Evaluation of the Bailey Method to Improve Permanent Deformation Resistance of Conventional Hot Mix Asphalt Used in Binder and Surface Course

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ABSTRACT: Mineral aggregates constitute a large proportion of an asphalt mixture and gradation is one of the most important properties of an aggregate blend. Hence, the link between aggregate gradation, and hot mix asphalt (HMA) performance is a considerable issue and has been recognizes since HMA was first used. Traditionally, in Iran and many other countries gradations for dense-graded HMA are specified, using gradation limits recommended by asphalt paving codes. Since these limits are constant and do not consider properties of aggregate blends from different sources, they don't necessarily result in desirable HMA. The Bailey Method, on the other hand, is a means of designing aggregate gradation, considering the volumetric properties of an aggregate blend, so that HMA can have a strong skeleton for high stability and adequate VMA for good durability. In this paper, resistance to permanent deformation of mixtures made of Iran Highway Asphalt Paving Code (IHAPC) gradations for binder and surface course and mixtures made of the Bailey Method gradations are compared. Bailey Method calculations are time consuming. As a result a Microsoft Excel spreadsheet was developed for saving time and reducing the possible calculation errors. Optimum bitumen content for each gradation was determined using Marshall Method (ASTM D1559) and HMA specimens were objected to dynamic creep test. Finally, test results showed that gradations adjusted by the Bailey Method result in mixtures with more resistance to permanent deformation compared to mixtures made of IHAPC gradations.

KEY WORDS: HMA, gradation, Bailey Method, dynamic creep test, permanent deformation

1 INTRODUCTION

Effect of aggregate gradation on hot-mix asphalt (HMA) performance has long been a considerable issue. Gradation affects almost all the important properties of HMA, including stiffness, stability, durability, permeability, workability, fatigue resistance, frictional resistance, and resistance to moisture damage (Powell et al. 2005).

Traditionally, in Iran and many other countries gradations for dense-graded HMA are specified, using "gradation limits" recommended by asphalt paving codes. In this case, the gradation curve in the middle of the upper and lower limit curve, known as "mid-limit", is recognized as the most proper gradation. Because these gradations are constant for all types of aggregate blends, we don't always expect desirable results from them.

The Bailey Method was developed by Mr. Robert Bailey and refined by Dr. Bill Vavrik and Mr. Bill Pine, to present a systematic approach to aggregate blending that is applicable to all dense-graded asphalt mixtures. This method can be used with any method of mix design, including Superpave, Marshall or Hveem (Vavrik et al. 2002).

In the Bailey Method aggregate interlock is selected as a design input. To ensure that the mixture contains adequate asphalt binder, VMA is changed by changing the packing of the coarse and fine aggregates. In this way asphalt mixtures developed with the Bailey Method can have a strong skeleton for high stability and adequate VMA for good durability (Vavrik et al. 2002).

To evaluate the volumetric combination of aggregates in the Bailey Method, additional information is needed. For each of the coarse aggregate stockpiles, the loose unit weight (LUW), and for each fine aggregate stockpile, the rodded unit weight (RUW) must be determined. RUW and LUW of a blend are respectively the amount of aggregate that fills a unit volume with and without any compactive effort applied. LUW condition represents the beginning of particle-to-particle contact without any compactive effort applied. For dense-graded mixtures, the voids created by the coarse aggregate at the chosen unit weight are filled with an equal volume of fine aggregate at the RUW condition (Vavrik et al. 2002).

Many studies have been intended on the Bailey Method of gradation. A mix design procedure to design stone mastic asphalt (SMA), based on and adapted to the Bailey Method, resulted in excellent rutting characteristics (Qiu and Lum, 2006). Results of a study in Oregon to investigate the Bailey Method for the design and analysis of dense-graded HMA recommended that a modified Bailey Method analysis should be used as an additional tool to develop and select trial blends for the design of dense-graded mixtures (Thompson, 2006).

Many studies have been intended on the link between aggregate gradation and resistance of HMA to permanent deformation. Laboratory analysis of the effect of varying the maximum aggregate size on rutting potential and on other properties of asphalt aggregate mixtures (Brown and Bassett, 1990) showed that mixtures with larger aggregate size and the same air void content (4%) generally show more resistance to permanent deformation than mixtures prepared with smaller aggregates. Another research indicates that finer gradations or oversanded mixtures are more susceptible to permanent deformation (Kandhal et al. 1998).

In this study, two gradations from Iran Highway Asphalt Paving Code (IHAPC) are considered as the *control gradations* and modified by the Bailey Method of gradation. Then the resistance to permanent deformation of mixtures made of the modified gradations and IHAPC mixtures are compared.

2 OBJECTIVE AND SCOPE

The objective of this research is to evaluate the effect of implementing the Bailey Method on resistance to permanent deformation of HMA. In fact, the Bailey Method is used to modify the IHAPC gradations. Finally, rutting resistance of mixtures that are modified by the Bailey Method and conventional mixtures (made of IHAPC gradations) are compared.

The control gradations which are used in this research include IHAPC No.4 and No.5 gradations. HMA specimens are prepared, using the Marshall Method (ASTM D1559).

A Dynamic Creep Test (AS 2891.12.1-1995) is performed to compare resistance to permanent deformation of different types of HMA. Other tests, such as wheel tracking test were not available, for the lack of laboratory tools and equipments. However, Dynamic Creep Test results were verified based on facts derived from the Marshal Test results.

3 AGGREGATE GRADATIONS OF RESEARCH

3.1 Control Gradations

The applied gradations are divided into two categories: “Coarser” and “Finer” gradations.

The control gradation of the first category is the mid-limit of IHAPC No.4 gradation, which is recommended for binder course. Maximum aggregate size (MAS) of this gradation is 19 mm and the control sieves are 19, 12.5, 4.75, 2.36, 0.3, 0.075 mm sieves. The control gradation for the second category is the mid-limit of IHAPC No.5 gradation, which is recommended for surface course. For this gradation MAS is 12.5 mm and the control sieves are 12.5, 9, 4.75, 2.36, 0.3, 0.075 mm sieves. However, using the Bailey Method, additional sieves are needed.

3.2 The Bailey Method Gradations

The Bailey Method is a means to develop and adjust the gradation of an existing aggregate blend. The method requires the existing gradation and some inputs, such as RUW, LUW, etc., which are presented in section 4.1. Using the inputs and IHAPC No.4 and No.5 gradations, and implementing the Bailey Method calculations, the modified gradations are obtained. The Bailey Method calculations are time consuming and there is a chance of error. As a result, a Microsoft Excel spreadsheet was developed to avoid errors and to save time (Figure 1).

The Bailey Method Spreadsheet

Aggregate Specification					
Specification	Coarse Agg.		Fine Agg.		Filler
Blend Type	CA 1	CA 2	FA 1	FA 2	MF
Gsb	2.460		2.430		2.595
Gse					
LUW(kg/m3)	1300.00				
RUW(kg/m3)			1500.00		
CUW(kg/m3)	1300.00		1500.00		

Initial Gradation of Blends					
Sieve Size (mm)	Percent Passed				
19	100		100		100
12.5	91		100		100
9.5	67		100		100
4.75	28		100		100
2.36	10		87		100
1.18	0		60		100
0.6	0		40		100
0.3	0		30		100
0.15	0		19		100
0.075	0		14		100
% in CA/FA Mix	100		100		
Total% in Blend	55		45		
% MF Desired	6				

Calculations				
Blend Type	CA 1	CA 2	FA 1	FA 2
CA Cont.	1300	0	-	-
Voids in CA	0.47	0.00	-	-
Cont. of FA	-	-	707.3	
UW of Blend	2007.3			
% by weight	64.76%	0.00%	35.24%	0

Initial :	%FA in CA		%CA in FA	
% in CA/FA	10	0	13	100
% in tot. Blend	6.5%	0.0%	4.6%	0.0%
Justified %s	66.7%	0.0%	33.3%	0.0%

Portion Adjustments				
% P # 200	0	0	14	0
%MF Cont.	0.00%	0.00%	4.67%	0.00%
%MF needed	1.33%			
2nd Adjt for FA			32.01%	0.00%

Final Portions				
CA 1	CA 2	FA 1	FA 2	MF
66.7%	0.0%	32.0%	0.0%	1.3%

Final Gradation	
Sieve Size (mm)	% passed
19	100
12.5	91
9.5	73
4.75	52
2.36	36
1.18	21
0.6	16
0.3	11
0.15	7
0.075	6

Bailey Distinct Portions	
% P. Half Sieve	59
% P. PCS	36
% P. SCS	16
% P. TCS	7

Bailey Raio Check	
CA =	0.55
FA c =	0.45
FA f =	0.46

Figure1: Spreadsheet provided for the Bailey method.

3.3 Applied Gradations

The applied gradations are entitled and presented in table 1. The letter “B” is selected for coarser gradations and the letter “S” is selected for finer gradations

Figures 2 and 3 illustrate the gradation curves of the applied gradations, accompanied by lower and upper limits of IHAPC No.4 and No.5 gradations (B-1 and S-1).

Table1: The applied gradations' titles and descriptions.

Gradation Type	Description
B-1	IHAPC No.4 gradation
B-2	B-1, modified by the Bailey Method
S-1	IHAPC No.5 gradation
S-2	S-1, modified by the Bailey Method

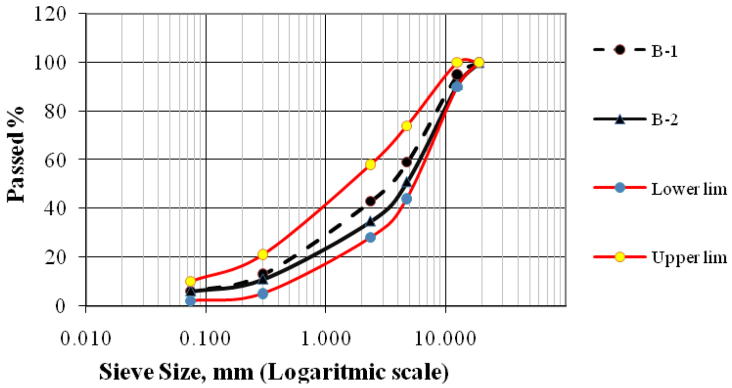


Figure2: B-1 and B-2 gradations with the lower and upper limits of IHAPC No.4 gradation.

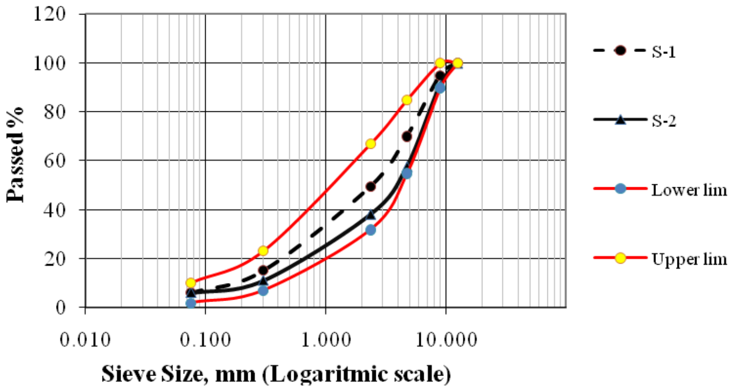


Figure3: S-1 and S-2 gradations with the lower and upper limits of IHAPC No.5 gradation.

4 EXPERIMENTAL PLAN

4.1 Materials and Related Tests

Applied materials included coarse and fine silicious aggregates, mineral filler and AC 60-70 bitumen, which are described in the following paragraphs.

- Aggregates: Coarse and fine aggregates were provided from Rigzar aggregate source near Tehran. Aggregates were sieved, using the IHAPC control sieves. Tests of flakiness and elongation index and percent crushed in two faces were also implemented to make sure the aggregates are appropriate for HMA. Also specific gravity, absorption and RUW/LUW of aggregates were determined. Aggregate test results are presented in tables 2 to 4.
- Bitumen: AC 60-70 bitumen, which is most widely used in Iran, was provided from Pasargad Oil Company (Tehran). Specific gravity, penetration, ring and ball (for softening

point) and ductility tests were implemented on the bitumen (Table 5).

Table 2: Test results for flakiness and elongation index and percent crushed in two faces.

Type of test	Test Result (%)	Asphalt Paving Code Limits		Standard
		Binder Course	Surface Course	
Elongation Index	7	-	-	BS-812
Flakiness Index	16	max 30	max 25	BS-812
Percent Crushed in two Faces	93	min 80	min 90	ASTM-D5821

Table3: Test results for LUW of coarse aggregate and RUW of fine aggregate.

Gradation Type	LUW for Coarse Agg. (kg/m^3)	RUW for Fine Agg. (kg/m^3)	Standard
Binder Course	1400.67	1659.82	AASHTO T 19
Surface Course	1383.21	1684.97	AASHTO T 19

Table4: Test results for aggregate specific gravity and absorption.

Mix Type	Aggregate Size	Apparent Specific Gravity (gr/cm^3)	Bulk Specific Gravity (gr/cm^3)	Absorption (%)	Standard
Surface Course	Retained on Sieve #8	2.644	2.501	2.1	ASTM-C127
	Passed of Sieve #8	2.668	2.487	3.1	ASTM-C128
Binder Course	Retained on Sieve #8	2.621	2.486	2.2	ASTM-C127
	Passed of Sieve #8	2.689	2.485	2.7	ASTM-C128

Table5: Test results for Bitumen.

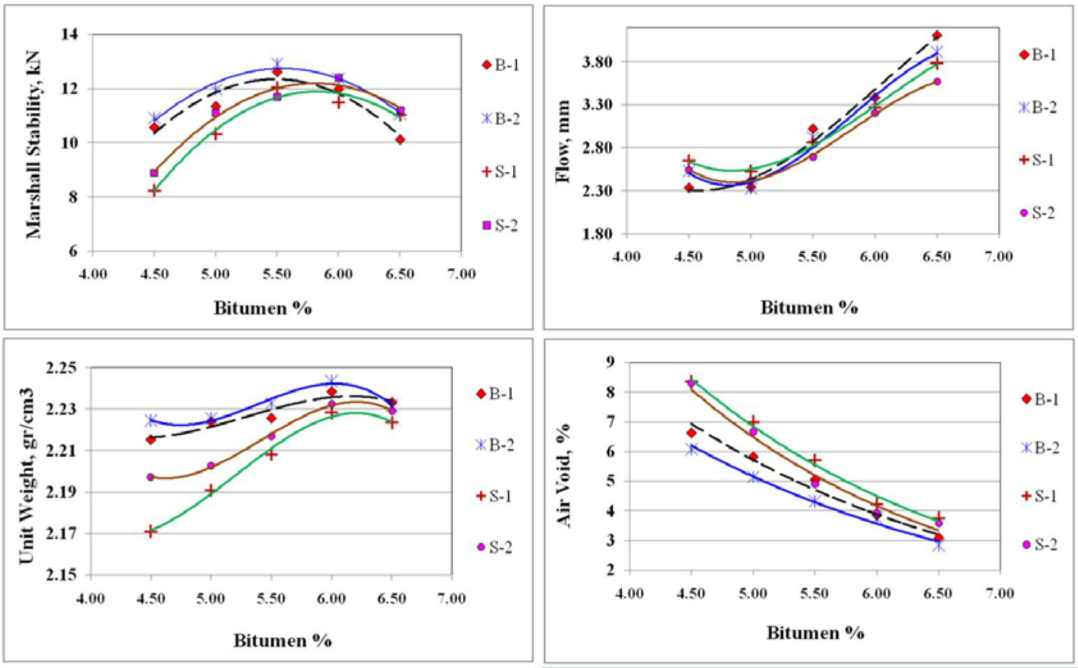
Type of test	Test Result	Standard
Specific gravity @ 25/25 C	1.03	ASTM-D70
Penetration @ 25 C	66	ASTM-D5
Softening point C	51	ASTM-D36
Ductility @ 25 C	101	ASTM-D113

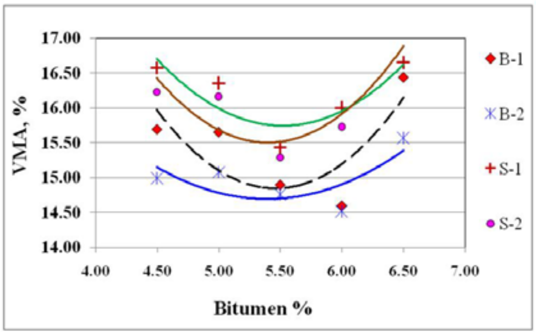
- Mineral filler: Filler was provided from Macadam-e-Shargh asphalt plant near Pakdasht (a small town near Tehran). Filler's specific gravity was 2.595 gr/cm3.

4.2 Determining Optimum Bitumen Contents

The mix design method used in this research is Marshall Method (ASTM D 1559) with 75 blows in either side of the mix. The selected bitumen contents to determine the OBC were: 4.5, 5, 5.5, 6 & 6.5 percent and 3 specimens were prepared for each gradation at each asphalt content (i.e., 60 Marshall specimens).

In this study, the National Asphalt Pavement Association (NAPA) approach was selected to determine the OBC. In this approach, the proposed OBC is selected at the mid-point of the air void content criterion (typically at 4%), and other Marshall parameters at the proposed OBC should be checked against the applicable specifications provided in the codes (Fwa, 2006). Figure 4 demonstrates the related Marshall Method plots and determined OBC for each gradation.





Optimum Bitumen Content			
B-1	**B-2**	**S-1**	**S-2**
5.9	**5.8**	**6.1**	**5.9**

Figure4: Marshall Method plots and determined optimum bitumen content.

4.3 Dynamic Creep Test and Flow Number

Permanent deformation refers to the plastic deformation of HMA under repeated loads. Aggregate interlock is the primary component that resists permanent deformation with the asphalt cement playing only a minor role (Fwa, 2006).

An approach to determine the permanent deformation characteristics of paving materials is to employ a repeated dynamic load test for several repetitions and record the accumulated permanent deformation as a function of the number of cycles (repetitions) over the testing period (witczak, 2005).

Universal Testing Machine (UTM) is an apparatus that provides repeated dynamic load for a Dynamic Creep Test. In this test a repeated pulsed uniaxial load is applied to an asphalt specimen and the accumulated deformation of the specimen under the repeated load is measured. Dynamic Creep Test, in this study, is based on AS 2891.12.1-1995 (Standards Australia, 1995). Operator of the UTM can select the loading parameters. Based on AS 2891.12.1-1995, the following loading parameters are used:

Loading wave shape: square pulse; Pulse width: 0.5 sec; Rest period: 1.5 sec.

Contact stress: 2 kPa; Deviator stress: 300 kPa.

A temperature of 50°C was utilized for all specimens, 3 hours (the time required to satisfy the conditions of AS.2891.12.1- note 3) before the test and during the test. Specimens were held in an environmentally controlled chamber throughout the mentioned sequence. Figure 5 shows a UTM and a specimen mounted in the machine for Dynamic Creep Test.

Figure5: UTM (right) and specimen mounted in the machine for dynamic creep test (left).

Implementing the test, UTM software reports the test results in form of a S-shaped curve. Figure 6 illustrates a typical S-shaped curve, in a form of accumulated permanent strain under repeated loads versus number of load cycles.

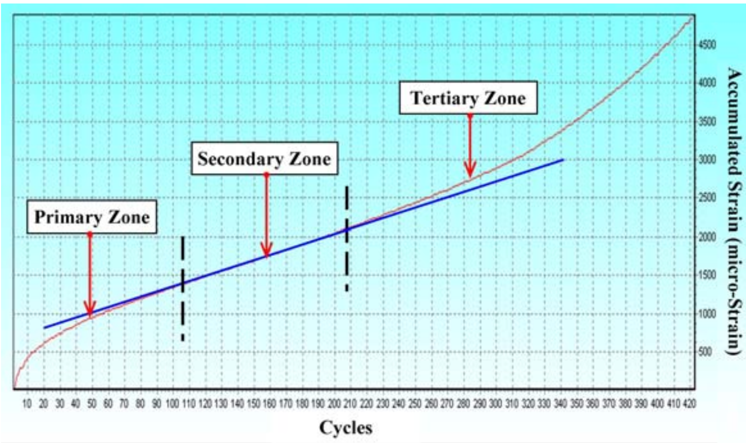


Figure6: Typical relationship between the total accumulated permanent strain and number of load cycles.

The cumulative permanent strain curve is generally defined by Primary, Secondary, and Tertiary zones (figure 6). The starting point, or cycle number, at which tertiary flow occurs, is referred to as the flow number (Witczak, 2005). The operator can't measure the rutting depth using the flow number, but this value is a criterion to compare creep behavior of different HMA specimens or their resistance to permanent deformation.

Using the determined OBC, the main specimens were prepared and exposed to Dynamic Creep Test. For each gradation, 3 specimens were prepared to be exposed to the test.

5 RESULTS AND DISCUSSIONS

Implementing the mentioned experiments, test results are collected and discussed in the following paragraphs.

5.1 Marshall Test and Determined Optimum Bitumen Contents

Marshall Stiffness (Marshall Stability divided by flow) is a term sometimes used to characterize asphalt mixtures. A higher value of Marshall Stiffness indicates a stiffer mixture and hence, indicates the mixture is likely to be more resistant to permanent deformation (Abukhettala, 2006). Marshall Stiffness values that are presented in figure 7 are the average values obtained from three Marshall Tests for each mixture type. The results show that the Bailey Method resulted in greater Marshall Stiffness values; therefore, greater resistance to permanent deformation is expected for B-2 and S-2 Compared to B-1 and S-1, respectively.

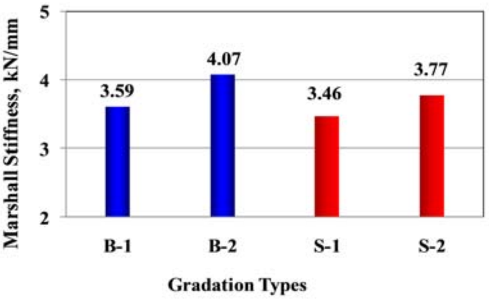
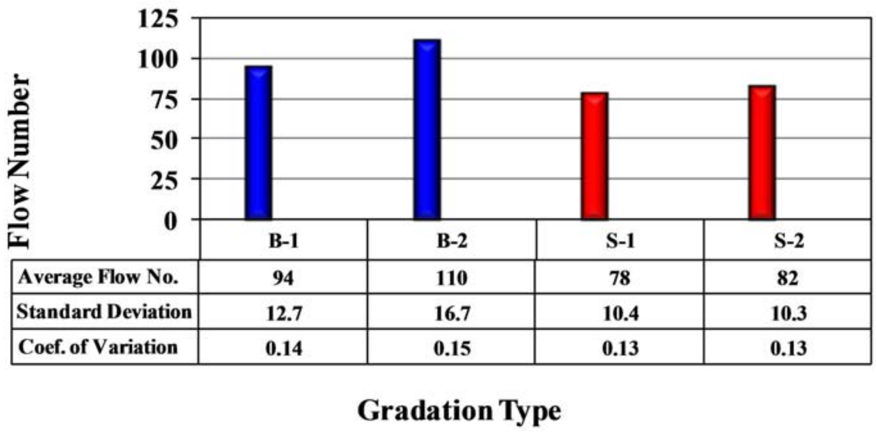


Figure7: Marshall Stiffness values of the four mixture types.

The Bailey Method gradations resulted in lower OBC. Reduction in OBC was 1.7% and 3.3% for “B” mixtures and “S” mixtures, respectively. This happens, because compared to B-1 and S-2 gradations, B-2 and S-2 gradations result in denser mixtures (“Unit weight-Bitumen %” graph of figure 4). Low bitumen content may result in low durability and low resistance to fatigue cracking and high bitumen content may result in rutting susceptibility. However, since compared to the control gradations, the adjusted gradations didn’t result in a significant difference in OBC, the mentioned problems do not seem to be encountered.

5.2 Results of Dynamic Creep Test

Flow numbers that are presented in figure 8 are the average values obtained from three Dynamic Creep Tests for each mixture type. Figure 8 also presents the values of standard deviation (SD) and coefficient of variation (CV) of the three flow numbers, for individual mixture types.



	B-1	B-2	S-1	S-2
Average Flow No.	94	110	78	82
Standard Deviation	12.7	16.7	10.4	10.3
Coef. of Variation	0.14	0.15	0.13	0.13

Figure8: Dynamic creep test results and values of SD and CV for individual mixture types.

The results Show that the Bailey Method gradations resulted in mixtures with greater flow numbers, comparing to IHAPC gradations, i.e., more resistance to permanent deformation.

Considering the “Unit weight-Bitumen content” curves (figure4), B-2 and S-2 gradations, resulted in denser mixtures than B-1 and S-1 gradations. Hence, these mixtures have greater aggregate interlock. In addition, OBC of these mixture types is less than IHAPC mixtures. As a result, B-2 and S-2 mixtures have greater permanent deformation resistance.

Figure 9 illustrates the increased percent of rutting resistance of IHAPC mixtures by implementing the Bailey Method, based on values of flow number. Implementing the Bailey Method, resistance to permanent deformation for the coarser mixture, i.e., B-1, increased more than the finer mixture, i.e., S-1. This can be derived from results of this research, that the Bailey method is more effective for coarser mixtures.

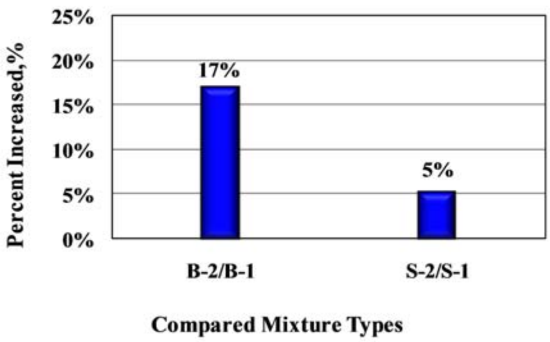


Figure9: The increased percent of rutting resistance by using the Bailey Method.

Comparing the Dynamic Creep Test results of the two categories, it is revealed that mixtures of first category which contain coarser aggregates show more resistance to permanent deformation than their corresponding gradations in the second category. In other words, coarser mixtures are more resistant to permanent deformation than finer mixtures. Figure 10 shows the percent by which the flow number of each coarser mixture is greater than its corresponding finer mixture.

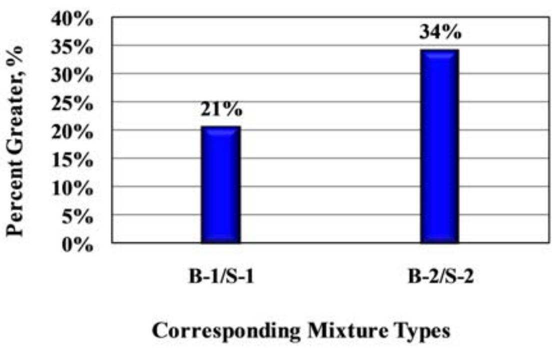


Figure10: The percent by which the flow number of each coarser mixture is greater than its corresponding finer mixture.

6 CONCLUSIONS

In this research an evaluation of the Bailey method of gradation to improve the rutting resistance of conventional HMA was studied. A Microsoft Excel spreadsheet was developed for saving time and reducing the possible calculation errors. The following conclusions are made:

The Bailey Method gradations resulted in mixtures that are more resistant to permanent deformation. This can be verified by the following points: Firstly, Marshall Stiffness was increased by using the Bailey Method, and a mixture with higher value of Marshall Stiffness is likely to be more resistance to permanent deformation. Secondly, the Bailey Method resulted in mixtures that are denser; hence have greater aggregate interlock which is the primary component that resists permanent deformation. Thirdly, OBC was decreased by using the Bailey Method, and rutting susceptibility is decreased by reduction in bitumen content.

The Bailey Method increased the flow number of courser mixture to a greater amount than the flow number of finer mixtures, i.e., based on results of this research, the method is less effective in adjusting finer gradations.

Coarser mixtures (B-1 and B-2) showed more resistance to permanent deformation compared to their corresponding finer mixtures (S-1 and S-2). In other words, coarser mixtures are more resistant to permanent deformation than finer mixtures.

After all, implementing a Bailey Method modification of IHAPC gradations to improve the performance of conventional HMA is recommended. However, further researches needs to be intended.

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