respectively, were designed to examine the appropriate CA ratio with mid values of FA ratios. Blend CUW80 was considered as a Superpave medium graded; the CA ratio was set at 0.60. Blends CUW90 and CUW100 were considered as the Superpave coarse graded blends. Literature review suggests that for coarse graded mixture, the mixture with a high CA ratio that contains more interceptor particles may be difficult to compact. Mixture with a low CA ratio, which contains more coarse aggregates, may not have enough fines to effectively interlock and may be prone to segregation [4]. Therefore, blends CUW90 and CUW100 were designed with 0.69 and 0.65 of CA ratios. Fig. 12 shows the gradation blends evaluated in the Part 3 experiment. The blends HNDM1 and M10 used in Part 2 are included for comparison. Blend HNDM1 was the replicate Marshall specimen but it was compacted with SGC at the equivalent compaction energy of the 75 blows of Marshall compactor. The equivalent N_{des} was 51 [11]. The result would indicate the performance of Marshall mixture.

Three tests, namely APA test, WTT test, and fatigue test, were performed to determine the rutting and fatigue resistance of the mixture. WTT was generally used to determine the rutting susceptibility of the airfield mixture used in Japan. The specimen was compacted to 300 x 300 mm in cross section and 50 mm in height by a rolling compactor. The test specimens were held in an environmental chamber for six hours at a temperature of 60℃. A contact pressure of 1.4 MPa with a load of 1.45 kN at a wheel speed of 200 mm/sec were set up. The test was stopped when the rut depth reached 20 mm. The fatigue test was used to evaluate the fatigue characteristics of the HMA mixture. The mode of loading and the effect of gradation were investigated. The applied strain rate was at a frequency of 5 Hz. The strain levels of 300, 400 and 500 micro strains were selected. The specimen was cut into the dimension of 300 mm x 40 mm x 40 mm. The tests were conducted at the temperature of 20℃. The test was discontinued when the specimen failed due to fatigue fracture.

Table 6 shows the combination of Bailey parameters, the volumetric properties, and the performance of the compacted specimens. Blend HNDM1 had the VMA value of 12.8% and rut depth value of 6.25 mm. As expected, blend CUW80, CUW90, and CUW100 met the Superpave criteria but did not have a high VMA. The VMA values ranged from 13% to 14.6% and rut depth values ranged from 3.30 mm to 3.89 mm. Blend M10, the finest graded mixture, had the lowest rut depth value of 2.88 followed by the CUW100, CUW80, CUW90, and HNDM1 blends. With the Bailey method, the required VMA values of the mixtures were obtained and the rut depth values were lower than the HNDM1 mixture.

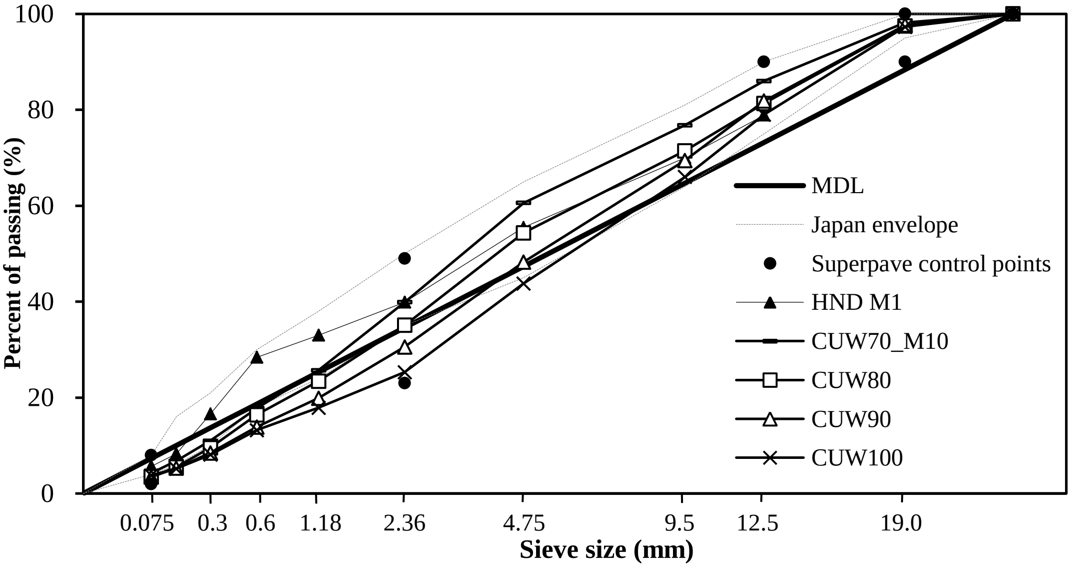

Fig. 12. The Gradation Blends of Part 3 Work.

Table 6. The Bailey Parameters, Volumetric Properties and Performance of the Blends.

Blend	CALUW (%)	CA	FA$_c$	FA$_f$	New CA	New FA$_c$	New FA$_f$	AC (%)	VMA (%)	APA (mm)	WTT (No. of Passes)	Fatigue (300 Strain)	Fatigue (400 Strain)	Fatigue (500 Strain)
HND M1	71	0.48	0.60	0.51	0.42	0.51	0.34	5.2	12.80	6.25	280	36548	14545	4936
M10	70	0.70	0.42	0.43	0.69	0.43	0.39	5.5	14.30	2.88	204	14777	6376	3101
CUW80	80	0.60	0.43	0.41	0.60	0.41	0.37	4.8	13.00	3.46	305	20516	6956	7411
CUW90	90	0.69	0.41	0.43	0.60	0.43	0.41	5.3	14.10	3.89	383	30742	13810	7096
CUW100	100	0.60	0.43	0.41	0.60	0.41	0.37	5.4	14.60	3.30	246	27035	12509	10144

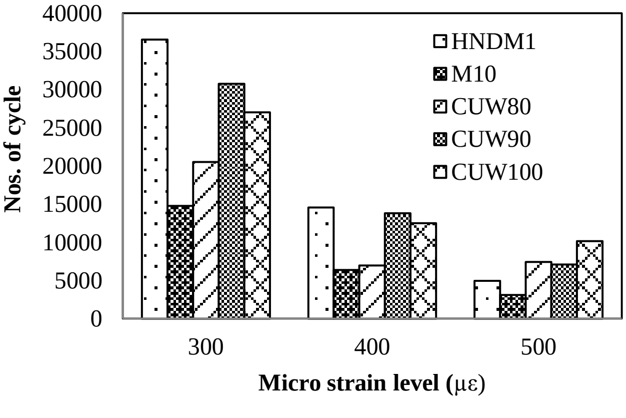

Fig. 13. The Fatigue Bending Test Results.

The WTT test results indicated blend CUW90 had the highest resistance to deformation, followed by the blends CUW80, HNDM1, CUW100, and M10. Blend M10 had the lowest deformation resistance. This result contradicted the APA test result. To determine whether the fine graded mixture with a lower CA ratio (in order to increase coarse particles) could improve the performance of the mixture, Blend M11 of Part 2 work was tested. Blend M11 had higher rutting resistance than M10. It had 373 passes. This shows that for a fine graded mixture, the mixture with a lower CA ratio and mid values of FA ratios was appropriate to produce a better performing mixture. The combination of Bailey parameters for coarse graded mixture was different from those of the fine graded mixture. The mixture CUW90 with a higher CA ratio performed better than the mixture CUW 100. This indicates that for coarse graded mixture, the mixture with mid value of CA ratio and FA ratio was appropriate to produce a better performed mixture.

Fig. 13 shows the results of fatigue bending test. The data with 300 micro strain levels indicated that the blend HNDM1 had the highest fatigue cycle. This result is acceptable because the HNDM1 mixture had higher asphalt content than the Superpave specimens. Blend HNDM1 specimen only had air voids content of 2.4% whereas the Superpave specimen had air voids of 4%. Among the Superpave specimens, blend CUW90 had the greatest resistance to fatigue cracking, followed by the blend CUW100, blend CUW80, and blend M10. Referring to results of the 400 micro strain-level, the trend shows the same as the 300 micro strain level. However, the difference between blend HNDM1 and blend CUW90 was mitigated. For 500 micro strain level, the blend CUW100 had the highest fatigue resistance, followed by the blends CUW80, CUW90, HNDM1, and M10. The Superpave mixtures except M10 had greater resistance than blend HNDM1. The test results were affected by the mode of loading and the types of mixture. It was seen that the fine graded mixtures, such as blend M10 and blend CUW80, had a lower fatigue resistance than the coarse graded mixture.

Comparison of Rutting Resistance of the Mixtures Designed with and without the Bailey Method

Christoper did not recommend using the Bailey method in

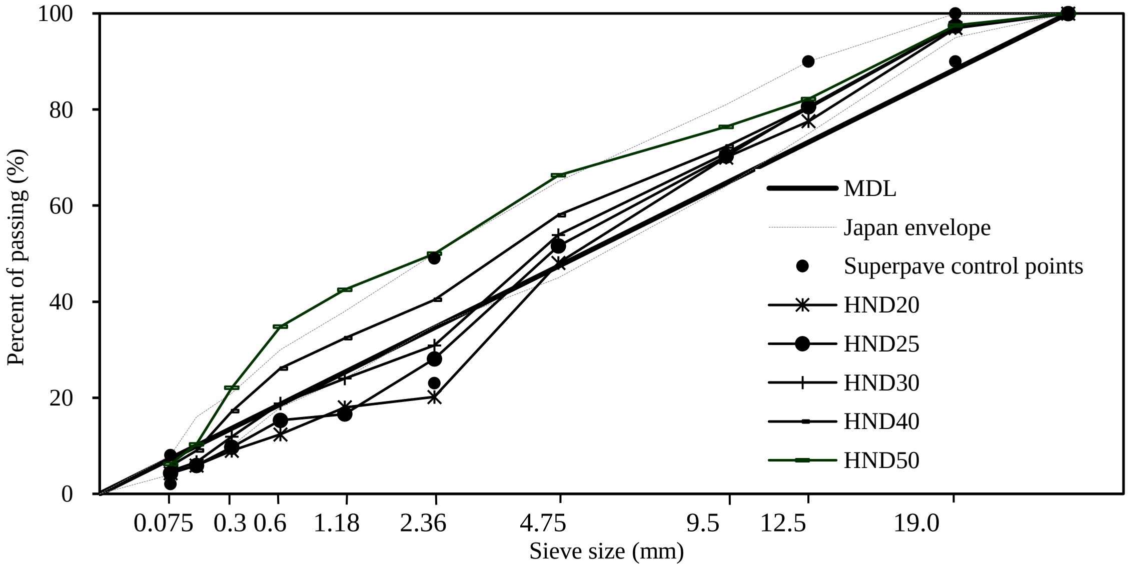

Fig. 14. The Blends Designed by the Conventional Method.

Table 7. The Bailey Parameters, Volumetric Properties and Performance of the Blends.

Blend	CALUW	CA	FA_c	FA_f	New CA	New FA_c	New FA_f	Bailey Compliance	AC (%)	VMA (%)	WTT Test (No. of Passes)
HND20	99	0.73	0.37	0.50	0.08	0.50	0.48	Yes	6.35	17.1	42
HND25	92	0.63	0.41	0.48	0.15	0.48	0.43	Yes	6.21	16.7	62
HND30	84	0.55	0.45	0.48	0.20	0.48	0.39	No	5.58	15.1	82
HND40	70	0.51	0.59	0.51	0.35	0.51	0.33	No	5.07	13.0	115
HND50	54	0.44	0.63	0.53	0.54	0.53	0.27	No	4.56	12.0	94

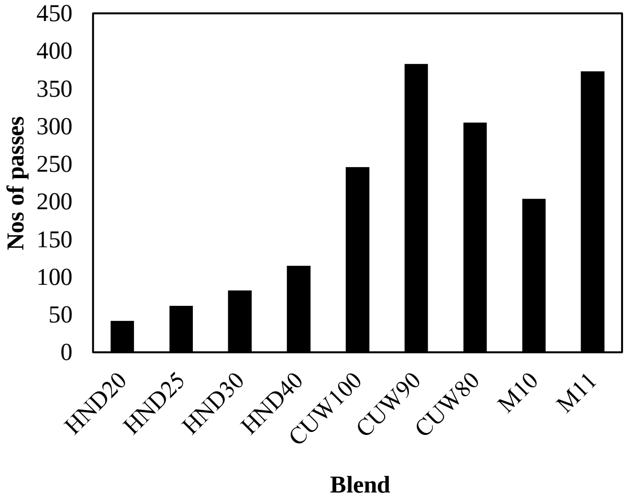

Fig. 15. The WTT Test Results of Mixtures.

Superpave mixture design, as he found the Bailey method did not provide significant improvement in performance from the conventional method [5]. In this study, a similar exercise was conducted. A comparison of rutting resistance of the mixtures between the gradation designed by the Bailey method and the design by the conventional Superpave method was made.

Fig. 14 shows the gradation blends designed by the conventional Superpave method. Five blends, namely HND20, HND25, HND30, HND40, and HND50, were used for comparison. The blends were adjusted from the HND blend and interfaced with the 2.36 mm sieve of Superpave control points. Each blend had 20%, 25%, 30%, 40% and 50% passing at the 2.36 mm sieve. Blend HND20 was below the lower limit of the Superpave control points. Table 7 shows the calculated CALUW, the Bailey ratios, and the test results of each blend. Blend HND20 and HND25 were both within the Bailey recommended limit, and the other three blends were not within the Bailey recommended limits. The VMA values ranged from 12.5% to 17.1%. All blends except the HND50 met the VMA requirement.

The WTT test was performed to evaluate the rutting resistance of the mixture. Four blends, HND20, HND25, HND30, and HND40, were used to compare with blends CUW100, CUW90, CUW80, M10, and M11 of this study. Fig. 15 shows the comparison of the WTT test results by both methods. The test results indicated that the gradation blends designed by Bailey method had higher rutting resistance than those designed by the conventional Superpave method. The main difference between the job mix gradations was the influence of the new CA ratio. The HND blends had a too low CA ratio that was not within the recommended limits.

Conclusions

The conclusions of this study are summarized as follows.

1. The Bailey ratios have more influence than the CALUW on the VMA of the mixture, and the CALUW has more influence than the Bailey ratios on the rutting resistance of the mixture. Further research is required to determine in a consistent manner the control of the rutting resistance.
2. In order to obtain a good rutting resistance mixture for HND

pavement, the target job mix gradation for coarse graded mix should be designed with the mid values of the recommended limits of Bailey ratios.

3. For fine graded mix, the target job mix gradation should be designed with a lower CA ratio and mid values of FA ratios in order to obtain adequate VMA and high rutting resistance mixture.
4. Comparing the gradation blends designed by the Bailey method with the gradation blends designed by the conventional Superpave method, the use of Bailey method is recommended in mixture design because it can control the VMA of the mixture and produce better rutting resistance mixture.

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