Rutting Performance of Hot Mix Asphalt Created Using Both Traditional Superpave Procedure and Bailey Techniques

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Abstract

The present investigation looked at whether the Bailey approach to aggregate gradation could be used to construct Superpave HMA blends. It also looked at how this approach influenced the rutting performance associated with these mixes and compared it to mixes of asphalt created by Superpave gradations. The current research included four aggregate gradations: both fine and coarse gradations for the Superpave and Bailey gradation procedures. The repeated loading test was utilized to assess the rutting performance. The findings indicated that temperature, stress level, and aggregate gradation all had a significant impact on rutting performance. In contrast to the other three gradations, the third mixture gradation exhibited the least amount of non-reversible deformation. It translates to pavement that is more resistant to rutting and less susceptible to it.

Keywords: Rutting Performance, Hot Mix Asphalt, Repeated Load Test, Superpave Method, Bailey Techniques.

اداء التخدد للخلطات الاسفلتية المصنعة بأتباع كلا من نهج السوبربيف التقليدي وتقنيات بيلي

علي عبد الخالق كمال ، حسن موسى جواد الموسوي، احمد نصار

الخلاصة:

تناول البحث الحالي ما إذا كان من الممكن استخدام نهج بيلي لتدرج الكتل لبناء مخاليط Superpave HMA. كما بحث في كيفية تأثير هذا النهج على أداء التخدد المرتبط بهذه المخاليط وقارنها بمخاليط الأسفلت التي تم إنشاؤها بواسطة تدرجات Superpave. تضمن البحث الحالي أربع تدرجات للركام: كل من التدرجات الدقيقة والخشنة لإجراءات تدرج Superpave و Bailey. تم استخدام اختبار التحميل المتكرر لتقييم أداء التشقق. أشارت النتائج إلى أن درجة الحرارة ومستوى الإجهاد وتدرج الكتل كان لها جميعًا تأثير كبير على أداء التشقق. وعلى النقيض من التدرجات الثلاثة الأخرى، أظهر تدرج الخليط الثالث أقل قدر من التشوه غير القابل للتخدد. وهذا يترجم إلى رصف أكثر مقاومة للتخدد وأقل عرضة له.

1. Introduction

Idealistic flexible pavement is a multi-layered elastic construction sitting on soil subgrade and a base of natural materials, designed to make it easier for vehicles to travel. Typical flexible pavement is composed of a top layer of asphalt concrete, a base, then a subbase course, and finally a subgrade of compacted soil [1]. Through the granular structure, the stresses imposed by vehicular traffic are transmitted from the interface of aggregate grains with one another. The layers of pavement are organized in descending order of load-bearing capacity. The most expensive material, which also has the largest load-carrying capacity, is placed on top, followed by the least expensive material, which also has the lowest load-bearing capacity. As a result, the stresses caused by moving vehicles are dispersed across a larger area, and as the depth increases, the stresses are reduced [1][2].

Because of the applied wheel loads, three principal distresses—rutting, fatigue cracking, and low-temperature cracking—are typically considered in flexible pavements throughout their service life. These issues shorten HMA's service life and raise maintenance costs [3][4]. Hot Mix Asphalt (HMA) therefore must be constructed to withstand the distress that results from and happen as a result of the applied wheel loads. Permanent deformation, also known as the rutting issue, represents one of the most serious distresses that severely affects the functionality of pavement structures in the majority of the road infrastructure in Iraq [5]. Rutting is widespread in flexible pavements due to asphalt mixtures' non-linear, viscous, and plastic behaviors [6][7].

The term "rutting" refers to a longitudinal depression in the pavement surface along the path of the wheels that is typically accompanied by pavement movement along the edges of the rut. Hydroplaning and significant structural damage can result from excessive rutting, which is a risk to safety. Rutting, which develops as a result of lateral deformation and densification, can happen in any of the pavement layers. Additionally, rutting is a gradual development of small permanent deformations caused by applied wheel loads [8]. Rutting can result from a confluence of factors including increased wheel load, hot weather, inadequate construction, and breakdown within one or maybe more structural layers. It could then lead to significant safety issues [9]. Rutting may be visible in the subgrade at deep levels or may just affect the surface of asphalt layers, which are composed of the viscoelastic and viscoplastic properties of asphalt and the plastic properties of aggregates particles [10].

As noted previously, rutting can occur in various layers of the pavement, but the main cause of the rut depth is cumulative deformation in the asphalt layers of the pavement surface. Although the condition of the pavement's granular and subgrade layers can have a huge impact on structural condition and play a major role in permanent deformation [11]. Table (1) displays an overview of a thorough literature review on the Bailey technique's effects.

The primary objective of this research is to assess how the Bailey approach for gradation affects HMA's rutting performance through the use of the Repeated Loading Test.

Table (1): Overview of a thorough literature review on the Bailey technique's effects.

No.	Outcomes generated by the research review	Reference
1	investigated the relationship among the compact ability of HMA and the aggregate gradation variables. For three coarser gradation combinations, a correlation was found between five HMA compact ability characteristics and the aggregate packing parameters as well as Bailey proportions. They came to the conclusion that they are strongly correlated. Researchers showed that Bailey proportions could be a highly helpful method for predicting the compact ability of HMA.	J.J. Komba et al., 2019
2	An effective technique for assessing aggregate mixtures is the Bailey approach. Mixtures containing coarser Bailey gradation, as specific, are more resilient to rutting over time The Bailey approach's primary drawback is that it simply takes aggregate dimension and gradation into account, ignoring additional aggregate characteristics including form, strength, texture of the exterior, kind and quantity of compaction energy, etc.	M.S. Oufa, and A.A. Abdolsamedb, 2016
3	The gradation approach used by Bailey is superior to that of the Asphalt Institute in terms of rutting performance. Additionally, the CA proportion for Bailey possesses a strong correlation coefficient, which may be represented as a value of R2 to predict the resistance to rutting. Blends having coarse gradation demonstrated stronger rutting resistance.	W. Teklu, 2015
4	a relationship between the hot mix asphalt's permeability and the most recent Bailey proportions.	S.A. Blaauw et al., 2019, and E. Horak et al., 2019
5	Improved outcomes are obtained by regulating the blend's VMA and creating stronger rutting resistance mixes when the Bailey approach for gradation is applied within the Superpave mix design procedure.	G.T. Shang et al., 2013
6	Blends made using the Bailey gradation technique outperformed blends made with the traditional technique.	K.R. Manjunath, and N.B. Poornachandra Dev, 2014
7	If aggregates that satisfy Superpave specifications are utilized, the Bailey Method may offer a helpful strategy for creating an ideal mix design that includes a sufficient estimate of the VMA parameter and verifying its verification.	J.P. Zaniewski, C. Mason, 2006
8	According to the Bailey technique of gradation, rut vulnerability might have been predicted because rutting was associated with rising VMA, which grew while reducing CA.	G. Thompson, ٢٠٠٦

2. Materials and Design Method of Hot Mix Asphalt

This part presents the materials that were chosen and prepared, including each material's physical characteristics. The materials preparation stage comprises crushed gravel, crushed sand, river sand, filler, and neat asphalt binder. The following parts cover the Hot Asphalt Mixtures used, the procedure to prepare a Superpave specimen includes figuring out the binder's viscosity, picking an appropriate performance grade, deciding on the mixing and compaction temperatures, developing aggregate gradation using the Bailey approach, and figuring out the optimum binder mix percentage for dense graded mixtures. The last section is the experimental procedure covering binder morphological characterization and mixture performance tests.

2.1 Materials Selection and Preparation

The materials that were employed in the present research are frequently utilized in asphalt construction projects in Iraq's central and southern areas and are readily available locally. Along with mineral filler (cement), they also incorporate neat binders of asphalt and mineral aggregates. The following paragraphs assess the qualities of these materials while comparing the results to the specifications of Superpave and the specification limits of the State Corporation for Roads and Bridges in Iraq (SCRB/R9, 2003).

2.1.1 Mineral Aggregates

Crushed gravel, crushed sand, and river sand have been selected as the three aggregate types that are most often used in Iraq for the surface course of flexible pavements. Table (1) displays the physical characteristics of the crushed gravel, crushed sand, and river sand employed in the current research. To ensure that the chosen aggregates are suitable for the Hot Mix Asphalt design, experimental Superpave evaluations were carried out and assessed alongside the required specifications as described in Table (2). The gradation of the selected types of aggregate is illustrated in Table (3).

2.1.2 Filler Material

Ordinary Portland Cement from Kufa Cement Plant in Al-Najaf Province - Kufa District - Al-Barakiyah was used as filler material for the preparation of the Hot Mix Asphalt samples in the current study. Table (5) summarize the physical characteristics of the filler that was employed. As stated in ASTM C110-16, the following tests are performed.

2.1.3 Neat Binder

The binder utilized in the current research was the asphalt binder that is manufactured in the AL-Daurah Refinery with a penetration grade of (40-50). The characteristics of the asphalt binder were summarized in Table (6). While the Superpave performance-graded (PG) of Asphalt Binder demonstrated in Table (7).

2.2 Superpave Mixtures Design

Superpave is a technique for creating asphalt mixtures that entail a series of four crucial steps: choosing the appropriate material, designing the aggregate structure (DAS), determining the design asphalt content (DAC), as well as assessing the moisture sensitivity of mixtures.

2.2.1 Bailey Approach for Designing the Aggregate Structure (DAS)

The major goal of this research project is to create the aggregate structure utilizing an analytical aggregate gradation method that will enable a sensible merging of various aggregate sizes to produce a densely packed aggregate skeleton for excellent stability and appropriate VMA. For this, the Bailey technique to perform a gradation assessment of the aggregate has been used. The equivalent unit weight for each kind of aggregate as well as the size of the sieve distribution must be obtained for the Bailey technique, which is frequently employed in dense-graded mix designs. The Bailey approach determines the Loose Unit Weight (LUW) and Rodded Unit Weight (RUW) for coarse aggregate and the RUW for fine aggregate following the procedures established by AASHTO T19-14. The aggregate structure is designed by Bailey's approach calculations. For example, in a mixture of (CACUW%) equal to (65%), the Bailey Approach procedure would be as in the Table (8). Table (9) illustrates the Bailey Ratios (Aggregate Ratios) of 12.5 mm NMAS for the selected four types of hot asphalt mixtures with specification limits of Superpave. Subsequent to this, Figure (1) shows the gradation of designated aggregate blends for the present research.

2.2.2 Mixing and compaction temperatures of asphalt mixtures

The viscosity of unmodified bitumen is typically measured using a rotational Brookfield viscometer utilizing the conventional standard method (D4402) / (AASHTO T 316) at temperatures of (135 C°) as well as (165 C°) with the objective of selecting the mixing and compaction temperatures of hot mixes asphalt. When using the equiviscous approach, the asphalt's temperature shall be raised to achieve viscosity values associated with (0.17 ± 0.02 Pa.s) followed by (0.28 ± 0.03 Pa.s), which will be used to decide the temperatures for mixing and compacting of hot asphalt mixtures, as demonstrated in Figure (2).

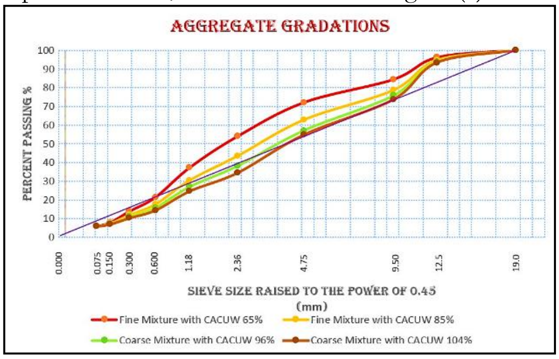


Figure (1): Gradation of designated aggregate blends.

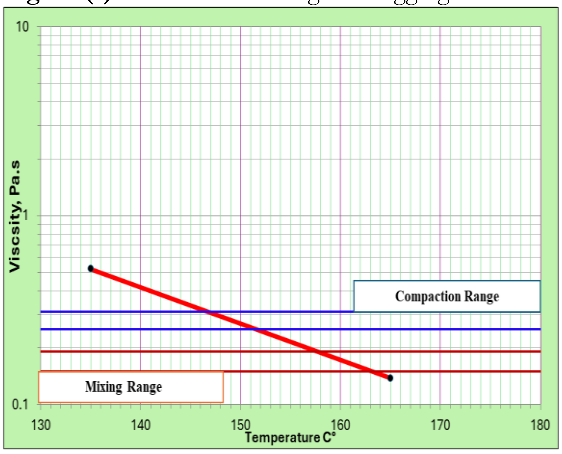


Figure (2): Mixing and compaction temperatures of asphalt mixtures.

According to the generated plot, the compaction as well as mixing temperatures for the neat bitumen utilized in the present research are 149 and 160.5 Celsius degrees, in that order.

2.2.3 Determination of Trial (Initial) Binder Content for Trial Blends

In accordance with the typical bitumen amounts for the designed aggregate structure recommended by the Asphalt Institute, the initial bitumen value was chosen as 5 percent. The objective was to determine the percentage of bitumen needed for the compacted specimens in order to satisfy the 4% designed air void content. According to the findings from compacted testing samples, an estimated design amount of bitumen will be determined (Institute, 2014). The estimated percentage of asphalt for each type of mixture is presented in Table (10).

2.2.4 Choosing Optimum Bitumen Content

For obtaining the optimum bitumen content or the design asphalt content (DAC), three samples corresponding to each chosen blend have been generated and compacted using the following four bitumen amounts:

- Pb estimated %.
- Pb estimated % + 0.5 %.
- Pb estimated % - 0.5 %.
- Pb estimated % + 1.0 %.

The Optimum Bitumen Content will be selected as the amount that satisfies the (4%) air void proportion after which the remaining volumetric parameters at (Nini) and (Nmax) are determined and checked in accordance with the recommended requirements. Figure (4) presented the volumetric properties against the bitumen percentage of the designed blend within (65% CACUW). Table (11) presents the design characteristics for selected mixtures with (12.5 mm NMAS).

2.2.5 Moisture Susceptibility Testing

Moisture susceptibility testing is the final stage in the Superpave mix design procedure. The moisture susceptibility of a mixture is assessed by examining it dry and then soaking it for specific periods of time. The Lottman Test (ASTM D 4867) serves as a typical approach to evaluating moisture susceptibility and stripping. For this test, six specimens are compacted to (7 ± 1 %) air voids. The Summary of the moisture susceptibility data for each type of bitumen mixture is presented in Table (12). The typical tensile strength ratio criteria are a minimum of 0.8 or 80 %, demonstrating a mixture of asphalt that is resistant to damage caused by moisture.

3. Hot Mix Asphalt Performance Tests and Results

The present section will describe the procedures used to evaluate blends of asphalt in laboratories and offers the outcomes of such tests.

3.1. Samples Preparation of Hot Mix Asphalt

Cylindrical samples with a diameter of 100 mm and thickness of 63.5 mm were prepared by utilizing the Superpave Gyratory Compactor (SGC) to be used in multiple asphalt performance tests. Table (13) below provides a summary of the sample mass for the four aggregate mixes required to provide the proper void percentage after compacting to the required thickness.

3.2. Repeated Loading Test

Repeated load test for HMA specimens is a typical technique for assessing the rutting as well as deformation properties of pavement made with asphalt. It aids in assessing the ability to withstand of the bitumen mixture against permanent strain under repetitive traffic loading, imitating the circumstances encountered by pavements in service. The experiments were performed through the use of a specific uniaxial cyclical stress and frequency. The test methods are designed to incorporate a ten-minute pre-loading process using a constant axial stress level of 5 kPa, which is applied to the specimen throughout the duration of the experiment, before carrying out the repeated load test. This procedure is performed in order to enable the establishment of good contact between the surface of the sample and loading plate. Once the pre-loading duration is completed, the sample is subjected to an axially cyclic, haversine-shaped loading pulse with a pulse width of 100 ms and a rest period of 900 ms. The contacting load applied to the sample guarantees that the LVDTs responding appropriately and that the vertically-loaded shaft cannot be lifted off the specimen being tested during the rest period.

3.2.1. Aggregate Gradation Impact

The goal of this subsection is to assist with choose the best hot mix asphalt type with the lowest rate of permeant deformation at the end of the experiment by creating multiple sets of charts that show accumulated strain percentage against the number of cycles for each sample that were examined under all the conditions of testing (three different stress levels as well as three different temperatures).

The results that were obtained from the repeated load test are displayed in Figures (4) for the two types of asphalt blends—fine and coarse blends—with different aggregate gradations. Four aggregate gradations were utilized, each with a different percentage of coarse aggregate chosen unit weight (CACUW%).

The mentioned figures showed that, under all testing settings, the (MX-3) gradation, had a minimum non-reversible deformation compared to the other three gradations. As can be seen in Figure (4-I), only the mixture (MX-3) that containing 96% CACUW was able to withstand the severe test circumstances, which included a temperature of 55°C and a stress level of 30 psi. Bitumen mixtures that exhibit smaller permanent deformation are typically less prone to rutting over time. In consideration of this explanation, the ideal gradation to complete the remaining assessment testing has been determined to be (MX-3), with a gradation of 96% CACUW. The results presented suggest that a properly graded blend with an appropriate ratio of fine to coarse particles enhances both the hot mix asphalt's mechanical characteristics and the duration of life.

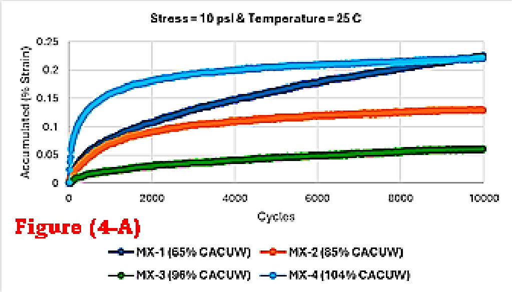


Figure (4-A)

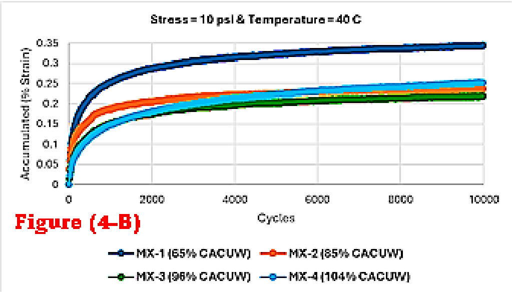


Figure (4-B)

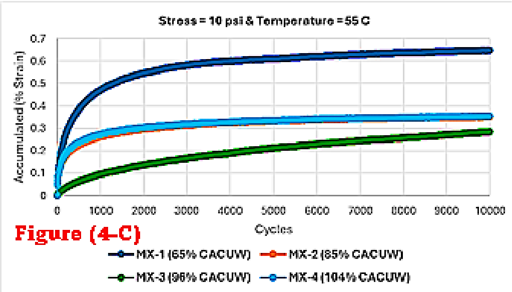


Figure (4-C)

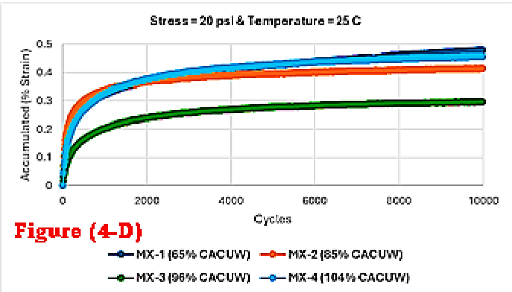


Figure (4-D)

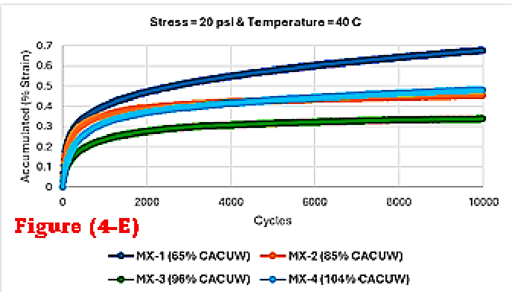


Figure (4-E)

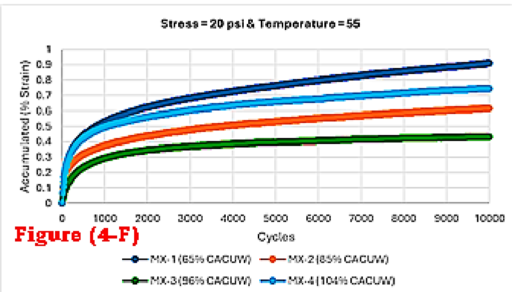


Figure (4-F)

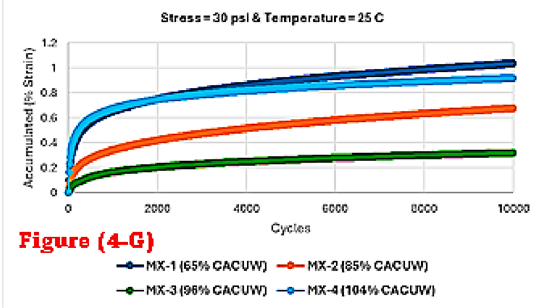


Figure (4-G)

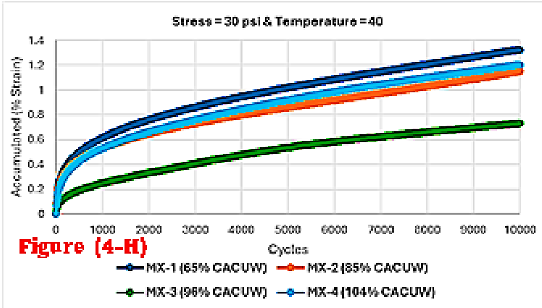


Figure (4-H)

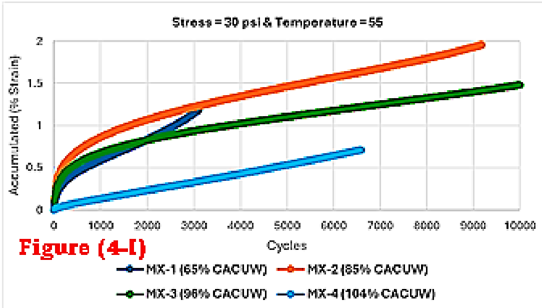


Figure (4-I)

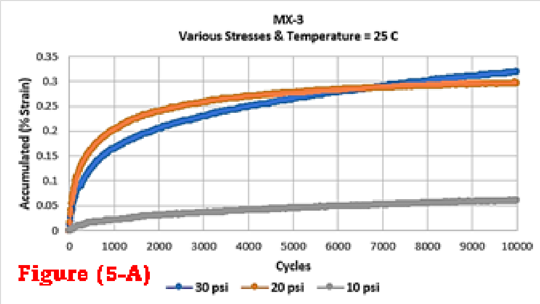
Figure (4): Creep curve for four different types of hot mix asphalt blends with various percentage of the CACUW at various stress level and various temperatures.

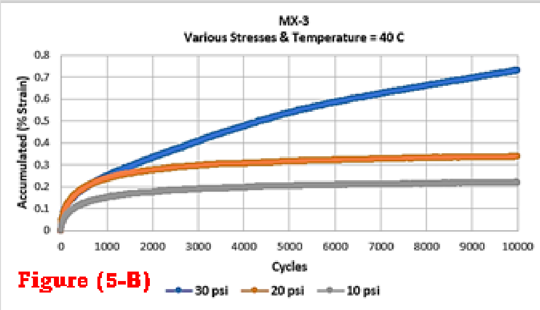
3.2.2. Stress Level Impact

The stress level has a major impact on asphalt mixtures' permanent strain characteristics, especially in tests like the repeated load testing. The current part focuses on examining the relationship between stress level and the progression of the permanent strain. In order to investigate the impact of stress level on asphalt blend behavior, a total of three different stress levels were selected for this experiment. The selected stresses were 10 psi, 20 psi, and 30 psi.

The stress levels suggested above were selected due to their closely represent the stress and pressure brought on by loads of traffic that occur above as well as below the surface of the pavement. The main objective of introducing various stress levels in this experiment was to replicate the range of strain rates present in HMA and, consequently, to better understand the bitumen blends' creep behavior. The repeated load test was conducted on four various bituminous blends; on the other hand, the results and evaluation shown in Figure (5) was restricted to the best bituminous blend (MX-3 with 96% CACUW).

The results clearly show that loading values have a significant impact on the long-term strain of asphalt mixtures. The comparison of the figures shows that permanent strain increases when the load applied increase from 10 psi to 30 psi and that a higher stress level is likewise represented in a higher permanent deformation. The explanation for this is because when stress levels are higher, both the binder that holds asphalt together and the aggregate structure deform more severely.





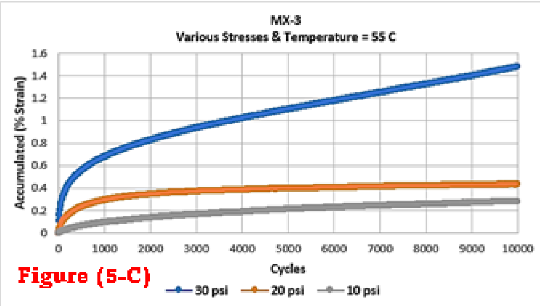


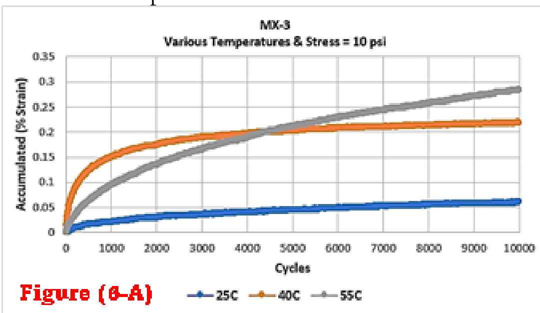
Figure (5): Creep curve for MX-3 with 96% of CACUW under testing condition of various stress level.

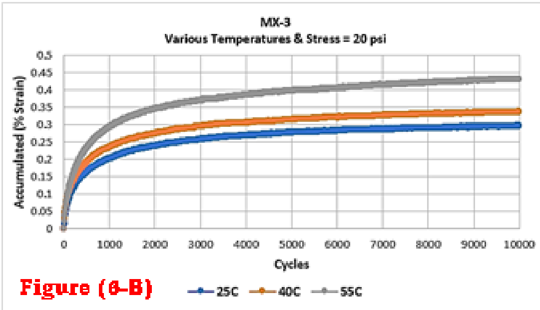
3.2.3. Temperature Impact

In order to examine the impact of temperature on the permanent deformation behavior of the HMA, the MX-3 samples containing 96% CACUW underwent the repeated load testing at three distinct temperatures. The findings of this investigation are displayed in Figure (6). The current investigation employed 25°C, 40°C, and 55°C as testing conditions. the rationale behind using the temperatures listed previously to evaluate rutting is that they show a range of typical operating temperatures and circumstances that pavements as well as bitumen materials deal with.

When comparing one temperature to another, 25°C usually serves as a control condition. It is representative of room temperature in moderate or temperate regions when pavements have not been subjected to significant temperature changes. Testing temperature of 40°C symbolizes higher temperatures found in areas experiencing hot weather or in pavements subjected to intense sunshine. It also assesses how well asphalt mixtures and pavements operate in hot weather, which can cause rutting because the asphalt binder softens. On the other hand, testing temperature of 55°C simulates the extremely high temperatures that may be encountered in particularly hot areas. It also evaluates how asphalt blends and pavements perform in extremely hot environments, which could lead to rutting problems.

Obviously, two major factors influencing the behavior of permanent deformation are temperature and stress. Increased temperatures and stress induce the asphalt binder to become more viscous, enhancing flow and rutting and hastening the deformation process in asphalt mix. The repeated load test was carried out up to the loading cycle of 10000, therefore the most of samples kept its status as within the secondary zone, additionally the flow numbers were not determined for the reason that the tertiary zone of the creep curve does not appear in the majority of the tests that were performed.





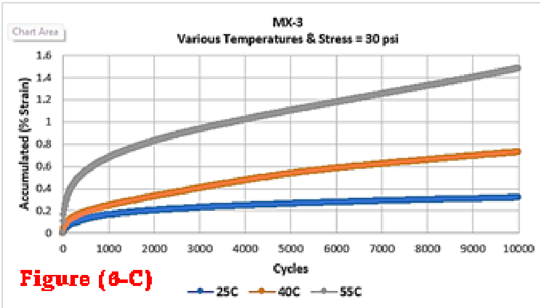


Figure (6): Creep curve for MX-3 with 96% of CACUW under testing condition of various temperatures.

4. Conclusions and Recommendations

4.1 Conclusions

The findings of the research led to the subsequent conclusions, which can be summed up as follows:

1. strong aggregate packing is typically achieved by employing Bailey method aggregate gradation, as demonstrated by strong rutting performance. Additionally, the Bailey ratios are useful classification tools for creating appropriate aggregate interlock.

2. When it comes to aggregate packing as well as general mixture qualities, Bailey blends outperform Superpave blends since the latter lack a set of guidelines for identifying irregular gradation.
3. Bailey gradation blends provide excellent rutting performance while saving money, working time, and labor.
4. The degree of stresses has a major impact on rutting performance; deeper rut depth is correlated with higher stress levels (more axial loads).
5. The primary testing factors (temperature, stress intensity, and aggregate gradation) significantly impacted the findings of the permanent strain test.

4.2 Recommendations

Because the present study was not focused on low temperature cracking as well as fatigue performance of Bailey gradation blends, more investigation is necessary. Additional testing parameters (such as the amount of asphalt and the confining pressure) need to be used in investigations. Furthermore, it is necessary to research further Bailey aggregate gradations by creating Bailey gradations with various Bailey ratio values.

5. Acknowledgements

This article is a part of Ph.D. dissertation in Civil Engineering at Al-Nahrain University.

Table (2): Physical characteristics of the crushed gravel, crushed sand, and river sand.

Measured properties	ASTM/AASHTO Designation	Test Results		
		Coarse Aggregate	Fine Aggregate	
		Crushed Gravel (CG)	Crushed Sand (CS)	River Sand (RS)
Bulk Specific Gravity	ASTM C127-15 AASHTO T 85-14 &ASTM C128-15 AASHTO T 84-13	2.598	2.637	2.625
Apparent Specific Gravity		2.657	2.702	2.691
Water Absorption, %		0.631	1.401	0.862

Table (3): Superpave tests results of the crushed gravel, crushed sand, and river sand.

Measured Properties	Superpave Requirements	Test Results		
Consensus Properties				
Coarse Aggregate Angularity (CAA), %	Min. 95/90	98 %		
Fine Aggregate Angularity (FAA), %	Min. 45	52 %		
Flat and Elongated particles (F&E), %	Max. 10	2 %		
Sand Equivalent (SE), %	Min. 45	61 %		
Source Properties	Superpave Requirements	Test Results		
		Coarse Aggregate	Fine Aggregate	
			Crushed sand	River sand
Toughness by Los Angeles abrasion, %	Max. 30	18.68 %	-	-
Soundness test by Na_2SO_4, %	Max. 15	2.86 %	1.14 %	1.21 %
Deleterious materials %	0.2 - 10	0.31 %	3.3 %	3.5%

Table (4): Aggregate gradation results for the crushed gravel, crushed sand, and river sand.

Sieve Size		Coarse Aggregate	Fine Aggregate	
inch	mm	Crushed Gravel	Crushed Sand	River Sand
3/4"	19	100	100	100
1/2"	12.5	89.7	100	100
3/8"	9.5	58.2	100	100
No.4	4.75	29.6	97.6	96.2
No.8	2.36	5.1	82.6	80.2
No.16	1.18	3.6	50.1	65.7
No.30	0.6	0.1	23.2	45.4
No.50	0.3	0.1	17.2	12.9
No.100	0.15	0	6.4	4.6
No.200	0.075	0	2.1	1.8

Table (5): Ordinary Portland Cement physical characteristics.

Property	SCRB specification	Test Result
Specific Gravity (G_{filler})	**/**	**3.12**
% passing sieve No.200 (0.075 mm)	**70 - 100**	**100**

Table (6): Physical characteristics of Neat Binder.

Binder Tests	ASTM Designation	Test results	SCRB Requirements
Penetration (25 °C, 100 g, 5 s, 0.1 mm)	D 5	42	40 – 50
Flashpoint (Cleveland open cup)	D 92	262	> 230 °C
Softening point (Ring & Ball)	D36	53.9	50 °C – 58 °C
Ductility (25 °C)	D 113	+100	> 100 cm
Specific gravity @ 25 °C	D 70	1.04	(1.01 – 1.06) gm/cm^3
Solubility in C_2HCL_3, %Wt	D 2042	99.9	> 99.0
Absolute viscosity at 60 ºC	D 2171	4152.6	(4000 ± 800) Poise
Kinematics viscosity at 135 ºC	D 2170	628.1	> 400 cSt
%Wt Loss in Heating (50g, 5h @ 163°C)	D 1754	0.028	< 0.5
% Original of Penetration after loss in heat (25 °C, 100 g, 5 s, 0.1 mm)	D1754 & D5	91	> 75
Ductility of residue (25 °C)	D1754 & D113	64	> 25

Table (7): Rheological characteristics of Asphalt Binder (40-50).

Aging Condition: Original binder (Un-aged)			
Type of Test	**Temperature**	**Test Results**	**AASHTO T-315 Requirements**
Rotational Viscometer (RV) Viscosity	135 C^0	0.523	≤ 3 Pa.s
	165 C^0	0.138	
Dynamic Shear Rheometer (DSR) │G*│ / Sin δ @ 10 rad/s, Kpa.	58 C^0	4.476	≥ 1 KPa
	64 C^0	1.859	
	70 C^0	0.858	
Aging Condition: RTFO Residue (Short-term aging)			
Type of Test	**Temperature**	**Test Results**	**AASHTO T-315 Requirements**
Dynamic Shear Rheometer (DSR) │G*│ / Sin δ @ 10 rad/s, Kpa.	58 C^0	5.918	≥ 2.2 KPa
	64 C^0	3.352	
	70 C^0	1.886	
Aging Condition: PAV Residue (Long-term aging)			
Type of Test	**Temperature**	**Test Results**	**AASHTO T-315 Requirements**
Dynamic Shear Rheometer (DSR) │G*│ / Sin δ @ 10 rad/s, Kpa.	22 C^0	9878	≤ 5000 KPa
	25 C^0	8641	
	28 C^0	4372	
Bending Beam Rheometer (BBR) Creep Stiffness (S) @ 60 sec.	0 C^0	72.35	≤ 300 MPa
	-6 C^0	148.71	
	-12 C^0	378.47	
Bending Beam Rheometer (BBR) m-value @ 60 sec.	0 C^0	0.376	≥ 0.3
	-6 C^0	0.311	
	-12 C^0	0.262	

Table (8): Results from the Bailey Approach procedure for the blend of (65%) Coarse Aggregate Chosen Unit Weight.

Sieve Size		Coarse Aggregate Blend by Volume	Fine Aggregate Blend by Volume		% Passing Sieve No.200	Obtained Gradation
inch	mm	CG	CS	RS	MF	
		100%	75%	25%		
3/4"	19	100	100	100	100	100.00
1/2"	12.5	89.7	100	100	100	96.15
3/8"	9.5	58.2	100	100	100	84.38
No.4	4.75	29.6	97.6	96.2	100	72.08
No.8	2.36	5.1	82.6	80.2	100	54.09
No.16	1.18	3.6	50.1	65.7	100	37.44
No.30	0.6	0.1	23.2	45.4	100	21.56
No.50	0.3	0.1	17.2	12.9	100	14.08
No.100	0.15	0	6.4	4.6	100	8.17

No.200	0.075	0	2.1	1.8	100	5.91
CUW of Coarse Aggregates %		65 %				
RUW of Fine Aggregates %			100 %			
LUW (kg/m³)		1382.4				
RUW (kg/m³)		1557.1	1653.6	1754.2		
Chosen Unit Weight (CUW)		898.56	1653.6	1754.2		
Bulk Specific Gravity, G_{sb}		2.598	2.637	2.625		
Percentage of Voids between CA		65.4%				
Unit Weight contributed by each Aggregate		898.560	811.257	286.870		
Unit Weight of Blend (UWB)		1996.687				
Initial Blend Percentage		45.0%	40.6%	14.4%		
% Fine aggregate in the coarse stockpile to its portion in a mix		2.295%				
% Coarse aggregate in the fine stockpile to its portion in a mix			7.064%	2.851%		
Justified blend percentage		37.38%	46.32%	16.3%		
% Passing Sieve No.200		0.00%	0.97%	0.29%		
Desired Mineral Filler %					6.00%	
Needed Mineral Filler %					4.74%	
Proportions of the Final Mixture		**37.38%**	**42.77%**	**15.11%**	**4.74%**	

Table (9): Bailey Ratios (Aggregate Ratios) of 12.5 mm NMAS for four types of hot asphalt mixtures with specification limits of Superpave.

Aggregate Mixtures	**Bailey Ratios (Aggregate Ratios) for 12.5 mm NMAS**					
	Coarse Graded Mixture			**Fine Graded Mixture**		
	CA%	**FA_c%**	**FA_f%**	**New CA%**	**New FA_c%**	**New FA_f%**
MX 1 (65% CACUW)	0.64	0.398	0.378	0.97	0.378	The size of the sieves was too small to estimate the value.
MX 2 (85% CACUW)	0.52	0.408	0.427	1.0	0.427	
MX 3 (96% CACUW)	0.50	0.415	0.461	/	/	
MX 4 (104% CACUW)	0.45	0.421	0.490	/	/	
Recommended Ratios	0.5-0.65	0.35-0.5	0.35-0.5	0.6-1.0	0.35-0.5	0.35-0.5

Table (10): Estimated Bitumen amounts for the chosen aggregate blends.

Mixture Kind	**MX 1 (65% CACUW)**	**MX 2 (85% CACUW)**	**MX 3 (96% CACUW)**	**MX 4 (104% CACUW)**
$P_{b\ estimated}$ %	5.5	5.0	4.9	4.8

Table (11): Summary of the mix design properties for the chosen aggregate blends.

Mix Properties	**Designed Mixtures**			
	MX1 65% CACUW	**MX2 85% CACUW**	**MX3 96% CACUW**	**MX4 104% CACUW**
Va% @N_{des}	4 %	4 %	4 %	4 %
	Requirements (4%)			
OAC %	5.6	5.2	5.1	5.3
	Requirements (4% - 6%)			
G_{mm}% @N_{ini}	87.45	87.73	87.24	87.17
	Requirements (≤ 89%)			
VMA %	15.83	15.28	15.05	14.85
	Requirements (≥ 14%)			
VFA %	74.7	73.8	73.4	73
	Requirements (65% - 75%)			
DP	1.07	1.16	1.18	1.14
	Requirements (0.6% - 1.2%)		Requirements (0.8% - 1.6%)	
G_{mm}% @N_{max}	96.63	97.34	97.02	97.45
	Requirements (≤ 98%)			

Table (12): Summary of the moisture susceptibility data for the chosen asphalt mixtures.

	Designed Mixtures			
	MX1 65% CACUW	**MX2 85% CACUW**	**MX3 96% CACUW**	**MX4 104% CACUW**
S_{tm}	1525	1411	1326	1128
S_{td}	1730	1627	1593	1381
TSR	88.15	86.72	83.23	81.68
Specification Limit	**Greater than or equal to 80 %.**			

Table (13): Mass of mixes for various types of cylindrical samples.

Mixture Type	G_{mm}	Sample Dimensions (mm)	Mass (Kg)
MX1 (65% CACUW)	2.442	D = 100, H = 63.5	1.1691
MX2 (85% CACUW)	2.440	D = 100, H = 63.5	1.1682
MX3 (96% CACUW)	2.461	D = 100, H = 63.5	1.1782
MX4 (104% CACUW)	2.465	D = 100, H = 63.5	1.1801

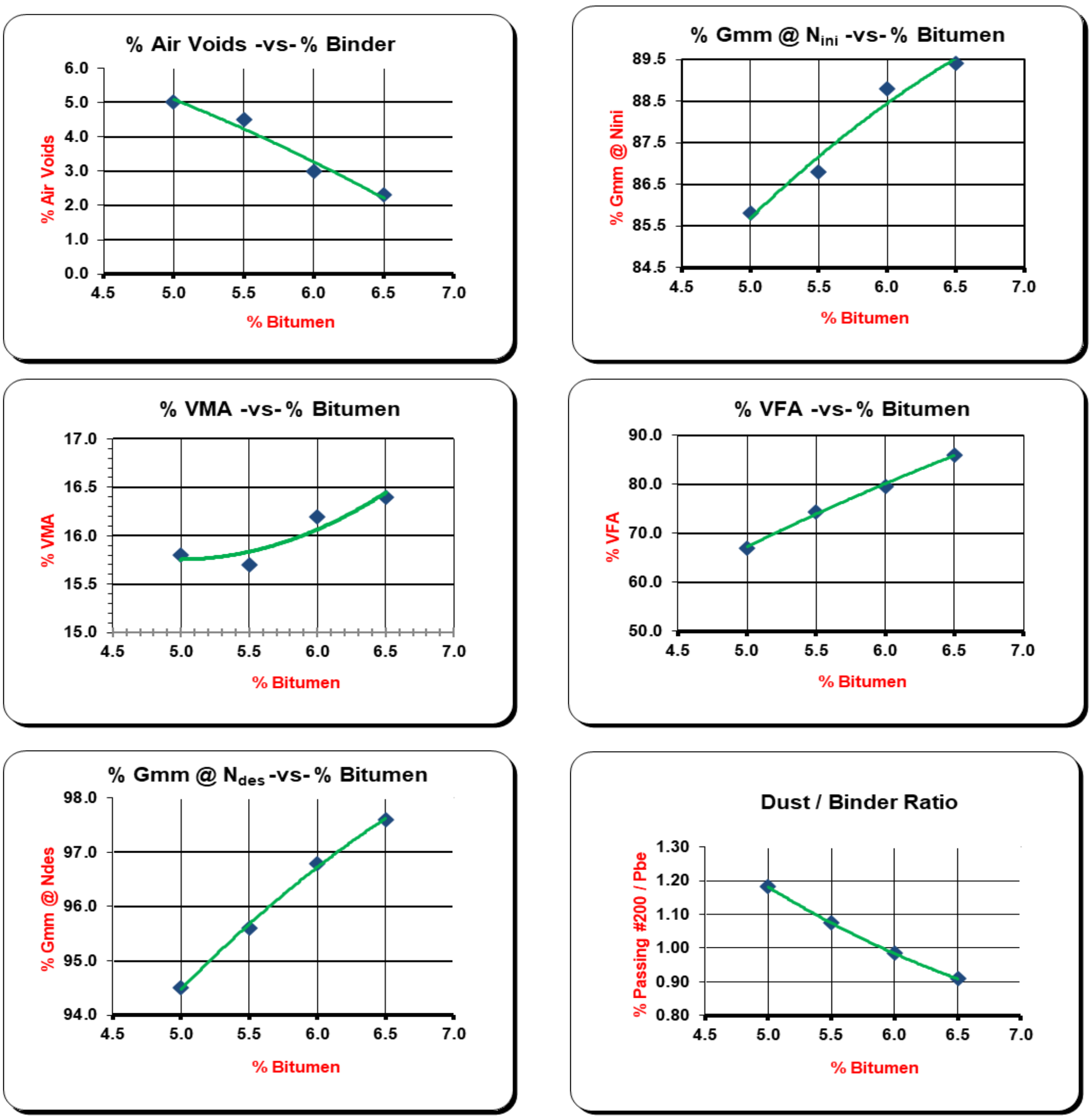


Figure (3): volumetric properties against the bitumen percentage of the designed blend within (65% CACUW).

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