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PERMANENT DEFORMATION AND MOISTURE DAMAGE OF ASPHALT MIXES CONTAINING RAP AND SASOBIT

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Abstract— **Recycling of Reclaimed Asphalt Pavement provide us with the need to save valuable aggregate and with the help of which the use of expensive asphalt binder will be reduced as well. In this study we have considered one WMA additive (Sasobit). The rut resistances of mixes were improved by adding either RAP or Sasobit or both as compared to control asphalt mixes. But for lower percentages of RAP i.e. up to 15%, highest rut resistance was observed at 2% Sasobit addition, but for higher percentages of RAP highest rut resistance was observed at 3% Sasobit addition. On the other hand, increasing RAP and Sasobit content increased the moisture susceptibility of mixes, so best recommended combination is to use 30-40% RAP in addition of 3% Sasobit as far as permanent deformation and moisture susceptibility criteria are concerned.**

Keywords— **HMA, WMA, Sasobit, Permanent Deformation, Rutting, Moisture Damage.**

I. INTRODUCTION

The increasing plea on our thoroughfares over the past couple of decade's results in a decrease of budgetary funds and to offer a cost effective, safe and efficient system of roads has steered to intense growth in the need to rehabilitate our present roadways.

Moreover, historical data revealed that the RAP mixes could have similar performance as virgin HMA mixtures, when accurately designed and constructed [1]. Many innovative products and procedures are available having proficiency of dropping the production temperature of HMA without negotiating the concert and harmony of the pavement. About 40% reductions in mixing and compaction temperatures are possible by using these products [2]. With the lower operating temperature another aided benefit is that it will reduce the oxidative hardening of the binder and this will help in increased performance of the pavement, such as averting the mix from being tender when placed, reduced block cracking and thermal cracking [2].

Sasobit is a long-chain hydrocarbon (aliphatic poly-methylene), fine crystalline, formed from the gasification of natural gas or coal feed stocks by the Fischer-Tropsch (FT) procedure (in which partial oxidation of methane to carbon monoxide (CO) takes place, and later on reacting with hydrogen (H) manufacturing a combination of hydrocarbons under catalytic conditions with molecular chain lengths of plus C5 to C100 carbon atoms). Sasobit is also known as FT hard wax [3].

Sasobit is an "asphalt flow improver" and is perfectly soluble in asphalt binder at a temperature higher than 120°C, because of its melting temperature of about 102°C and Sasobit forms a crystalline grid structure in the binder at a temperature below its melting point that leads to additional permanency [3] [4]. The range for Sasobit use as endorsed by Sasol is from 0.8% to 3% by mass of binder. In marketable applications in Asia, Europe, the United States and South Africa Sasobit has been mixed straight with aggregate mix as melted liquid through a dosing meter or solid prills (small pellets). Marshall tests executed on blends prepared in this way signposted no variance in flow or stability values as associated to premixing with the binder [5]. For the purpose of comparing with conventional HMA technology, we need to carry out an inclusive laboratory and field examination to explore permanent deformation and moisture damage of WMA technology. The temperature regimes at which WMA are produced will help to distinguish it from other asphalt mixtures and then by comparing the strength and durability of final product [6]. There are extensive conclusions for WMA additives. Info obtained from industrialists and materials traders specify that, there is possibility to reduce CO2 emissions and energy consumption to about 30% as compared to standard HMA [7]. A positive influence on pavement performance may be demonstrated by these technologies, as they allow reduced HMA mixing and compaction temperature [8]. Using Sasobit there is an opportunity of dropping the production temperatures by 18–54^{o}C [9] [10]. By lowering the production temperature, we can extend the paving season as the capability to perform late/early-season paving will be enhanced. This is due to the asphalt mix preparation occurs at a reduced temperature, will not cool as quickly, thus allow a longer production time period [11].

As far as the materials selection is concerned, in most of the laboratory and in field research on WMA, ordinary dense-graded mixtures like those they normally use in HMA were used. There is currently no need to modify the gradation of ordinary dense-graded HMA mixes for accommodating WMA [12]. From description of LEA method, it is clear that laboratory mix design methods for WMA is the same as that apply to HMA paving mixtures, although it is recommended that laboratory production temperature and temperature of the mixtures from the plant production process must be adjusted. It is also stated that like HMA, LEA mixes also uses the same grades of asphalt in the same quantities. It is also stated that Sasobit has also been used in gussasphalt and in Stone Mastic Asphalt (SMA) [13]. With some WMA practices, it's good to utilize one grade harder bitumen than that typically used with HMA, but not until fully investigated [14].

Rutting is the accumulation of small amount of irrecoverable strain due to applied load on the pavement, also known as permanent deformation [15]. Rutting has become the major mode of flexible pavement failure because of increase in truck pressure in the last decades. Rutting is principally caused by the accumulation of permanent deformation in different layers and in different portion of layers in the pavement structure. There are two types of rutting: Instability rutting, which is caused by weak asphalt layers and structural rutting, which is caused by weak subgrade [16]. It has been revealed that for the larger part of the lifetime of the roadway, shear deformation is considered to be the primary mechanism of rutting [15] [17]. Using some of WMA products along with high percentage of RAP may badly affect the rutting potential, because of reduced stiffness because of lower production temperature [18]. Physical behavior of HMA changes when RAP is added. RAP binder's increased stiffness is thought to be the cause of higher modulus of HMA. In the same way it also disturbs the mixture's low temperature cracking as well as its fatigue behavior [1].

Moisture damage is the loss of durability and strength of asphalt mixtures affected by moisture. Moisture damage is the result of interaction of moisture with the adhesion between asphalt aggregate and binder, and thus during cyclic loading it become more susceptible to moisture. It means that asphalt mixture can result moisture damage because of reduced bond strength with in the fine aggregate and the asphalt binder [15]. Moisture present in air voids adversely affect the durability and strength of asphalt mixes and causes moisture damage. Moisture damage can occur in two different types: cohesive failure and adhesive failure. Cohesive failure is the strength reduction of the binder due to moisture damage, while Adhesive failure is in between the aggregate and binder [19]. Conventional measure of moisture susceptibility can be reinforced by the consideration of contact angle measurements and dynamic modulus results, which were proposed recently to be promising alternatives to assess moisture susceptibility of asphalt mixes [20]. According to Washington State Department of Transportation (2009) [21], Indirect tensile strength test is a very common and easy performance test conducted in the paving industry, which aid in measuring the asphalt mix susceptibility to moisture. In Indirect tensile strength testing, we test conditioned and unconditioned samples, which provide a consistent crack potential indication. For producing WMA lower production temperatures are used and thus moisture susceptibility increases. Incomplete drying of aggregate causes moisture damage of mix as water remains confined in the aggregate skeleton.

II. PROPOSED METHODOLOGY

A. Selection and Laboratory Testing of Materials

In this research coarse and fine aggregate were brought from Margalla quarry and penetration grade of 60/70 bitumen was used, which was collected from Attock Refinery Limited (ARL) Rawalpindi, Pakistan. RAP material was collected from Islamabad-Lahore Motorway in the form of milled material. Aggregate gradation used in testing was NHA class B according to NHA (1998) specifications for dense graded surface course mixtures, for which the nominal maximum aggregate size is 19 mm according to Marshal Mix Design (MS2). Properties of asphalt mix are greatly influenced by gradation, surface texture and shape of the aggregates, as higher shear strength is provided by aggregates which are rough-textured and angular as compared to rounded shaped aggregate with smooth-textured and almost 95% of the mixture is composed of aggregate and remaining 5% is the asphalt binder, so aggregate is the component that provides resistance to deformation and provide a strong stone skeleton. According to the standard specifications of ASTM and BS for materials classification, compulsory tests were made on utilized aggregate and binder. The essential aggregate tests including specific gravity test and gradation detailed were performed. Results of tests performed on aggregate are given in Table 1:

Table -1 Laboratory Test Results of Aggregate

Test Description	Specification Reference		Result	Limits
Elongation Index (EI)	**ASTM D 4791**		**3.578 %**	**≤ 15 %**
Flakiness Index (FI)	**ASTM D4791**		**12.9 %**	**≤ 15 %**
Aggregate Absorption	**Fine**	**ASTM C 127**	**2.45 %**	**≤ 3 %**
	Coarse		**0.73 %**	**≤ 3 %**
Impact Value	**BS 812**		**17 %**	**≤ 30 %**
Los Angles Abrasion	**ASTM C131**		**22**	**≤ 45 %**
Specific Gravity	**Fine**	**ASTM C 128**	**2.618**	**-**
	Coarse	**ASTM C127**	**2.632**	**-**

Asphalt content in RAP was determined using Ignition method in accordance with ASTM D 6307 – 98 and it was found that 4.46% of the total re-graded mass of RAP was aged-binder. While using Standard Test Method for Recovery of Asphalt from Solution by Abson method in accordance with ASTM D1856 – 09, to extract aged bitumen from RAP for testing. Table 2 and Table 3 shows the tests performed on bitumen

Table -2 Laboratory Tests Performed on Virgin Bitumen

Test Description	Specification	Result
Penetration Test @ 25 (°C)	**ASTM 5**	**64**
Flash Point (°C)	**ASTM D 92**	**232**
Fire Point (°C)	**ASTM D 92**	**241**
Specific gravity	**ASTM D 70**	**1.03**
Softening Point (°C)	**ASTM D36-06**	**48.2**
Viscosity Test (Pa.sec)	**ASTM D4402**	**.19**
Ductility Test (cm)	**ASTM D113-99**	**104**

Table -3 Laboratory Tests Performed on Extracted Bitumen

RAP (%)	Asphalt Source & Grade	Test Type	
		Penetration Test (60-70) ASTM D5	Ductility Test (≥ 100cm) ASTM D113
0	**ARL 60/70**	**63**	**120**
15		**58**	**103**
25		**52**	**93**
35		**47**	**83**
50		**41**	**74**

The selected gradation is shown in Table 4 and Figure 1 shows gradation which is plotted with percentage passing verses sieve sizes.

Table -4 NHA Class-B Gradation Selected for Testing

S. NO	Sieve Size (mm)	NHA Specification Range (% Passing)	Our Selection	Retained (%)
1	**19**	**100**	**100**	**0.00**
2	**12.5**	**75-90**	**82.5**	**17.50**
3	**9.5**	**60-80**	**70**	**12.50**
4	**4.75**	**40-60**	**50**	**20.00**
5	**2.38**	**20-40**	**30**	**20.00**
6	**1.18**	**5-15**	**10.00**	**20.00**
7	**0.075**	**3-8**	**5.5**	**4.50**
8	**Pan**	**…**	**…**	**5.50**

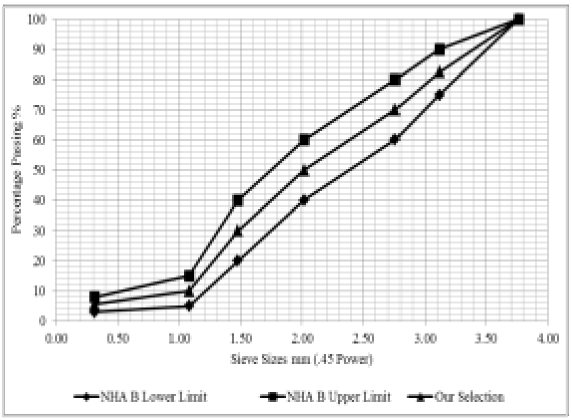

Fig. 1. Class-B Gradation plot with NHA Specified limit

The amount of RAP was varied by 0%, 15%, 25%, 35% and 50% in asphalt mix. Stability, flow values and volumetric were calculated using Marshall Mix design procedure. Therefore, five different RAP percentages and corresponding aggregate on different sieves were found which are shown in Table 5 and Table 6 while Figure 2 shows gradation which is plotted with percentage passing verses sieve sizes for mentioned percentages of RAP.

Table -5 RAP gradation

Sieve Dia (mm)	RAP (% Retained)
19	**0.00%**
12.5	**7.02%**
9.5	**11.15%**
4.75	**20%**
2.38	**18%**
1.18	**31%**
0.075	**10.25%**
Pan	**2.70%**

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Table -6 Weight of Aggregate as per Gradation

Sieve Dia (mm)	% Passing						
	NHA B Lower Limit	NHA B Upper Limit	Our Selection	15% RAP	25% RAP	35% RAP	50% RAP
19	100	100	100	100	100	100	100
12.5	75	90	82.5	85.2	85.9	86.5	87.3
9.5	60	80	70.0	69.0	69.7	70.1	70.7
4.75	40	60	50.0	50.2	50.8	51.0	51.4
2.38	20	40	30.0	32.5	33.7	34.5	35.3
1.18	5	15	10.0	10.9	12.8	13.6	14
0.075	3	8	5.5	5.0	5.3	5.5	6.3

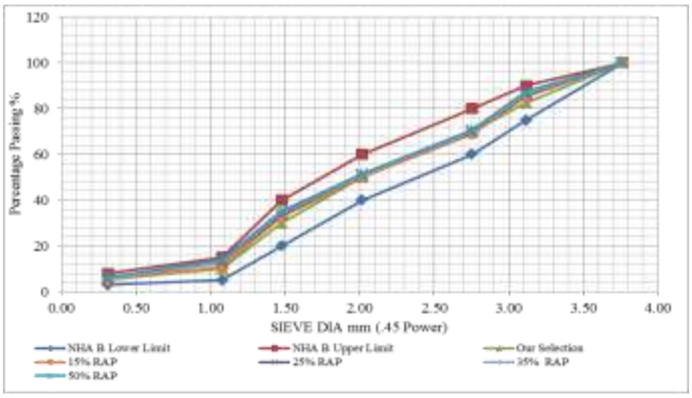

Fig. 2. Gradation plot of RAP Percentages with Specified limit of NHA Class B

B. Preparation of Aggregates and Bitumen for Marshall Mix Design

After sieve analysis, aggregate were dried to constant weight at a temperature of 105^{O} to 110^{O}. The amount of aggregate needed for the preparation of marshal compacted specimen of 101.6 mm diameter, by Marshall Mix design method (ASTM D6926), should be approximately 1200 g. As there were five types of gradations with respect to percentage of RAP i.e. 0%, 15%, 25%, 35%, and 50%. Specimens were prepared at five different binder contents of 3.5, 4.0, 4.5, 5.0 and 5.5%. The amount of asphalt cement added to each specimen was taken as the percentage of total weight of the mix. The reason of five trial blend was to select a mix that performs optimal at minimum bitumen content at 4% air voids. The volumetric properties, stability and flow were measured and verified in light of Marshall Mix design criterion by revising the Marshall Mix design procedure thrice for each mix, thus fifteen specimens for each mentioned percentage of RAP were prepared for OBC determination and thus a total of 75 specimens were prepared for determination of five OBCs, based on varying percentage of RAP. Separate graphical plots for all values were drawn as tabulated in Table 7 and shown in Figure 3 (a, b, c, d, e, and f).

Table -7 Volumetric for Different Percentages of RAP

(%) RAP	OBC at 4% Air Voids	VMA, (%)	VFA, (%)	Stability, (KN)	Flow, (mm)	Unit Weight, (mg/cm^3)
0	4.31	13.49	70.04	12.32	2.72	2.37
15	4.33	13.56	70.19	12.37	2.75	2.37
25	4.39	13.96	71.10	13.02	2.93	2.36
35	4.5	13.66	70.7	13.12	2.89	2.37
50	4.59	13.79	71.07	13.22	2.87	2.37

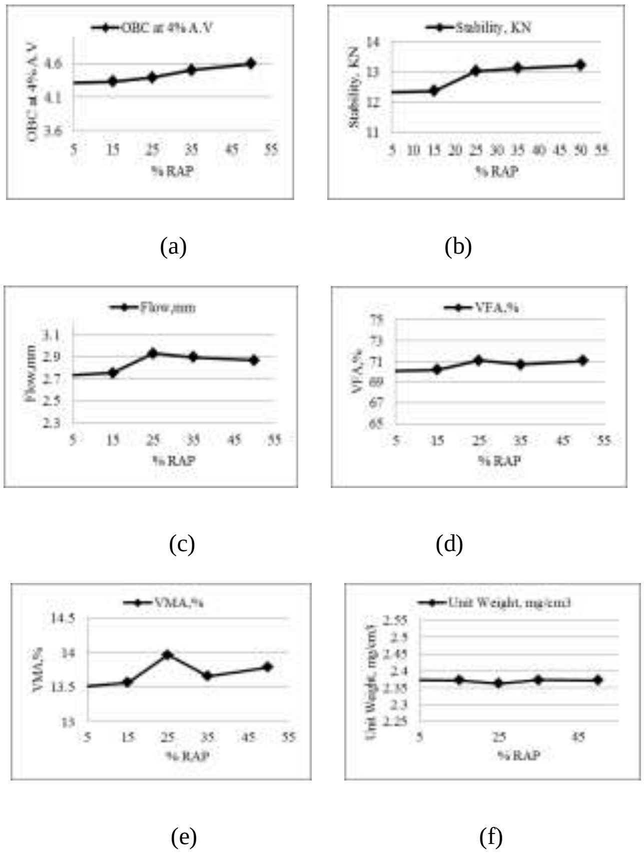

Fig. 3. (a, b, c, d, e & f): Plots between RAP percentages Vs Volumetric

C. Sample Preparation for Performance Tests

Sasobit utilized in the study was in the form of prills as shown in Figure 4, and was imported through an authorized product distributor. In this study Sasobit was pre-blended with the binder in appropriate amount; samples were prepared with 0%, 1%, 2% and3% Sasobit of OBC. Thus based on five percentages of RAP and with further addition of Sasobit percentages to each of the RAP percentage there were total of twenty mixes.

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Fig. 4. Sasobit Prills

Superpave mix design procedure was used to prepare specimens for performance testing. After sieving, similar to marshal mix design, the aggregates were dried to constant weight at a temperature of 105°C to 110°C. Mixing temperature of 160±5°C and compaction temperature of 135°C was used for HMA, while using 125±5°C and 100°C as mixing and compaction temperature for WMA respectively, as obtained from the viscosity plots of binders through RV test at 135oC and 160oC and also the general manufacturing temperature range for WMA is 93°C to 135°C. The required quantity of aggregate for preparing 152.4 mm diameter gyratory compacted specimens was 5000 g. Before compaction, conditioning of loose mix for short term aging was carried out for 2 hours at compaction temperature. Compaction of specimens was done by providing 125 gyrations as specified by the Superpave mix design. Further, resizing of samples for testing were carried out by utilizing saw cutter and core cutter, to obtain standard sample of 38.1 mm height and 152.4 mm diameter for wheel tracker test and 63±2.5 mm height and 101.6 mm diameter for moisture damage testing through UTM as shown in Figure 5 and 6 respectively.

Fig. 5. HWT Tested Sample

Fig. 6. UTM Tested Sample

D. Permanent Deformation (Wheel Tracker Tests Results)

Wheel tracker tests were conducted on specimens prepared for rutting under wet condition. For wheel tracker test a total of sixty samples were prepared for the twenty mixes. All the controlled specimens showed good resistance to rutting, whereas the specimens with 0% and 15% RAP shows higher resistance to rutting at 2% Sasobit addition and at 3% percent Sasobit addition these samples have less rut resistance than that of samples having 2% Sasobit. But samples with higher percentages of RAP that is 25%, 35% and 50% showed higher rut resistance at 3% Sasobit. All of the specimens passed the wheel tracker test criteria of 12.5 mm rut depth at a temperature of 45oC, which is the required testing temperature for bitumen of 58 grades (ARL 60/70) used in the study, while the numbers of passes were fixed to ten thousand which is the required criteria for rutting. The wheel tracker tests results are shown in Figure 7 and tabulated in Table 8.

E. Moisture Damage (ITS Test Results)

Moisture susceptibility testing were carried out on asphalt mixtures according to ALDOT 361 (resistance of compacted HMA to moisture induced damage). For the twenty different mixes a total of 120 gyratory samples at 4% air voids were prepared and tested for Indirect Tensile Strength. Thus six samples per mix were prepared, three of them were tested unconditioned by only placing in a water bath at a temperature of 25ºC for one hour right before testing, while the other three specimens per mix were soaked in warm water at a temperature of 60oC for 24 hours, followed by placing in a water bath at 25oC for one hour before being tested for Indirect Tensile Strength. The raw wet (conditioned) and dry (unconditioned) strength values for the 20 mixtures are shown in Figure 8 while the tensile strength ratios are shown in Figure 9. From the results it is clear that as we increase the RAP percentage the strength of the asphalt mix increases.

Table -8 HWTD & ITS Tests Results

Specification	Codes	Average RUT Depth (mm)	S1, (kPa)	S2, (kPa)	TSR= S2/S1
0% RAP, 0% SASOBIT	R0S0	4.455	777.85	777.5	99.96
0% RAP, 1% SASOBIT	R0S1	4.410	779.35	777.35	99.74
0% RAP, 2% SASOBIT	R0S2	4.383	780.2	776.3	99.50
0% RAP, 3% SASOBIT	R0S3	4.420	781.3	774.15	99.08
15% RAP, 0% SASOBIT	R15S0	3.690	783.05	770.55	98.40
15% RAP, 1% SASOBIT	R15S1	3.545	785.15	768.7	97.90
15% RAP, 2% SASOBIT	R15S2	2.855	787.9	767.2	97.37
15% RAP, 3% SASOBIT	R15S3	2.965	789.25	766.45	97.11
25% RAP, 0% SASOBIT	R25S0	2.820	791.8	764.7	96.58
25% RAP, 1% SASOBIT	R25S1	2.680	794.15	763.65	96.16
25% RAP, 2% SASOBIT	R25S2	2.615	796.75	763.3	95.80
25% RAP, 3% SASOBIT	R25S3	2.405	802.45	761.7	94.92
35% RAP, 0% SASOBIT	R35S0	2.130	806.85	759.1	94.08
35% RAP, 1% SASOBIT	R35S1	1.940	817.2	757.35	92.68
35% RAP, 2% SASOBIT	R35S2	1.845	820.75	748.4	91.18
35% RAP, 3% SASOBIT	R35S3	1.655	828.2	739.15	89.25
50% RAP, 0% SASOBIT	R50S0	1.530	835.1	730.85	87.52
50% RAP, 1% SASOBIT	R50S1	1.410	842.3	715.6	84.96
50% RAP, 2% SASOBIT	R50S2	1.060	858.7	710.3	82.72
50% RAP, 3% SASOBIT	R50S3	0.850	877.6	692.45	78.90
S1 = Average Strength of Un- Conditioned samples, S2 = Average Strength of Conditioned samples					

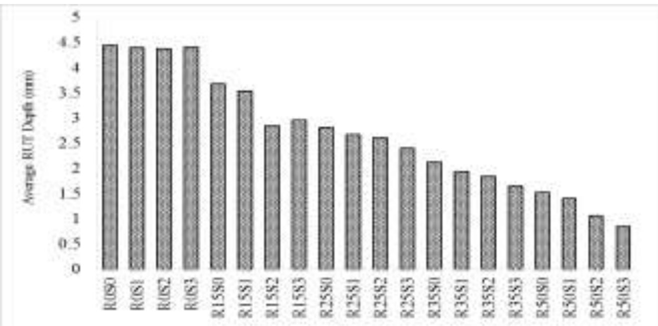

Fig. 7. Average Rut depth from HWTD testing

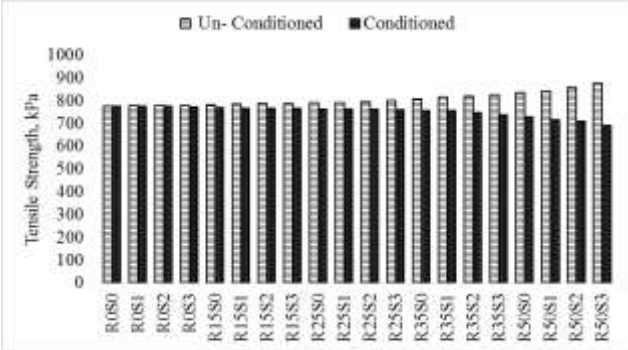

Fig. 8. Tensile Strength of different mixes

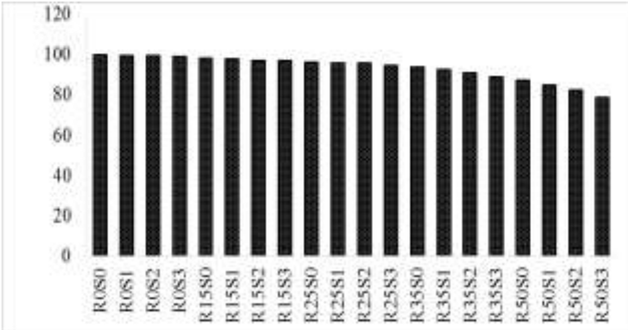

Fig 9: Average TSR for different mixes

The minimum tensile strength ratio specified by superpave for mixes having no anti-stripping agent is 80%. The calculated tensile strength ratios for the 20 mixes were all above 80 percent, except for the mix having 3% Sasobit and 50% RAP which was 78.9%. Also, the indirect tensile strength values show that all the conditioned samples give strength value lower than that of unconditioned samples, showing that, Sasobit increases the moisture susceptibility of asphalt mixes.

Figure 10 shows Gyratory Samples Before and After Testing.

Fig. 10. Gyratory Samples Before and After Tests

III. CONCLUSIONS

The conclusions drawn from laboratory tests are listed as under;

Resistance of HMA to rutting containing RAP increases by increasing RAP content.

Rut resistance of controlled asphalt mixes and asphalt mixes containing RAP increases by increasing Sasobit content as compared to controlled mixes and mixes containing RAP only.

Increase in rut resistance is also due to decreased production temperature and this may be associated more to the reduced binder aging.

Asphalt mixes having low percentages of RAP i.e. up to 15% give best rut resistance at 2% sasobit addition and then decreases unlike for mixes with higher percentages of RAP i.e. above 15% for which rut resistance increases linearly up to 3% sasobit. The decreased in rut resistance may be due to increased workability and viscosity.

The indirect tensile strength for mixes with either sasobit alone or both sasobit and RAP were slightly higher as compared to the control mixes. Which may be due to the formation of lattice structure.

The indirect tensile strength for mixes with sasobit plus RAP was slightly higher, as compared to mix containing RAP only.

The resistance against moisture damage of asphalt mixes containing RAP or sasobit or both is lower than that of control mixes, and this may be contributed to lower mixing and compaction temperatures for WMA as compared to HMA and potential for moisture damage increases due to incomplete drying of aggregate in the resultant asphalt mix using WMA technology. The moisture damage may be due to water trapped in the coated aggregate.

For asphalt mixes with 0% RAP the tensile strength ratios are very slightly lower from that of control mix i.e. 99.96% for control mix and 99.74%, 99.5%, and 99.08% for addition of 1%, 2% and 3% sasobit respectively.

For any percentage of RAP and sasobit the values of tensile strength ratio are above the minimum range of 80% except for 50% RAP and 3% sasobit which is 78.90%. While for the mix with 3% sasobit and 35% RAP the tensile strength ratio is 82.72% which is too close to the lower limit.

As far as rutting resistance and moisture susceptibility is concerned which are the most prevalent forms of asphalt concrete distresses in our region and also in most of developing countries with no control on wheel axel loads the recommended percentages are 3% sasobit and 30-40% RAP for adequate resistance to rutting and moisture damage. Further it is recommended that it’s a better option to use 2% sasobit with control mixes and mixes containing lower percentages of RAP i.e. up to 15%, while for higher percentages of RAP better option is to use 3% sasobit.

Conflict of Interest Statement

The authors of this research paper, whose names are listed on title page, certify that they have conducted this research as a part of project financially supported by Pakistan Higher Education Commission with the title Characterization of Reclaimed Asphalt Pavement (RAP) for use in pavement construction industry in Pakistan.

Acknowledgement and Disclaimer

The researchers appreciatively recognize the support of Pakistan Higher Education Commission for sponsoring this research project under National Research Program for Universities (NRPU) with award No.20-45%/R&D/HEC/14/1067. This is only a technical article for experimental investigation along with optimization of RAP and sasobit for permanent deformation and moisture damage of asphalt mixes the mixtures’ durability (moisture susceptibility) was measured by the Universal Testing Machine (UTM) performing Indirect Tensile Strength (ITS) test and permanent deformation (Rutting) by Hamburg Wheel Tracking device (HWTD). This research study does not establish a standard, specification, or a regulation.

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