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The Use of SBS-Modified Binder to Eliminate the Aggregate Gradation Deviation Effects in Asphalt Mixtures

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ABSTRACT

Asphalt Hot Mix (HMA) is mainly applied in highway construction in Iraq because of its economic advantage and easy maintenance. Various factors impact the performance of HMA in the field. It is one of the significant impacts on aggregate gradation. The Universal Specification for Roads and Bridges in Iraq (SCRB) limits the different types of asphalt layers and allows for designed tolerance aggregate gradation. It is quite hard for contractors in the present asphalt industries to achieve the required job mix because of sieves' control problems. This study focuses on the effects on the required specification performance of aggregate deviations by using original and modified asphalt binder with AC(40-50) and 4% SBS, respectively. A mid gradation of the base asphalt mixture was selected as a reference mix, and more than 24 deviated mixtures were then prepared. Typical Marshall routine studies on prepared compounds were performed to assess the properties of the mixture. Bailey's theory (CA, Fac ratios) was also employed for understanding the impact of these deviations on the arrangement of particles and blending performance. Results show that the mixture performance is not affected greatly by minor aggregate deviations. However, a significant deviation in coarse aggregates leads to a decrease in Marshall properties. Results showed that a good tool for understanding mixing performance is the Bailey performance assessment method. This paper aims to study the effects of using 4% Styrene Butadiene Styrene (SBS) and eliminating the effect of aggregate gradation deviations on the mixture performance.

Keywords: Binder, SBS-Modified Binder, Aggregate Gradation, Asphalt Mixtures.

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استخدام مادة رابطة معدلة SBS للتخلص من اثار انحراف التدرج الكلي في خلطات الاسفلت

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الخلاصة

يتم تطبيق بناء الطرق السريعة في العراق بشكل أساسي بسبب ميزته الاقتصادية وسهولة الصيانة حيث تؤثر عوامل مختلفة على أداء HMA في هذا المجال. أحد التأثيرات الرئيسية في التدرج الكلي. تضع المواصفات العالمية للطرق والجسور في العراق (SCRB) حدودا لأنواع مختلفة من طبقات الأسفلت وتسمح بتدرج إجمالي للتحمل. من الصعب جدا على المقاولين في صناعات الأسفلت الحالية تحقيق مزيج الوظائف المطلوبة بسبب مشاكل في السيطرة على الغربال. حيث تركز هذه الدراسة على التأثيرات على أداء المواصفات المطلوبة للانحرافات الكلية باستخدام الأسفلت الأصلي والمعدل مع p (40−50) و 4٪ SBS على التوالي. تم اختيار تدرج منتصف خليط الأسفلت الأساسي كمزيج مرجعي وتم بعد ذلك إعداد أكثر من 24 خليطا منحرفا. تم إجراء دراسات روتينية نموذجية مارشال على المركبات المعدة لتقييم خصائص الخليط. كما استخدمت نظرية بيلي (CA، نسب Fac) لفهم تأثير هذه الانحرافات على ترتيب الجسيمات وأداء المزيج. تظهر النتائج أن أداء الخليط لا يتأثر بشكل كبير بالانحرافات التجميعية الطفيفة، ومع ذلك، فإن انحرافا كبيرا في المجاميع الخشنة يؤدي إلى انخفاض في خصائص مارشال. وأظهرت النتائج أن طريقة بيلي أداة جيدة لفهم أداء الخلط. تهدف هذه الورقة إلى دراسة تأثير استخدام SBS%4 على انحرافات التدرج الكلي على أداء الخليط.

الكلمات الرئيسية: الرابط، الرابط المحسن ، تدرج الحمل، خلائط الاسمنت.

1. INTRODUCTION

Hot asphalt (HMA) mixtures are complex materials consisting of asphalt, minerals, and air voids. **(Zaumanis, et al., 2018)**. As well known, the performance of the asphalt is determined by the type of aggregate gradation **(de Souza, 2009 and Lee, et al., 2000).** Any changes in aggregate gradient change many factors, such as directions and contact points, which affect the performance of asphalt mixtures **(Plati, et al., 2014 and Al-Mosawe, et al., 2015)**. By the aggregate gradation, (**Golalipour, et al., 2012)** studied the effect on rutting performance in asphalt pavements. According to the Asphalt Institute, they have selected aggregated degrees with a nominal size of 19 mm and have used three different gradations, maximum, minimum, and middle limit. The results of the Marshall test show that the maximum gradient limit is the highest stability and the minimum gradient limit is the lowest. While the coarser combats permanent deformation better than, the finer aggregates have been demonstrated by **(Ahmed, et al., 2013)** with four different types of aggregate gradation and wheel tracking tests. According to the Egyptian requirements, the combinations are known as coarse gradations, fine gradation, open gradation, and dense gradation. Since it was founded, a great deal has been done to validate the concept, and in recent years Bill Pine, the Heritage Research Group, promoted his approach **(Vavrik, et al., 2002)**. The 'Bailey gradation method' is mainly a tool in which laboratory and field gradations can be developed and analyzed. It gives designers and contractors a better grasp of the packaging and influences its compatibility and volume **(Ghuzlan, et al., 2020, M. K., 2014 and, Lee, J.-S. et al., 2015)**. The Bailey approach focuses on aggregate packaging. To better understand the aggregate packing, the particles from the coarse structure and fit in the voids within this structure. The properties of the packaging are based on different factors: the aggregate shape, strength, and textures, mixing gradations, and the type of stress and quantity **(Daniel, J.S. and Rivera, F., 2009, Feng, X., et al., 2013 and Stimilli, et al., 2017)**

Cubic particles, for instance, are denser than extended flat particles. Smooth particles slide more easily than crude surface texture **(Aurangzeb, et al., 2012 and Wang, et al., 2019)**. The gradation, the mix between different sizes, also affects how the mix fills the voids of large particles. Similarly, compact aggregates of different strengths differ depending on how compacted they are **(Sefidmazgi, et al., 2012)**. The strength of the fine aggregate, for example, plays a much more important role than a coarse mix **(Abed, et al., 2021).**
Finally, the designer selects a skeleton using the Bailey method, which can stand the deformation of the VMA and modifies the packing for coarse and fine add-ons to provide the mixture with a suitable asphalted binder **(Graziani, et al., 2012, Komba, et al 2019)**. Perhaps this has caused some concerns in Iraq. Field Compaction stressed the necessity of designing mixtures with sufficient VMA, which improved the need to understand the overall design of mixtures better.

1.1 Aim and Objectives

This study aims to assess the effect of aggregate gradation deviations on the base asphaltic mixture because most Baghdad Governorate projects use the base layer in the rural roads with low traffic volumes. The research will be conducted by selecting the mid gradation of specification limits as a control mixture and then manufacture 24 mixtures with different aggregate deviations. The samples will then be tested and evaluated according to the SCRB requirements, which follow Marshall properties. The mixtures will then be evaluated by using different packing ratios. The main objective of this research is to study the effects of using 4% SBS polymer modifiers and aggregate gradation on asphalt mixture performance with PG(64-16) for ordinary binder and PG(76-16) for modified asphalt binder.

1.2 The Baily Method Principles

One of the methods is found with a detailed background and basic Bailey principles **(Vavrik et al., 2002).** As a primary control sieve (PCS) for the 12,5-mm NMAS admixture, **(Vavrik et al. 2002)** recommended the size No. 8. For plant 1 and 2 materials, the sieve size No. 8 (P8) proportion was maintained constantly at 32% and 29%, respectively. The VMA values shown in bold, however, do not meet the minimum demand of 15%. The OAC and VMA values of Plant 2 are higher than that of Plant 1. **(Garcia et al., 2020)** concluded in his study that for two typical Superpave mix designs of nominal 12.5 mm maximum size, the mixture of design information and paving materials was collected. Most of the volumetric properties of mixtures in mineral aggregates were evaluated concerning the voids. The rutting potential and the strength of the combinations were evaluated with the Hamburg wheel tracking and indirect tension testing. The Bailey method was originally designed to design and adjust aggregate proportions according to the packaging and its effect on the performance of HMA blends. The procedure can also be used to evaluate the properties of the aggregate packaging. The Bailey method is based on a grading curve that determines the ratio of total packaging efficiency with certain control strands. The first control sieve is the Nominal Maximum Particle Size (NMPS), which is usually defined as a sieve greater than the sieve, which retains more than 10% of the total **(Asphalt Institute, 1996).** From the NMPS, another control sieve can be estimated. These control sieves include the half sieve (HS), which is the sieve closest to the half of the NMPS, the Principal Control Sieve (PCS), which is defined as the sieve closet of 22% of the NMPS, the Secondary Control Sieve (SCS), which is defined as the sieve armchair at 22% of the PCS and the Tertiary Control Sieve (TCS), which is defined as the sieve closet of 22% of the SCS. With the Bailey method, there are four key principles, as in **Fig 1**:

- Determination of which aggregate structures are controlled (i.e. the coarse aggregate) creates and fills the voids in the second point.
- Coarse fraction packaging has an impact on packaging with fine fractions.
- The fine, coarse aggregate fraction concerns the packing of the total fine fraction in combination.

The fine aggregate fraction is related to the fine gradation of the mixture.

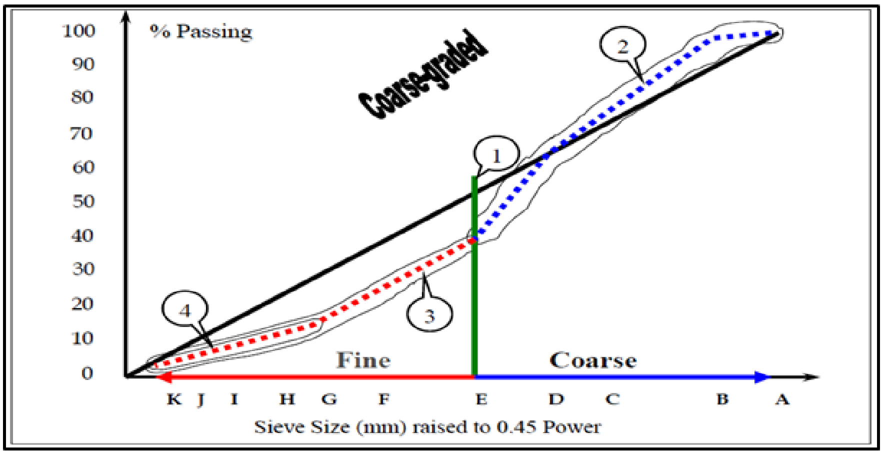


Figure 1. The four Bailey method principles.

The two Bailey ratios CA and FAc can be calculated from the following Equations:

$$CA = \frac{\%Passing\ HS - \%Passing\ PCS}{100 - \%Passing\ HS} \qquad (1)$$

$$FAc = \frac{\%Passing\ SCS}{\%Passing\ PCS} \qquad (2)$$

The CA ratio is the coarse aggregate's description and void structure, while the FAc represents the interlocking of coarse particles in the fine section. The ratios introduced by **(Al-Mosawe, 2016)** [25] and are used in this research are:

$$C_f/F_c = \frac{\%\text{Passing PCS} - \%\text{Passing SCS}}{\%\text{Passing HS} - \%\text{Passing PCS}} \qquad (3)$$

This ratio defines the fine-coarse particles interlock.

$$F/C = \frac{\%Passing\ PCS}{100 - \%Passing\ PCS} \qquad (4)$$

The ratio of the fine particles in the mix is to give the percentage to coarse particles.

1.3 Materials and Methodology

The materials used here are available locally and are currently used in Iraqi road construction. In addition to additives, they include asphalt binders, aggregates, and fillers.

1.3.1 Asphalt Cement

In this work, a (40-50) penetration grade asphalt cement was used. The asphalt was brought from the refinery at Al-Duarah, southwest of Baghdad. In particular, The physical properties of this asphalt cement are described in **Table 1**, and optimum asphalt contents were found in Base course mixes (4%) by weight of aggregate, as shown in **Table 5.**

Table 1. Physical properties of asphalt cement.

Test	Unit	Result	Specification Requirement
Penetration At 25˚C,100 gm, 5 sec. (0.1mm).ASTM D 5-06	1/10mm	46	40-50
Ductility at 25˚C, 5cm/min, (cm). ASTM D 113-07	cm	110	≥100
Flash Point (Cleveland open cup) ASTM D 92-05	˚C	280	≥230
Specific gravity (25 ˚C). ASTM D 70-08	----	1.03	----

1.3.2 Modified Asphalt Cement

One type of polymers was used in this research added to the asphalt binder known as SBS collected from the local market. The qualities of the SBS modifier are often solid, basically odorless white, also with a density of 880-950 kg/m^3. By weight, 4% of SBS content has been used with a control binder for asphalt. The SBS enhanced asphalt was prepared through mixing by hand. **Table 2** illustrated the physical properties and material specifications of SBS**.**

Table 2. Physical properties and material specification of SBS.

Type of Asphalt	Designation	Non-Modified		4%SBS		Requirements
R.V @135 ^{O}C (Pa.sec)	D4402	0.462		1.182		
R.V @165 ^{O}C (Pa.sec)	D4402	0.112		0.286		
G^* /sin δ(kPa)	D7552	@64 ^{O}C	3.16	@76 ^{O}C	2.43	
		@70 ^{O}C	1.73	@82 ^{O}C	1.13	
Ageing		RTFO				
G* /sin δ(kPa)	D7552	@64 ^{O}C	5.17	@76 ^{O}C	2.67	
		@70 ^{O}C	1.92	@82 ^{O}C	1.96	
Loss (%)		<1		<1		
Ageing		PAV				
G* .sin δ(kPa)	D7552	@25^{O}C	7421	@25^{O}C	7450	

		@28^{O}C	4735	@28^{O}C	4782	
Creep Stiffness(MPa)	D6648	@-16^{O}C	188	@-16^{O}C	215	
		@-22^{O}C	438	@-22^{O}C	456	
Slop m-value		@-16^{O}C	0.399	@-16^{O}C	0.363	
		@-22^{O}C	0.289	@-22^{O}C	0.269	

1.3.3 Aggregate

Crushed quartz aggregates, which are routinely used in the production of HMA mixes, were sourced from Al-Nabai quarries in Al-Taji. One aggregate gradation was used in this study, as shown in **Fig. 2** for aggregate's orientation detection, referred to as coarse and fine mix which was specified by the State Commission of Road and Bridges **(SCRB)/Iraq.** To evaluate its physical properties, typical standard tests were conducted on the aggregate. The results are summarized in **Table 3** and **Table 4.**

Table 3. Physical Properties of Al-Nabai Aggregate.

Property	Coarse Aggregate	Fine Aggregate
Bulk Specific Gravity ASTM C-127 and C-128	2.524	2.646
Apparent Specific Gravity ASTM C-127 and C-128	2.546	2.687
Percent Water Absorption ASTM C-127 and C-128	0.369	0.519

Table 4. Physical Properties of Limestone Dust.

Property	Result
Specific Gravity	2.933
Passing sieve No.200 (0.075mm)	%95

Asphaltic samples of 10.16 cm in diameter with an approximate thickness of 6.35 cm, was compacted by Marshall Hammer to fabricate twenty-four samples of different mixtures (for two types of deviations), as in **Fig. 3.** Bailey ratios were calculated, and other ratios were introduced by **(Al-Mosawe, et al., 2015)** were also calculated.

Table 5. Selected Gradation of Combined Aggregate and Mineral Filler for Asphalt Mixture (Control Base Course).

Sieve Opening(mm) (Base Course)	Sieve size (inch)	Specification limits(SCRB) (Base)	Selected Gradation (Base)
37.5	1(1/2)´	100	100
25	1´	90-100	95

19	3/4´	76-90	83
12.5	1/2´	56-80	68
9.5	3/8´	48-74	61
4.75	No.4	29-59	44
2.36	No.8	19-45	32
0.3	No.50	5-17	11
0.075	No.200	2-8	5

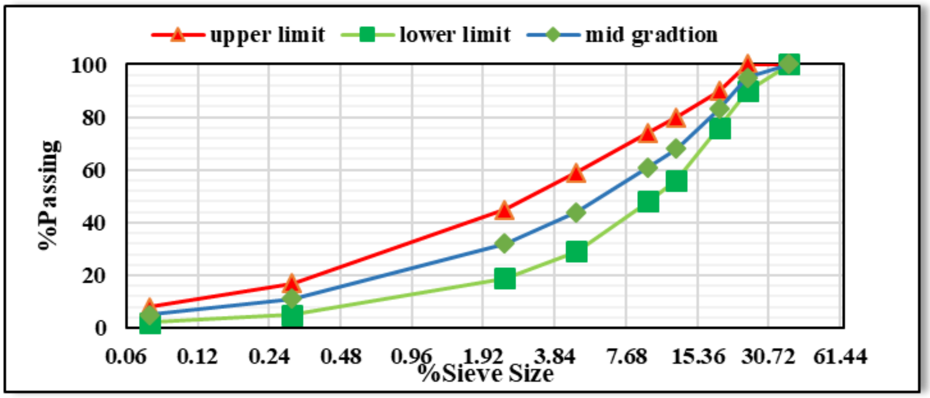


Figure 2. Selected gradation of combined aggregate and mineral filler (control base course).

Figure 3. Specimen's preparation.

2. EXPERIMENTAL DATA ANALYSIS

The base course mixture was evaluated using Iraq's requirements, which is the Iraqi Specifications for Roads and Bridges (SCRB). The required tests are Marshall stability and flow and their volumetric properties (see Fig 4 and **5.** After the determination of the optimum asphalt content, twenty-four different mixtures of the base course between the tolerance of the Iraqi specifications and beyond the upper and lower limit of these specifications were tested in the laboratory, as shown in **Table 6** and **Table 7** below.

The symbols of the mixtures are defined as follow:

B = the Base course.

T = the tolerance of Iraqi specifications.

S = the mixtures out of specifications.

U = the deviations near or out of the upper limit of the specifications.
L = the deviations beyond or out of the lower limit of the specifications.

It can be seen in**Error! Reference source not found.Figs. 4, 5, 6,** and **7** that most of the deviations caused a reduction in Marshall stability. The first twelve different asphalt mixtures for the tolerance, as shown in **Fig. 8** and **Fig. 9,** are BTU1 and BTL1 for mixtures that are close to the upper and the lower limits inside the range at the sieve (19 mm). BTU2 and BTL2 for mixtures that are close to the upper and the lower limits inside the range at sieve (12.5). BTU3 and BTL3 for mixtures that are close to the upper and the lower limits inside the range at sieve (9.5 mm). BTU4 and BTL4 for mixtures that are close to the upper and the lower limits inside the range at the sieve (4.75 mm). BTU5 and BTL5 for mixtures that are close to the upper and the lower limits inside the range at the sieve (2.36 mm). BTU6 and BTL6 for mixtures close to the upper and the lower limits inside the range at sieve (0.3 mm). The second twelve different asphalt mixtures for the type of deviation BSU1 which are asphalt mixtures that are within the tolerance of SCRB specification beyond the upper limit at sieve size (19 mm). BSL1 for mixtures that approach the lower limits of specification at sieve size (19 mm). BSU2 and BSL2 for mixtures that exceed the upper and the lower limits outside the range at sieve size (12.5 mm). BSU3, and BSL3 for mixtures that exceed the upper and the lower limits outside the range at sieve size (9.5 mm). BSU4 and BSL4 for mixtures that exceed the upper and the lower limits outside the range at sieve size (4.75 mm). BSU5, and BSL5 for mixtures that exceed the upper and the lower limits outside the range at sieve size (2.36 mm). BSU6 and BSL6 for mixtures that exceed the upper and the lower limits outside the range at sieve size (0.3 mm).

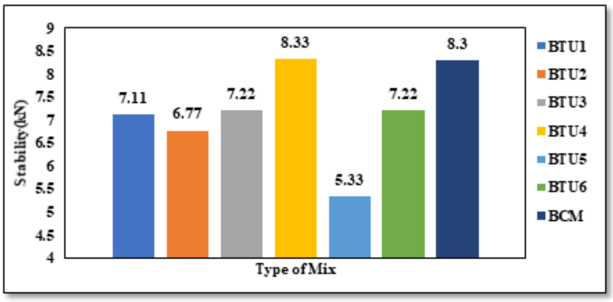


Figure 4. Marshall Stability Values for the Upper Limits Approached Mixtures within the Tolerance for (Base Course).

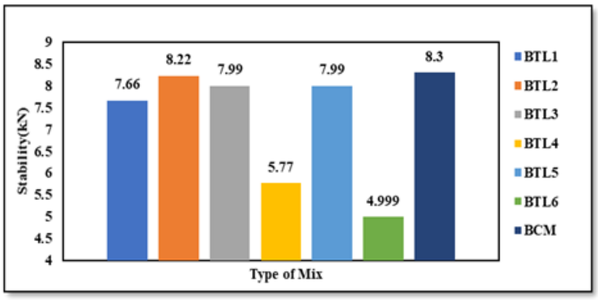


Figure 5. Marshall Stability Values for the Lower Limits Approached Mixtures within the Tolerance for (Base Course).

Table 6. Mixture Gradations for Tolerance deviations and Results for Base Course

Sieve mm	BTU1	BTL1	BTU2	BTL2	BTU3	BTL3	BTU4	BTL4	BTU5	BTL5	BTU6	BTL6	Control mix (BCM)	Tolerance Limits	SCRB Limits
	%Passing														
37.5	100	100	100	10	100	100	100	100	100	100	100	100	100	100	100
25	95	95	95	95	95	95	95	95	95	95	95	95	95	90-100	90-100
19	90*	76*	83	83	83	83	83	83	83	83	83	83	83	77-89	77-89
12.5	68	68	78*	61*	72*	68	68	68	68	68	68	68	68	62-74	62-74
9.5	61	61	61	61	71*	51*	61	61	61	61	61	61	61	55-67	55-67
4.75	44	44	44	44	44	44	55*	33*	44	44	44	44	44	38-50	38-50

2.36	32	32	32	32	32	32	32	32	42*	22*	32	32	32	28-36	28-36
0.30	11	11	11	11	11	11	11	11	11	11	17*	5*	11	7-15	7-15
0.075	5	5	5	5	5	5	5	5	5	5	5	5	5	3-7	3-7
	Volumetric Properties														
Density g/cm3	2.243	2.241	2.257	2.27	2.243	2.276	2.263	2.27	2.246	2.279	2.297	2.224	2.23		
%AV	6.28	6.35	5.72	5.22	6.27	4.90	5.46	5.20	6.14	4.79	4.0	7.10	4		
Stability KN	7.11	7.66	6.77	8.22	7.22	7.99	8.33	5.77	5.33	7.99	7.22	5.00	8.3		
Flow(mm)	3.65	2.9	2.3	2.7	2.8	3.45	3	2.3	2	2.6	2.8	2.0	2.8		
	Gradation Ratios														
CA	0.75	0.75	1.54	0.43	1	0.75	0.4	1	0.75	0.75	0.75	0.75	0.75		
Fac	0.45	0.45	0.45	0.45	0.45	0.45	0.36	0.6	0.55	0.35	0.53	0.37	0.45		
Cf/Fc	1	1	0.7	1.41	0.85	1	2.69	0.37	0.82	1.17	0.85	1.14	1		
F/C	0.86	0.86	0.86	0.86	0.86	0.86	1.37	0.53	0.86	0.86	0.86	0.86	0.86		

(*) refers to deviation

The SCRB deviations, as shown in **Table 7**, are formed as eliminating one of the sieves. The gap that is made in the mixture highly affected the results

Table 7. Mixtures Gradations Beyond Specification Requirements for Base Course.

Sieve mm	BSU1	BSL1	BSU2	BSL2	BSU3	BSL3	BSU4	BSL4	BSU5	BSL5	BSU6	BSL6	Control mix (BMC)	Tolerance Limits	SCRB
		%Passing													
37.5	100	100	100	10	100	100	100	100	100	100	100	100	100	100	100
25	95	95	95	95	95	95	95	95	95	95	95	95	95	90-100	90-100
19	95*	71*	83	83	85*	83	83	83	83	83	83	83	83	77-89	76-90
12.5	68	68	83*	50*	80*	68	68	68	68	68	68	68	68	62-74	56-80
9.5	61	61	61	50	79*	44*	65*	61	61	61	61	61	61	55-67	48-74
4.75	44	44	44	4	44	44	64*	29*	50*	44	44	44	44	38-50	29-59
2.36	32	32	32	32	32	32	32	27*	49*	14*	32	32	32	28-36	19-45
0.30	11	11	11	11	11	11	11	11	11	11	27*	3*	11	7-15	5-17
0.075	5	5	5	5	5	5	5	5	5	5	5	2*	5	3-7	2-8
	Volumetric Properties														
Density g/cm3	2.28	2.27	2.25	2.28	2.22	2.29	2.27	2.3	2.21	2.25	2.31	2.24	2.29		
%AV	4.51	4.97	5.67	4.72	6.88	4.24	4.78	3.52	7.29	5.67	3.15	6.0	4		
Stability KN	5.55	6.33	5.83	6.00	5.77	11.11	8.00	8.88	6.77	6.22	10.55	3.77	8.3		
Flow (mm)	2.5	3.6	2.75	2.5	3.15	3.25	3.2	3	1.5	2.9	3	1.5	2.8		
	Gradation Ratios														
CA	0.75	0.75	2.29	0.12	1.8	0.75	0.12	1.21	0.56	0.75	0.75	0.75	0.75		
Fac	0.45	0.45	0.45	0.45	0.45	0.45	0.31	0.61	0.54	0.27	0.66	0.34	0.45		
Cf/Fc	1	1	0.61	4	0.66	1	11	0.28	1.26	1.32	0.61	1.19	1		
F/C	0.86	0.86	0.86	0.86	0.86	0.86	2.06	0.43	1.11	0.86	0.86	0.86	0.86		

Bailey ratios and those introduced by Al-Mosawe were calculated, and it can be seen that in **Table 6** for example, mixes BTU4 and BTL4; the difference between them is the percent of passing in sieve No.4. BTU4 has a deviation that makes the number of fine particles much more than that in BTL4. This is reflected in the ratio Cf/Fc, which has great change between them and compared to the control mix. This explanation is compatible with the reference finding, which states that many fine particles support the interceptor particles, such as in BTU4.

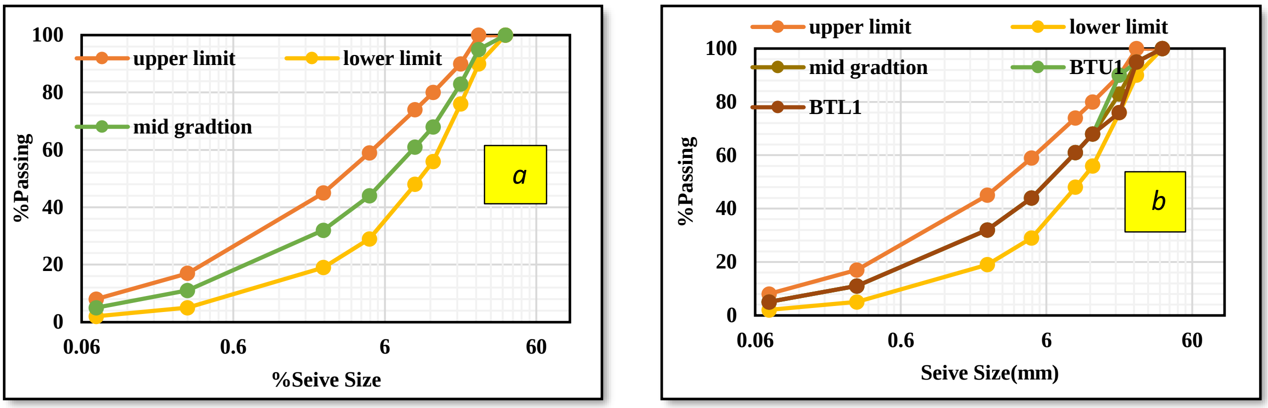
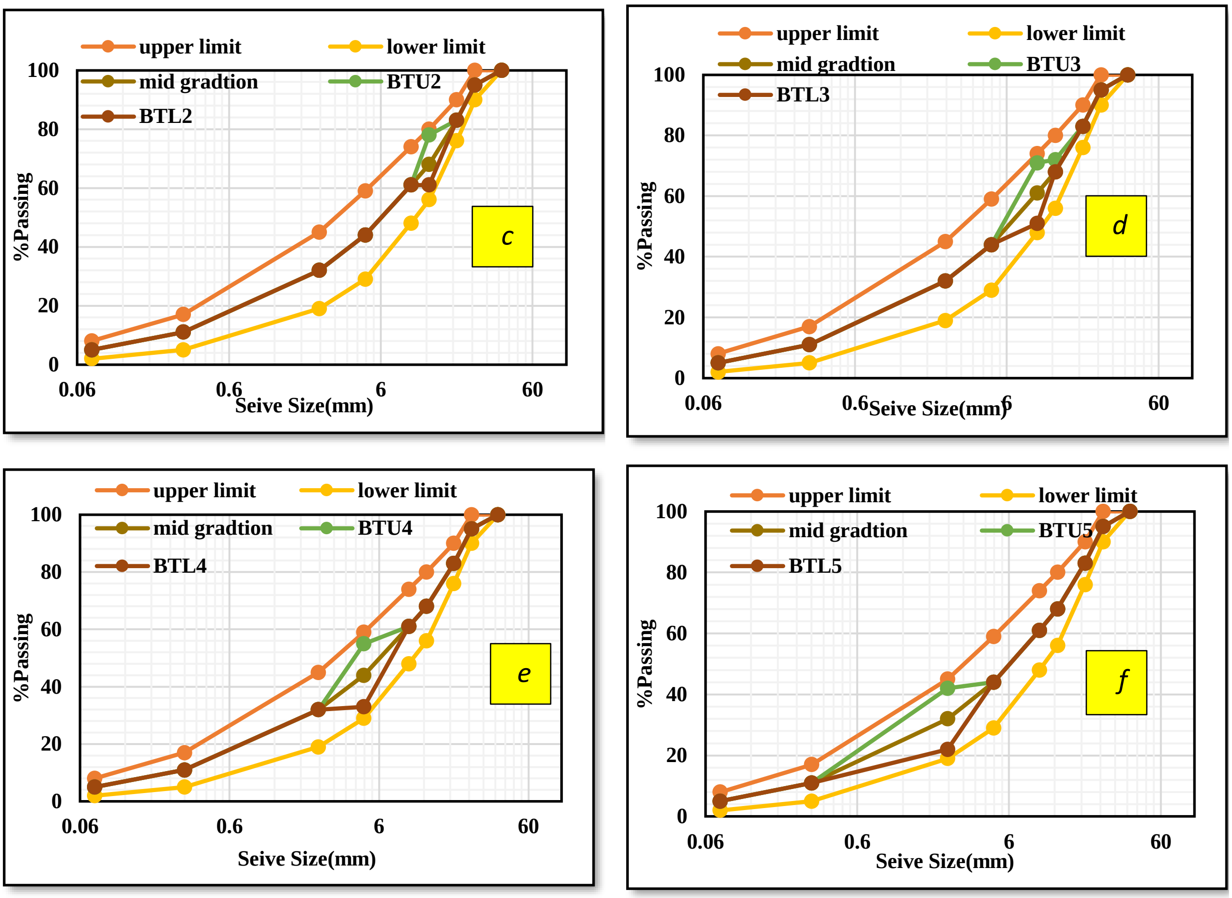


Figure 8. Aggregate gradation for asphalt mixtures (Tolerance limit).



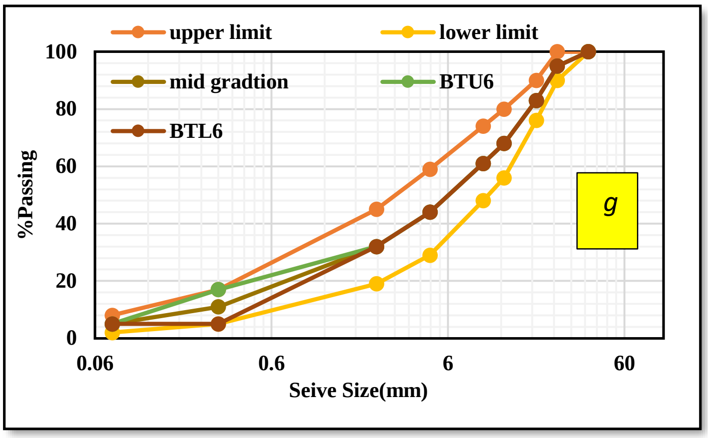


Figure 8. Aggregate gradation for asphalt mixtures (Tolerance limit) (Continued).

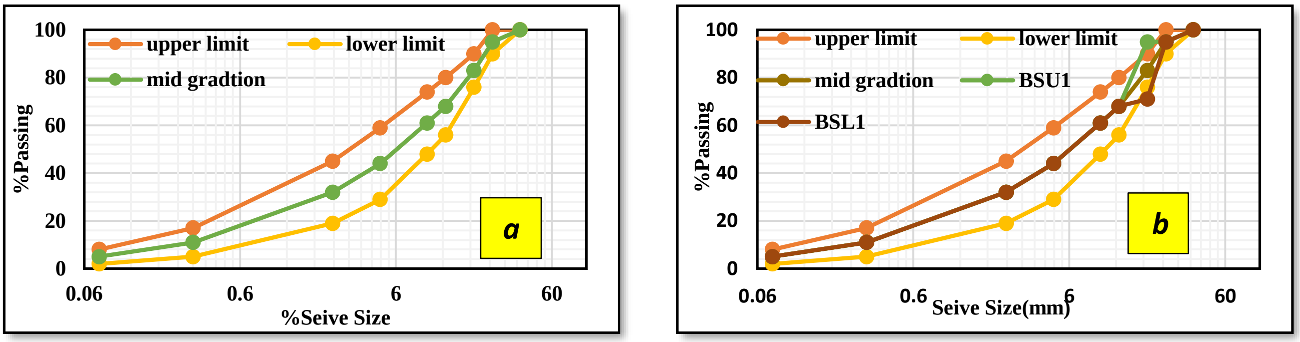
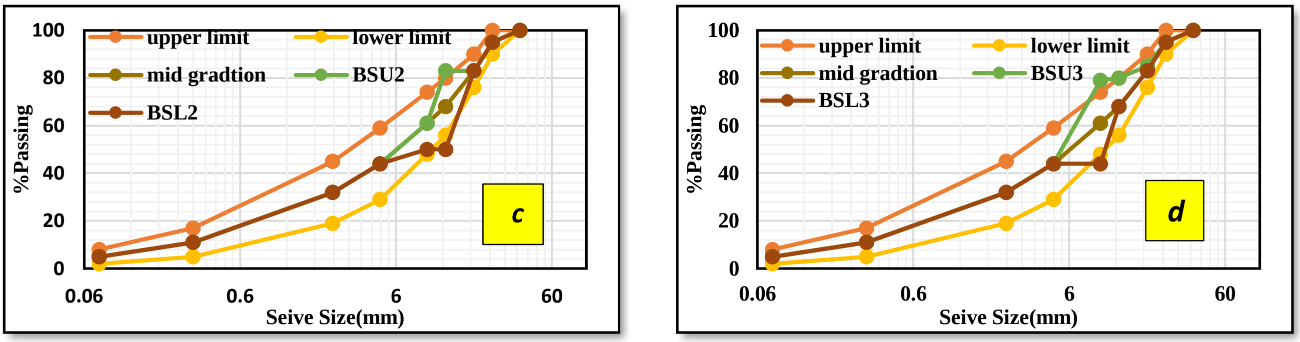


Figure 9. Aggregate gradation for asphalt mixtures (out of specification).



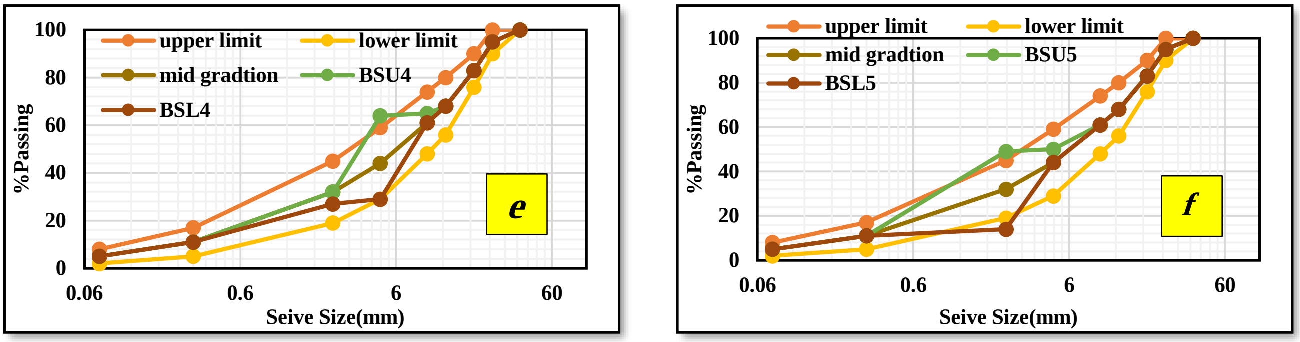


Figure 9. Aggregate gradation for asphalt mixtures (out of specification) (Continued).

3. MODIFIED MIXTURES

To enhance the performance of the deviated asphalt mixtures and control the distress that could be induced from the traffic loading or the environmental effect, this study focused on determining the polymer modification influence of the responses of the deviated hot mix asphalt and apply the proposed enhancement on both categories of HMA base course.

3.1 Effect of SBS- Modification Base Deviated Mixtures Performance

After using an ordinary asphalt binder in all previous mixes, the highest and lowest stability samples were re-manufactured, using modified (improved) asphalt binder, to show the difference in results as shown in **Table 8.**

Table 8. Modified Mixtures Gradations for Tolerance deviations and Results for Base Course.

	MBTL4	MBSU5	MBTL6	M control mix (MBCM)	Toleranc e Limits	SCRB
Sieve mm	%Passing					
37.5	100	100	100	100	100	100
25	95	95	95	95	90-100	90-100
19	83	83	83	83	77-89	76-90
12.5	68	68	68	68	62-74	56-80
9.5	61	61	61	61	55-67	48-74
4.75	33*	44	44	44	38-50	29-59
2.36	32	42*	32	32	28-36	19-45
0.30	11	11	5*	11	7-15	5-17
0.075	5	5	5	5	3-7	2-8
Volumetric Properties						
Density g/cm3	2.31	2.25	2.23	2.28		
%AV	3.5	5.6	6.5	4.4		
Stability kN	11.11	9.99	7.11	12.22		
Flow(mm)	1.8	1.9	1.6	2.2		

Obviously, there is an increase in the stability values for the modified base mixtures by 47.2%, Increasing air voids content by 10.5%, and a decrease in the flow by 21.4%, as shown in **Fig. 10.** The increase in the Stability values is due to the higher resistance of the modified asphalt binder to deformation than the neat binder at a certain temperature. Therefore, the modified binder carries an amount of the load when applying pressure to the sample more than that of the neat binder due to its higher viscosity and more temperature resistance. Modified mixtures gradations for tolerance deviations and Base Course mixtures are shown in **Fig. 11**, where the stability is increased by a range of 42.4 to 92.5% **.**

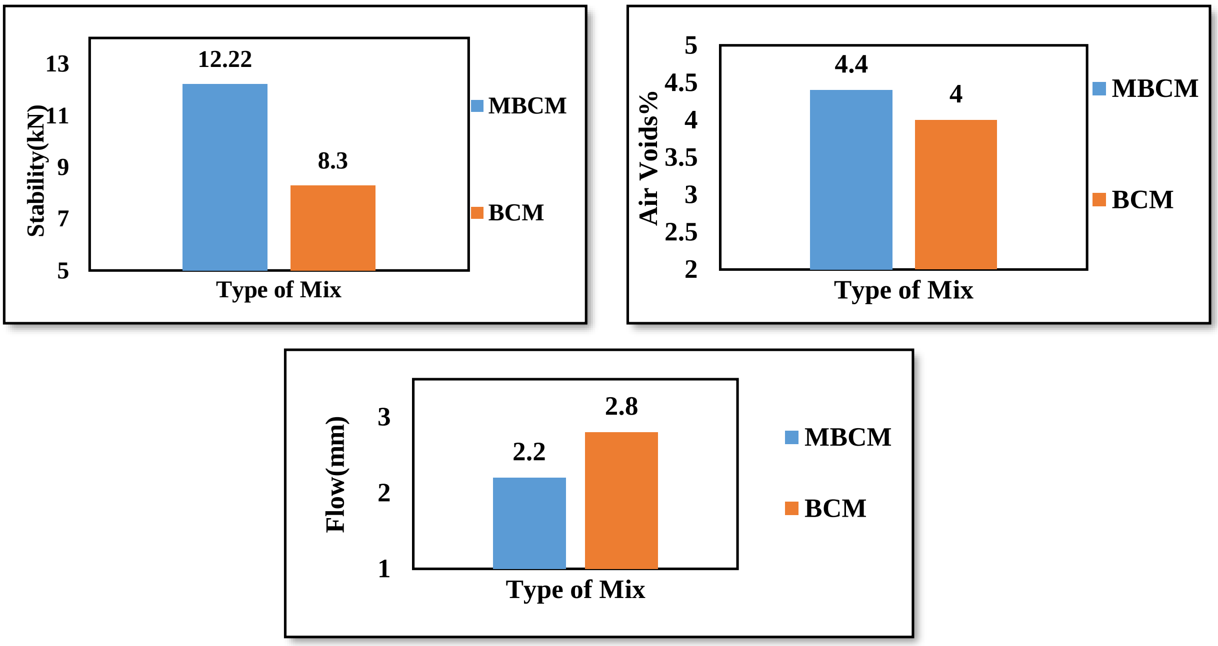
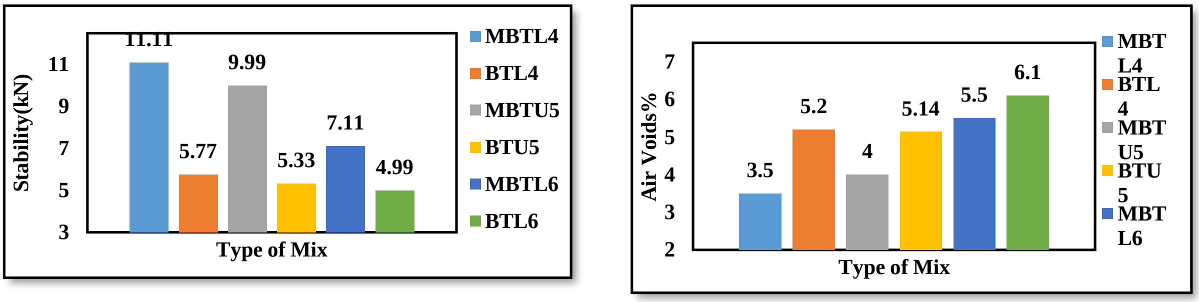


Figure 10. Effect of SBS on the Stability for Control Base Mixture.



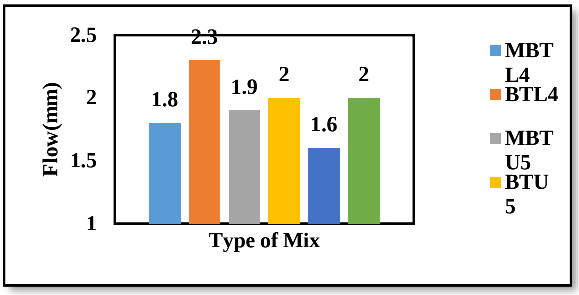


Figure 11. Effect of SBS-Modification on Marshall properties within the Tolerance Limits Deviated Mixtures for Base Course.

3.2 Effect of Modified Mixtures Gradations beyond Specification Requirements

Additionally, Modified Mixtures Gradations Out of Specific Requirements had been tested to assess the effect of the SBS-modification on the volumetric properties, as shown in **Table 9.**

Table 9. Modified Mixtures Gradations beyond Specification Requirements (Base Course).

	MBSU2	MBSU3	MBSL6	M control Mix (MBCM)	Tolerance Limits	SCRB
Sieve mm	%Passing					
37.5	100	100	100	100	100	100
25	95	95	95	95	90-100	90-100
19	83	85*	83	83	77-89	76-90
12.5	83*	80*	68	68	62-74	56-80
9.5	61	79*	61	61	55-67	48-74
4.75	44	44	44	44	38-50	29-59
2.36	32	32	32	32	28-36	19-45
0.30	11	11	3*	11	7-15	5-17
0.075	5	5	2*	5	3-7	2-8
Volumetric Properties						
Density g/cm3	2.271	2.254	2.249	2.28		
%AV	5.13	5.84	6.04	4.4		
Stability kN	12.44	9.99	6.66	12.22		
Flow(mm)	2.5	1.9	1.3	2.2		

Fig. 12 illustrates the modifier's effect on the stability of out-of-specification limits. It is clear that SBS can raise the stability of the extremely deviated mixtures by 133, 73.1, and 76.6% for BSU2,

BSU3, and BSL6, respectively. The modified binder's higher stiffness contributes to carrying the load more than that of the neat binder mixtures.

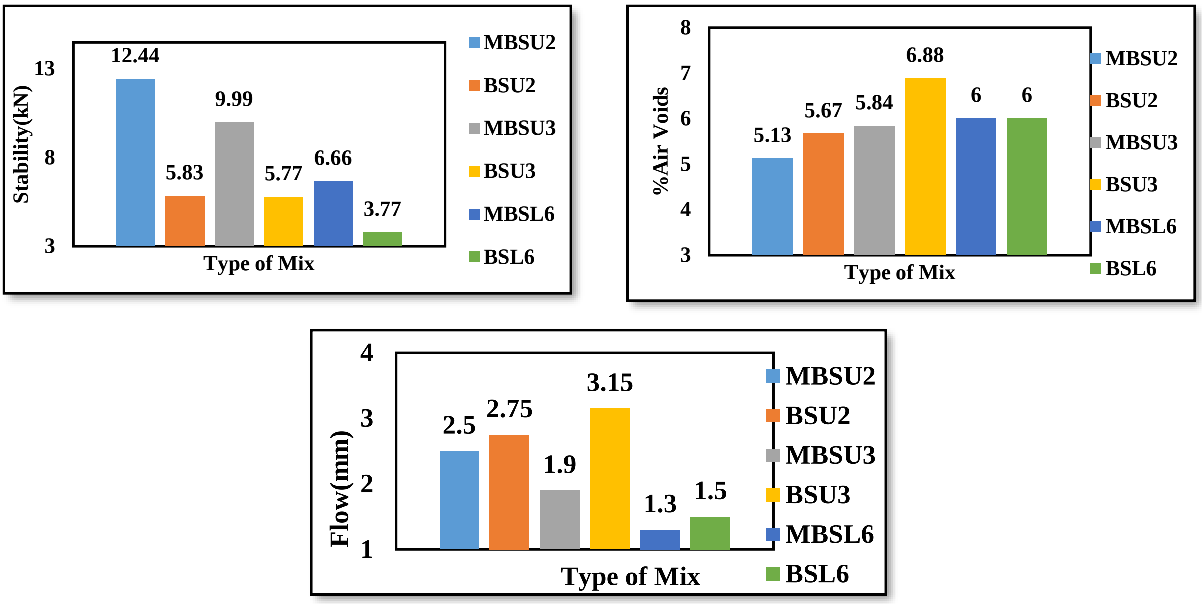


Figure 12: Effect of modified binder on Marshall Properties.

4. CONCLUSIONS

This study examined the impact on the performance and particle packing of the inner structure of the mixture. The base course mixing properties were selected for this study, and the mid gradation as a control mix was chosen. In the designed mix, the out-of-control sieves in the asphalt concrete industry were applied with two types of deviations. The two types of deviation are: beyond the SCRB's tolerances, and the second is beyond the SCRB specification. The combined gradation has a significant impact on asphalt mixture performance. The following conclusions can be summarized:

1. The first type of deviations has been found to have less effect on the mixture performance of Marshall properties.
2. The deviations which exceed the lower limit (coarser mixture) do not adversely affect the performance of the mixture in comparison with those which exceed the upper limit for the first type of deviation (tolerance deviated samples). The reason behind this is probably due to the increase in the contact points with large particles, and this caused an increase in the stability of the sample. The second type of deviation shows, in general, deterioration in the mixture performance.
3. Aggregate gradation deviation in Base Course has also shown a reduction in Marshall stability, but the reduction in stability kept it within the accepted limits.
4. There is a good indication about using SBS-modification for the deviated asphalt mixtures, which is clear that SBS can raise the stability value by 47% compared to their neat deviated mixture.

5. The increase in Marshal stability for the modified mixtures was about 47% for the tolerance-deviated mixtures, while the second type of deviations the increase was larger up to 133%.
6. Packaging ratios were a good tool for understanding aggregate packing and the mixing efficiency in turn.

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