Enhancement of Rutting Resistance for HMA Pavement Layers by Incorporating with SBS Modified Asphalt and A High Percentage of RAP

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Abstract. The loss of natural resources is one of the growing problems due to the inability to replace these resources on the one hand, and environmental pollution resulting from damage to asphalt pavements on the other hand. So the use of RAP in asphalt mixture has been promoted. The research addressed the inclusion of RAP in bulk and its effect on the resistance of asphalt mixtures to "RUTTING" as one of the most important problems. What mixtures are exposed to during high-temperature cycles where there are four different percentages of RAP (10, 15, 20, 25%), (30, 40, 50, 60%) and (40, 50, 60, 70%) For each of the three paving layers (surface, bond, base) respectively. Four samples were taken at three different temperatures (45, 55, and 70) degrees Celsius of asphalt mixtures for each of the three pavement layers. Various types of asphalt bonds have been used. To evaluate mixtures during the Hamburg Wheel Track test at different temperatures. The results indicated an improvement in the corrosion resistance of the mixture with the inclusion of RAP. The resistance of the asphalt mixture increased when SBS asphalt was used, which improved the mechanical properties of the asphalt mixtures. The experimental results of the Hamburg wheel test also showed a significant improvement in "Rutting Resistance" when RAP was added at its optimum value. For each of the three layers (surface, binder, base), the use of SBS modified asphalt reduces permanent deformation of the asphalt mixture.

Keywords: Rutting Resistance; HMA Pavement Layers; Asphalt

1. INTRODUCTION

Bitumen in the hot asphalt mixture is one of the most widely used paving materials worldwide. Repeated load resulting from traffic and high temperatures is a source of damage to the pavement and encourages the aging of the binder [1,2]. In the presence of these conditions, the layers of the pavement deteriorate, so the pavement is removed and ground, and its reusd as reclaimed asphalt pavement, which is known by the term (RAP)[3]. RAP is one of the most important materials that can be reused to achieve sustainability, as many countries tended to use it in high quantities, as the rate of use in China of reclaimed asphalt pavement is 220 million tons annually, and it is constantly increasing [4]. The composition and mechanical performance of the asphalt binder also changes over time and applied loads, in addition to the processes of evaporation and oxidative condensation as a result of exposure to sunlight at different temperatures [5,6] in addition to being a factor in reducing global warming and the emission of toxic gases [7-9] and the use of RAP had many advantages from The most important of which is the decrease in the cost of pavement construction and resource conservation [10,11].

Studies have also shown that increasing the percentage of RAP inclusion in the asphalt mixture leads to a decrease in the total cost of the mixture [12] due to RAP's compensation for the basic mixture components represented by asphalt and aggregates [13,14]. It was indicated [5] that RAP is characterized by a bituminous material with higher hardness than the source asphalt, that the use of reclaimed materials in high quantities causes a decrease in adhesion ability, and that the pavement is subject to deformation [15], but the rheological properties of the binder can be restored during the mixing process [16]. It was revealed that the "old asphalt film" reduces air voids and contributes to the asphalt mixture's resistance to thermal cracking, as found in a study conducted by Walaa et al. The effect of asphalt modified with regenerators is positive on mixtures with high RAP content, as it helps to restore the old bitumen to the required viscosity, and the resistance of (RAP-HMA) mixtures increases. [17] confirmed that the behavior of asphalt mixtures increased to resist rutting when percentages of RAP were included. It was also found [18] that the RAP-HMA mixture is less susceptible to permanent deformations resulting from an increase in temperature and traffic loads compared to mixtures that do not contain RAP.

The research aims to evaluate the effect of mixtures containing "Reclaimed Asphalt Pavement" (RAP) in its optimal ratio for each of the paving layers (surface, binder, and base layer) through rutting resistance using the" Hamburg wheel tracking" test to determine the amount and depth of the crack for the mixtures containing RAP and compare it with the asphalt mixture The original is the presence (limestone dust) as filler with the use of two types of asphalt source and modified with SBS. The study included a study (characterization of the components of the asphalt mixture) through the Marshall method. Models were made to obtain optimal RAP ratios for each layer characterized by a balance in terms of Marshall properties. The models are produced in the laboratory, depending on the specific gradation of the dense gradient mix HMA [19]. These samples were pressed at 75 strokes for each face, and through the samples that are characterized by the highest stability, it was found that they have the optimal percentage of RAP, and then these percentages were used in making the models used in the Hamburg wheel test.

3. MATERIALS AND METHODS

3.1 Asphalt Cement

The virgin asphalt that was used for this research is characterized by the degree of "penetration" (40/50) which was obtained from the factory (basic asphalt treatment) "Al-Dora" (AC 40/50). The rheological properties of asphalt are listed in Table 1, and the actual properties of asphalt concrete have been approved according to ASTM Standards.

Table 1: Physical characteristics of Asphalt binder and standards limitations.

Table 1: Physical characteristics of Asphalt binder and standards limitations.**Tests**	**Standard**	**Unit**	**Tests value**	**Standards Limitations as per to SCRB / R9, 2003**
Penetration,25 °C	ASTM D 5	1/10 mm	42	40-50
Ductility, 25 °C	ASTM. D.113	cm	>100	>100
Softening Point	ASTM. D.36	˚C	52	……
Specific gravity, 25 °C	ASTM. D.70	……	1.04	……
Flash and fire points	ASTM D.92	˚C	295°C	> 232 °C
Rotational Viscosity a (centistokes)	ASTM. D.4402	……	550 @ 135ºC	……

3.2 Polymer Modified Asphalt By Styrene Butadiene Styrene

SBS is a ternary copolymer containing styrene and butadiene monomers by the polymerization process. A material that has excellent impact strength on asphalt properties. In this study, SBS-modified asphalt was used at a rate of 4% of the total asphalt weight. SBS polymer-modified asphalt cement (PMAC) is suitable for the city of Baghdad. The specifications of this type of asphalt were obtained from the company. Laboratory tests of the virgin asphalt and asphalt modified with SBS were conducted in the consulting office of Al-Nahrain University, see Table 2.

Table 2: Rheological characteristics of base asphalt binder modified with 4%SBS.

Type of Asphalt	**Standard Specification**	**Performance Grade of Modified Asphalt**		
Parameter		**Temperature Measured**	**Parameter Measured**	**Requirements**
Aging	Original Binder			
Rotational Viscosity (Pa.sec)	ASTM D 4402	@135 °C	1.2	3 Pa.s, Max
Dynamic Shear Rheometer (DSR) G*/sin δ, kPa	ASTM D 7175	@76ºC	1.21	1 kPa, Min
Flash Point (ºC)	ASTM D 92	---	270	230 ºC, Min
Aging	Rolling Thin Film Oven (RTFO) Residue			
Dynamic Shear Rheometer (DSR) G*/sin δ, kPa	ASTM D 7175 ASTM D 2872	@76 ºC	2.31	2.2 kPa, Min
Mass Loss (%)	ASTM D 2872	0.66		1, Max
Aging	Pressure Aging Vessel (PAV-110 C)Residue			
Dynamic Shear Rheometer (DSR) G*.sin δ, kPa	ASTM D 7175 ASTM D 6521	@37 ºC	3950	5000 kPa, Max
Bending Beam Rheometer (BBR) Creep Stiffness, mPa	ASTM D 05	@ 0 ºC	105	300 mPa, Max
Bending Beam Rheometer (BBR) Slop m-value	ASTM D 6648	@ 0 ºC	0.42	0.3, Min

3.3 Aggregates

The aggregate used in this research was obtained from the "Nubian Quarry" which is widely used for the asphalt mixture production line. Laboratory tests were conducted to obtain "chemical and physical properties" according to "ASTM Standard Designation" for both (coarse and fine aggregates). The maximum size of the used aggregate used in the "asphalt concrete mixture" was chosen as (19 mm), (12.5 mm), and (25 mm) for the surface, binder, and base asphalt mixture for each layer respectively, the binder layers, and the base layer according to SCRB [20], as shown in Tables 3 to 5 and Figures 1 to 3 for each layer of paving, respectively. Based on the Marshall method for designing asphalt mixtures, the optimal asphalt content was calculated according to ASTM D 6926-10 [21] and ASTM D6927-15 [22].

Table 3: Gradation of asphalt mix for the surface layer

Sieve Size	**Sieve size (mm)**	**Percentage passing by weight of total aggregate**	
		Specification Limits [S.C.R.B]	**Work Choice**
3/4"	19	100	100
1/2"	12.5	90 - 100	97
3/8"	9.5	76 - 90	83
No.4	4.75	44 - 74	66
No.8	2.36	28 - 58	46
No.50	0.3	5 - 21	12
No.200	0.075	4 - 10	7

Table 4: Gradation of asphalt mix for the binder layer.

Sieve Size	Sieve size (mm)	Percentage passing by weight of total aggregate	
		Specification Limits [S.C.R.B]	Selection Gradation
1"	25	100	100
3/4"	19	90 - 100	94
1/2"	12.5	70 - 90	88
3/8"	9.5	56-80	64
No.4	4.75	35-65	50
No.8	2.36	23 - 49	35
No.50	0.3	5 - 19	10
No.200	0.075	3 - 9	6

Table 5: Gradation of asphalt mix for the base layer.

Sieve Size	Sieve size (mm)	Percentage passing by weight of total aggregate	
		Specification Limits [S.C.R.B]	Work Choice
1.5"	37.5	100	100
1"	25	90-100	91
3/4"	19	76-90	84
1/2"	12.5	56-80	65
3/8"	9.5	48-74	59
No.4	4.75	29-59	46
No.8	2.36	19-45	25
No.50	0.3	5-17	9
No.200	0.075	2-8	5

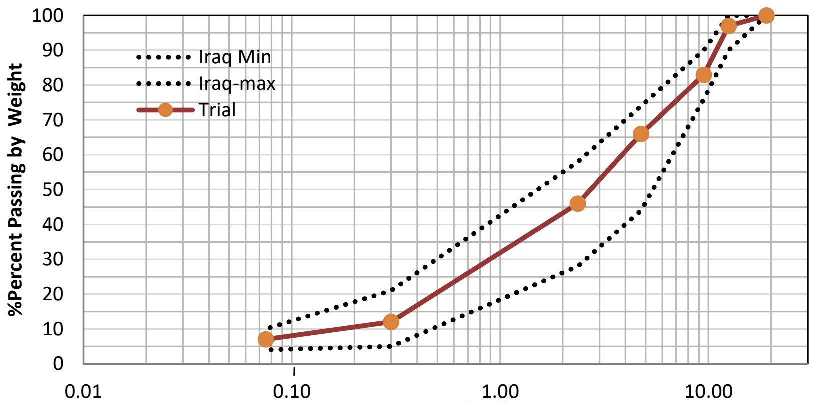

Figure1: Specification limits and mid-point gradation of (SCRB,2003) for surface course layer.

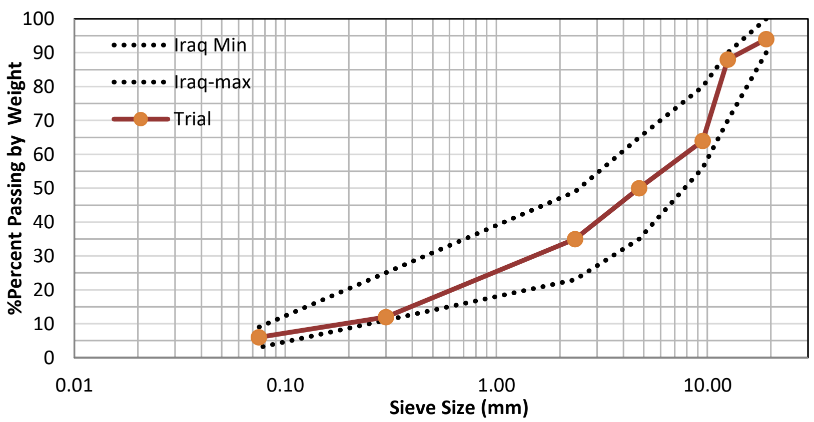

Figure 2: Specification limits and mid-point gradation of (SCRB,2003) for BINDER course layer.

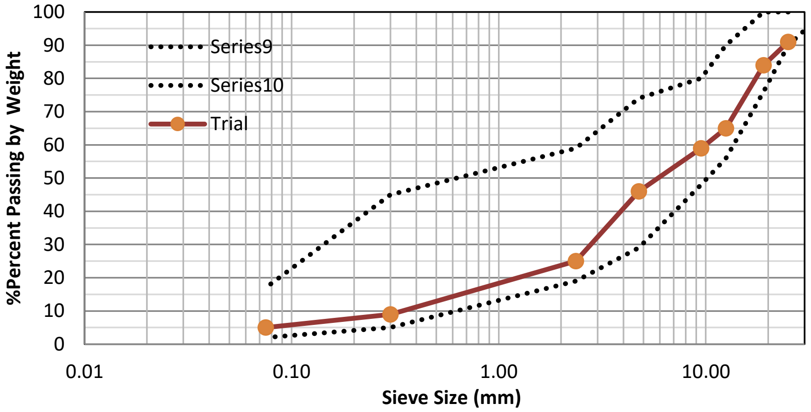

Figure 3: Specification limits and mid-point gradation of (SCRB, 2003) for base course layer.

3.4 Reclaimed Asphalt Pavement

Reclaimed asphalt pavement (RAP) used in this research or study was obtained from " Baghdad Governorate" of the Republic of Iraq and was tested to find the percentage of binder in the RAP mixture depending on the specification (ASTM D6307-10) to calculate the asphalt content [23], the percentage of asphalt binder obtained in RAP was 4.6%. In addition, the "total gradient" distribution in (RAP) is shown in Figure 4.

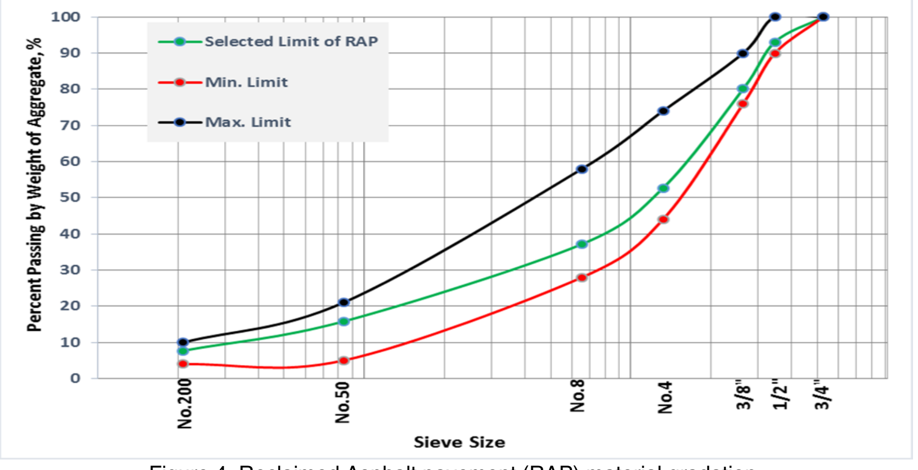

Figure 4: Reclaimed Asphalt pavement (RAP) material gradation.

Four percentages from RAP were used (10, 15, 20, and 25%) and (30, 40, 50, and 60%) and (40, 50, 60, and 70%) as percentages of the" total weight of mixture" for pavement layers respectively, Through the "sieve analysis" of RAP and its distribution on the sieves, where it was divided through a sieve "No. 4" before using it for the process of preparing asphalt mixtures as shown in Figure 5 to obtain the "behavior of high and low ratios" of (RAP) in addition to Compensation for the decrease in the percentage of binder content.

Figure 5: Fractionated samples (coarse and fine) of the reclaimed asphalt pavement (RAP).

3.5 Fillers Materials

3.5.1 Limestone Dust

limestone dust brought from the lime factory in Karbala' governorate. The physical properties of the used lime filler are presented in the "Iraqi" standard specification that was adopted in determining the (lime) that is used in building No. "807" for the year (1988) [24].

3.6 Wheel Tracking Test

A pavement wheel tracker is a device commonly used to assess the potential for "rupture" of control mixture and RAP-containing asphalt mixtures in various proportions by competing with the actual pavement lag progression. “Test Apparatus,” Figure 6 shows the process of compacting asphalt slabs using the compactor apparatus incorporating rotating wheels described in [25]. Models of "compressed asphalt slabs" have also been prepared. The measurements of the “pressed panels” used in this study were (400 mm) (15.7 in) in length, (300 mm) (11.8 in) in width, and (50 mm) (1.9 in) in height as required by (EN). 12697- Part 22: 2005).

Figure 6: Pressing the asphalt panels using the compressor device that includes rotating wheels.

Asphalt slabs are pressed using a standard iron press with dimensions (400 mm) (15.7 inches) in length, (300 mm) (11.8 inches) in width, (120 mm) (4.7 inches) in height), as shown in the nameplate (2). The asphalt shingles are prepared with a weight (14,100 g) of an asphalt mix comprising various ratios of RAP to simulate a "surface wear" layer. Aggregates are heated in an oven to mixing temperature after being prepared and stacked in a mixing vessel. Aggregates are collected before starting to make asphalt mixtures, where they are mixed with specified proportions of hot and highly heated asphalt (RAP). The above ingredients are mixed. together in a bowl. It is designed to mix until the aggregate is sufficiently covered with asphalt to obtain a consistent mixture. The mixture and its contents are transferred to the oven where it is stored for two hours at a temperature of “135°C” to allow all the pores in the mixture to absorb the content of the asphalt binder. the mixing of the asphalt mixture every “30 minutes” to ensure uniform aging everywhere [26]. Then the asphalt mixture is pressed into a compression mold which is heated to the required pressure temperature according to EN 12697-33 using a cylindrical compressor, and the molds, their shapes, the method of placing the sample in the mold, and their uniqueness are shown. In Figure 8 shows how to compress the sample with pressure, after that the mold is left for "24 hours", after which the sample is extracted from the mold. The prepared samples are shown in Figure 7. The test provides information on the percentage of “permanent deformation” produced by concentrated and diffuse loads. External "linear valued" displacement transformers (LVDT's) are used to determine the maximum fault depths over coherent pass intervals. The applicable wheel load is about 700 N (158 lb) with a total travel distance of (230 ± 10) mm and a constant load frequency of (26.5 ± 1.0) load cycles per 60 seconds at the contact points as they repeatedly pass over a fixed pattern. until you reach "10,000 cycles". The maximum limit of occurrence before 10,000 cycles, the wheel is lifted for the failed specimen described by [25]. The tests were conducted in cooperation with the National Center for Building Laboratories and research.

Figure 7: Shows the shape of the molds.

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Figure 8: Shows how to compress the sample with the piston device.

4. RESULTS AND DISCUSSION

Through the results of Marshall stability, the "optimum ratio" of RAP was found (20, 50, and 50%) for each of the surface layers, the bonding layer, and the base layer, respectively, which gave the highest Marshall stability results. These ratios were used in the production of samples to be tested in the Hamburg track wheel, All results of the (Permanent Deformation) .The results are plotted graphically illustrating the "depth of estrus" about the test temperature was carried out in three degrees "45°C", "55°C", and "70°C" and set the temperature. Figures 9 to 11 show the results as the "permanent displacement" (RD) shows how it is affected by the temperature change from 45 to 70 degrees Celsius for the surface layer.

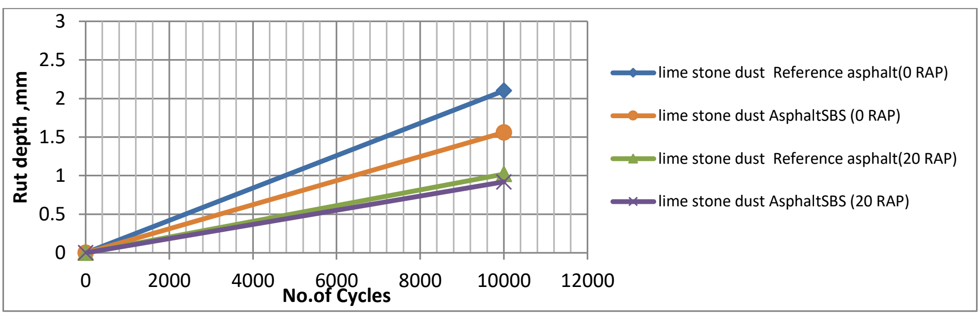

Figure 9: Influence of RAP content on rutting depth at testing temperature 45˚C using different types of asphalt for the surface layer.

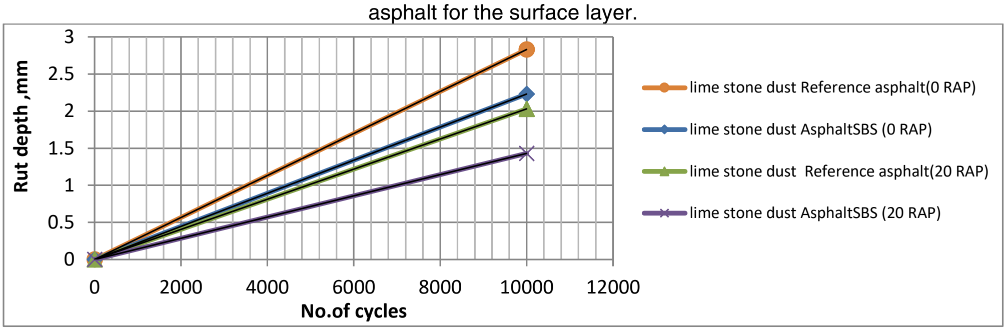

Figure 10: Influence of RAP content on rutting depth at testing temperature 55˚C using different types of asphalt for surface layer.

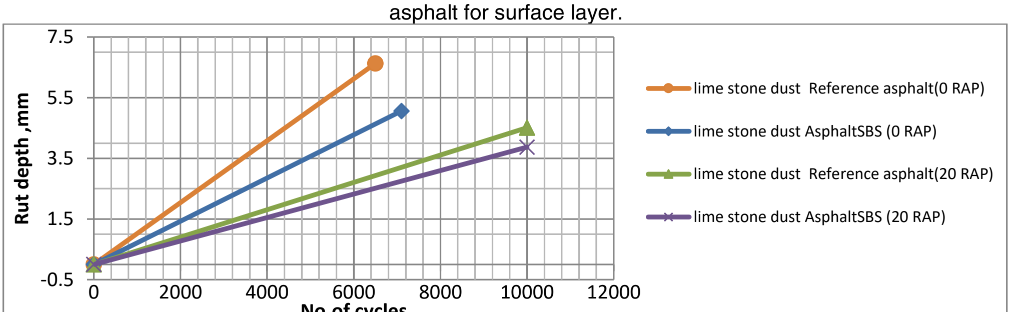

Figure 11: Influence of RAP content on rutting depth at testing temperature 70˚C using different types of asphalt for the surface layer.

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Figures 12 to 17 show the relationship between rut depth and number of cycles for each binder and base layer respectively using different types of asphalt.

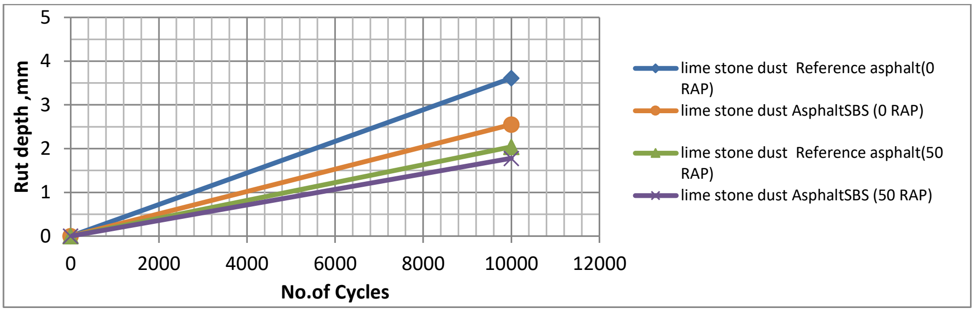

Figure 12: Influence of RAP content on rutting depth at testing temperature 45˚C using different types of asphalt for binder layer.

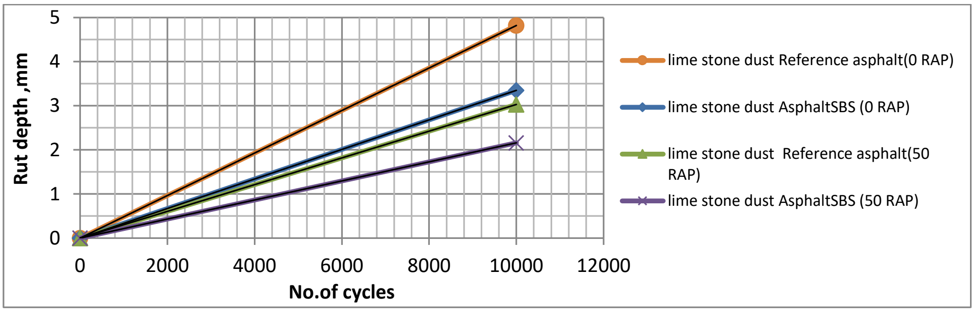

Figure 13: Influence of RAP content on rutting depth at testing temperature 55˚C using different types of asphalt for binder layer.

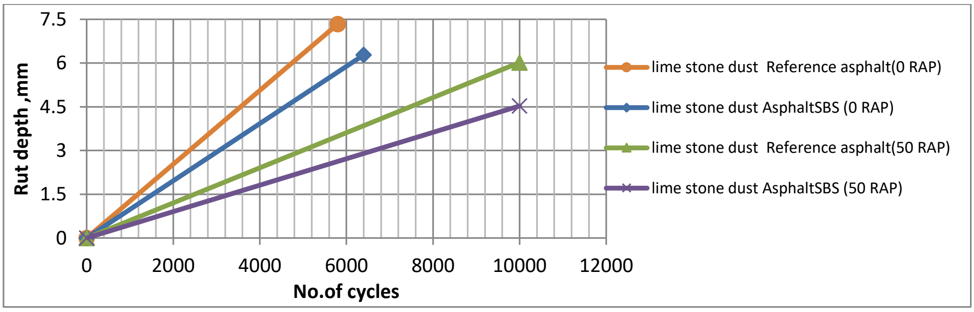

Figure 14: Influence of RAP content on rutting depth at testing temperature 70˚C using different types of asphalt for binder layer.

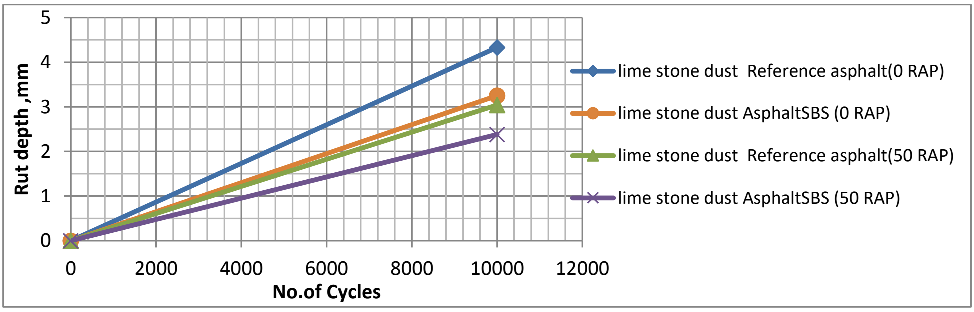

Figure 15: Influence of RAP content on rutting depth at testing temperature 45˚C using different types of asphalt for base layer.

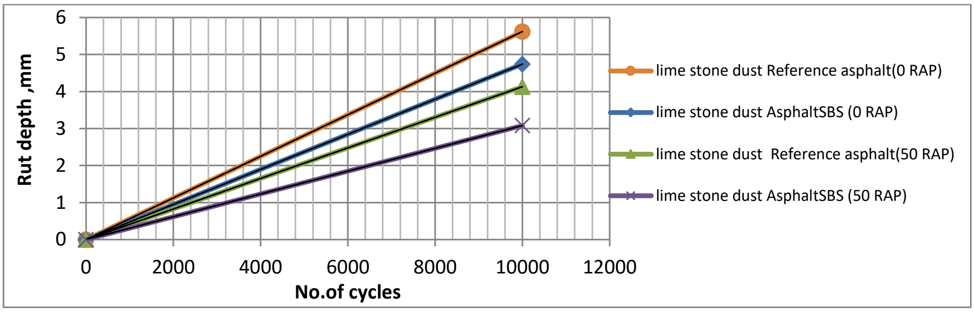

Figure 16: Influence of RAP content on rutting depth at testing temperature 55˚C using different types of asphalt for base layer.

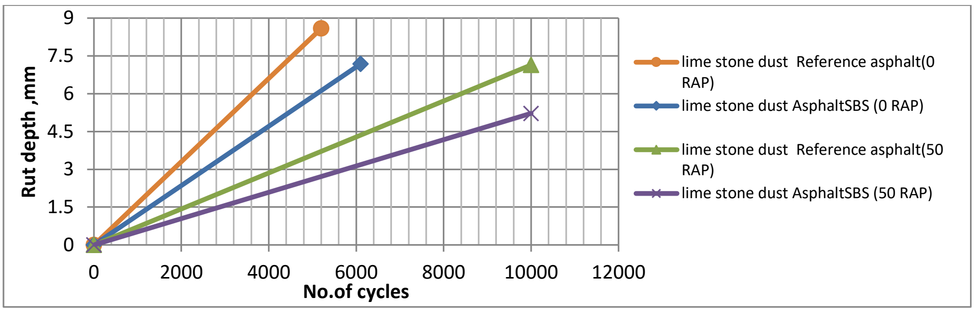

Figure 17: Influence of RAP content on rutting depth at testing temperature 70˚C using different types of asphalt for base layer.

Figures above show an increase in the tear strength ,as the(RAP) content increases from [0% to its optimal value at each layer], when the test is carried out at a temperature of “70°C”,this, in turn, increases the number of cycles until the sample reaches failure. This is because the inclusion of (RAP) increases and enhances the hardness of the asphalt mixtures. The use of asphalt modified with SBS also led to good, where the results showed the progression of the mixtures and their high resistance to deformation when adding modified asphalt compared to other mixtures. The same as regular asphalt, and this is due to the properties of asphalt, which were improved by "Polymers", which increased the hardness of the mixtures and improved the bonding between its components to be good bonding bonds that reduce failure and increase the resistance of the asphalt mixture to deformations Because of spider web resembles the structure of the asphalt content, works to strengthen it, in addition to the effect of SBS atoms on large cracks and improves cohesion within the asphalt component more than what we find in the modified asphalt.

5. CONCLUSIONS

Through the results of the study, many conclusions were obtained through which the addition and inclusion of RAP in high quantities in the asphalt mixture were evaluated using two types of asphalt during the Hamburg wheel tracking test for different temperatures:

- The “rut depth” results in the Hamburg wheel tracking test for each of the surface, binder and base layers showed that the inclusion of the RAP additive in the asphalt mixture gave greater crack resistance compared to the asphalt mixtures without RAP where the percentage of the amount of decrease in the rut depth was At a temperature of 45 degrees Celsius (51.4, 43.5, and 29.8%), these percentages increased further by replacing the reference asphalt with SBS-modified asphalt for the same temperature to become (56.5, 51, and 45%) for each of the three layers, respectively.
- The resistance to permanent deformation at high temperatures at 70°C was improved for the hot asphalt mix containing RAP compared to the “control mixture” containing “0%” RAP, where the rutting depth reached (4.51, 6.02, and 7.14)% for each of The three tiling layers are in a row.
- Depending on the results of asphalt mixtures that contain limestone dust as a filler with the reference asphalt, compared with the asphalt mixture containing the same filler material with the modified binder with SBS, its resistance improved greatly to the effectiveness of SBS, which improved the rheological properties of the asphalt and increased the viscosity of the asphalt. Which leads to strengthening bonds and enhances the adhesion of the components of the asphalt mixture.
- The results confirmed that the rutting depth increases with the slope of the tiling layers, and that this depth decreases with the addition of RAP. This is because the farther we move away from the surface of the earth, the greater the granular gradient of the aggregates for each layer, and the less the amount of binder binder for each layer. The binder layer and the base layer. The results confirmed that the use of RAP

affects positively and significantly on the surface layer more than the rest of the paving layers by comparing the results of the rut depth for each of the three layers (surface, binder and base) of the asphalt mixtures containing SBS asphalt without RAP with the asphalt mixtures containing the same type of asphalt with the presence of RAP at The temperature is 55 degrees Celsius as an average temperature.the percentage of the decrease in depth, where it was found (35.9%, 35.5%, and 35%). This is an indication of the effectiveness of the modified asphalt SBS with RAP, as it produces a solid unit that resists permanent deformations resulting from loads and high temperatures.

- The permanent deformation of the asphalt mixture is a function of both temperature, stress level, and finally the loading time, which are considered variables with the paving depth. Therefore, for a promising future vision, the examination can be carried out at higher temperatures than the degrees dealt with in the research, with an increase in the applied loads to simulate the worst conditions that the pavement can go through with the calculation of all indicators. And highlighting the use of other sustainable resources and their effectiveness and their link to the components of RAP-HMA and a statement of effective renewals that can be combined with the documented link and applied in recent studies and the effect of RAP on all of the above in general.
- Latest inclusion of RAP In the hot asphalt mixture, one of the most ways that lead to green sustainability sought by the countries of the world, and the higher the ratios of RAP in the mixture to reach the optimum RAP ratio, the thickness of the binder film increases, which leads to better resistance for rutting .With this increase, it is accompanied by a decrease in the cost of road construction in terms of reducing the cost of the binder while reducing its percentage in the mixtures and increasing the shelf life of the pavement while reducing permanent distortions.

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