

OPTIMIZATION OF RECLAIMED ASPHALT AND FT PARAFFIN FOR PERMANENT DEFORMATION AND MOISTURE DAMAGE OF ASPHALT MIXES

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ABSTRACT

Recycling of Reclaimed Asphalt Pavement (RAP) provides us the need to save valuable aggregate and the help of which the use of expensive bituminous binder will be reduced as well. In this study we have considered one WMA additive (Sasobit). The rut resistance of mixes was improved by adding either RAP or Sasobit or both as compared to control asphalt mixes. For lower contents of RAP i.e. up to 15 %, highest rut resistances was observed at 2 % Sasobit addition, and for higher content 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

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 mixing 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. 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].

FT waxes 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) synthesis (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. The carbon chain length in Sasobit ranges from plus C₅ to C₁₀₀ carbon atoms.

Sasobit is an “asphalt flow improver” with melting point of 102 °C and because of this reason Sasobit is perfectly soluble in bitumen at a temperature higher than 120 °C. At a down temperature it forms a crystalline grid structure in the binder that leads to additional permanency [3].

The range for Sasobit use is 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 [4]. 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 [5]. There are extensive conclusions for WMA additives. Info obtained from industrialists and materials traders specify that there is a possibility to reduce CO₂ emissions and energy consumption to about 30 % as compared to standard HMA [6]. A positive influence on pavement performance may be demonstrated by these technologies, as they allow reduced HMA mixing and compaction temperature [7]. Using Sasobit there is an opportunity of dropping the production temperatures by 18–54 °C [8]. 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 [9].

Rutting is the accumulation of small amount of irrecoverable strain due to applied load on the pavement, also known as permanent deformation [9]. 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 [11]. It has been revealed that for the larger part of the lifetime of the pavement, shear deformation is considered to be the primary mechanism of rutting [10]. Using some of WMA products along with high content of RAP may badly affect the rutting potential, because of reduced stiffness due to lower production temperature [12]. Physical behaviour of HMA changes when RAP is added. RAP binder's increased stiffness is thought to be the reason for higher modulus of HMA. In the same way it also disturbs the mixture's low temperature cracking as well as its fatigue behaviour [1].

Moisture damage is the loss of strength and durability of asphalt mix affected by moisture. Moisture damage is caused due to the interaction of moisture with the adhesion between asphalt binder and aggregate, and thus during cyclic loading it becomes more susceptible to moisture. It means that asphalt mixture can result moisture damage because of reduced bond strength between the fine aggregate and the asphalt binder [10]. Moisture present in air voids adversely affects 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 [13]. 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 [14]. According to Washington State Department of Transportation (2009), indirect tensile strength testing of asphalt is a very common and easy way to check the performance of asphalt, 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 a mix as water remains confined in the aggregate skeleton [15].

PROPOSED METHODOLOGY

Selection and laboratory testing of materials

Materials used in this research had all the results within the specified limits as per American and British standards and the aggregate gradation with nominal maximum aggregate size of 19 mm was used as per Marshall Mix Design.

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. 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 Abson method in accordance with ASTM D1856 – 09, to extract aged bitumen from RAP for testing.

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

Tab. 1- 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

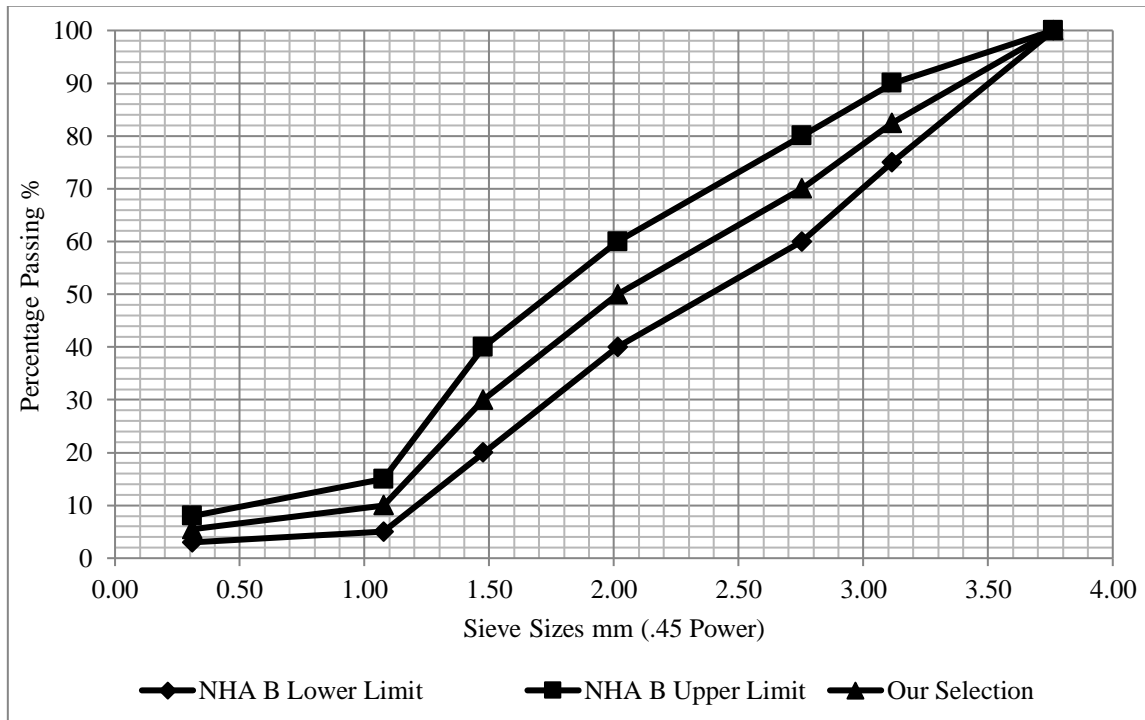


Fig. 1 – Class-B Gradation plot with NHA Specified limit

The amount of RAP was varied by content of 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 contents and corresponding aggregate on different sieves were found which are shown in Table 2 and Table 3 while Figure 2 shows gradation which is plotted with percentage passing verses sieve sizes for mentioned percentages of RAP.

Tab. 2 - 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%

Tab. 3 - Weight of Aggregate as per Gradation

Sieve (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

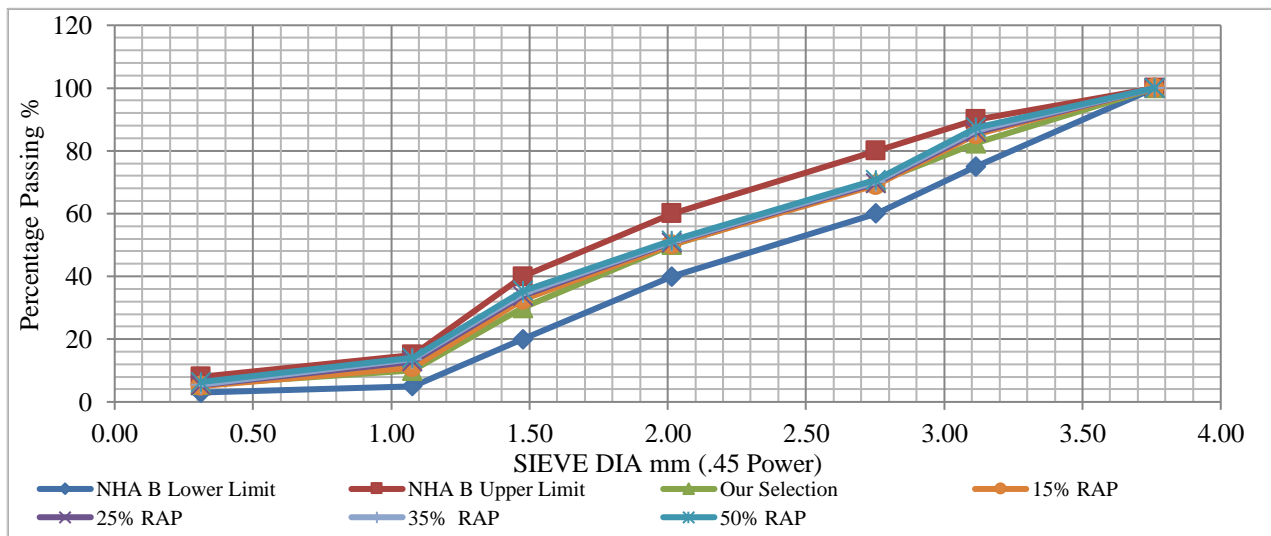


Fig. 2 – Gradation plot of RAP Percentages with Specified limit of NHA Class B

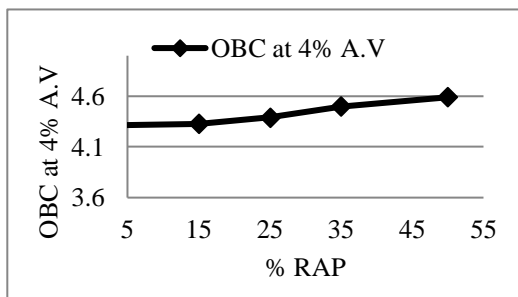
Optimum Bitumen Content determination

After the process of sieve analysis, aggregates were placed in oven to make it dry at a temperature of 105 °C to 110 °C. The amount of aggregates needed for the preparation of Marshall compacted specimen of 101.6 mm diameter, by Marshall Mix design method (ASTM D6926), should be approximately 1200g. 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 an asphalt mix that performs optimal at minimum bitumen content reaching voids of 4 %. 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 optimum binder content (OBC) determination and thus a total of 75 specimens were prepared for determination of five OBCs, based on varying

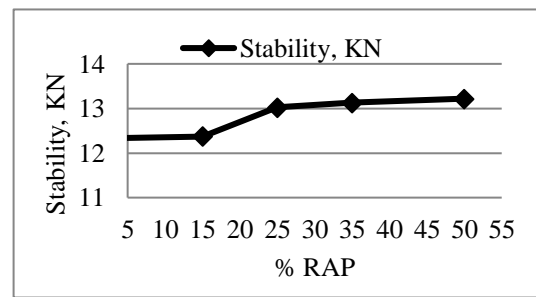
percentage of RAP. Separate graphical plots for all values were drawn as tabulated in Table 4 and shown in Figure 3 (a, b, c, d, e, and f).

Tab. 4 - Volumetric for Different Percentages of RAP

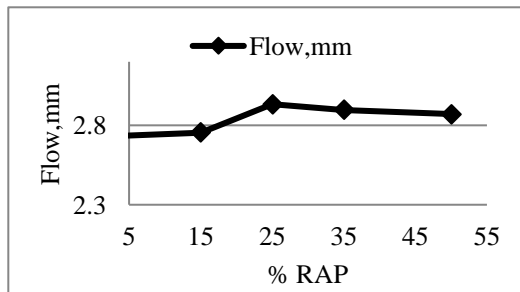
(%) RAP	OBC at 4 % Air Voids	VMA, (%)	VFA, (%)	Stability, (KN)	Flow, (mm)	Unit Weight, (mg/cm ³)
0	4.31	13.49	70.04	12.32	2.72	2.37
15	4.33	13.56	70.19	12.37	2.75	2.37
25	4.39	13.96	71.10	13.02	2.93	2.36
35	4.5	13.66	70.7	13.12	2.89	2.37
50	4.59	13.79	71.07	13.22	2.87	2.37



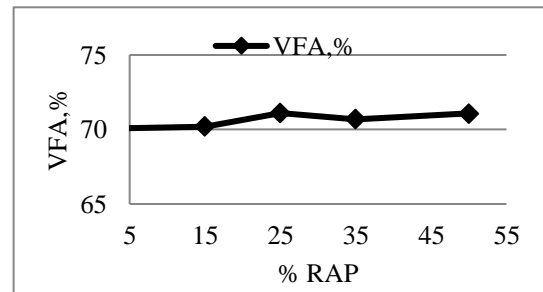
(a)



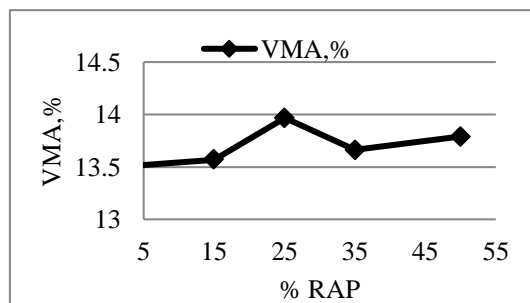
(b)



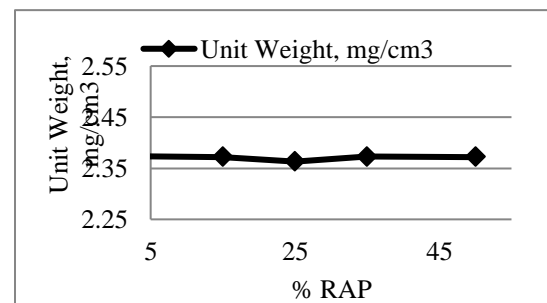
(c)



(d)



(e)



(f)

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

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 % and 3 % 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.



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 heated to 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 135 °C and 160 °C and also 93 °C to 135 °C is the general used manufacturing temperature range for WMA. 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. Samples were prepared as per Superpave Mix Design method. Further, resizing of asphalt 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

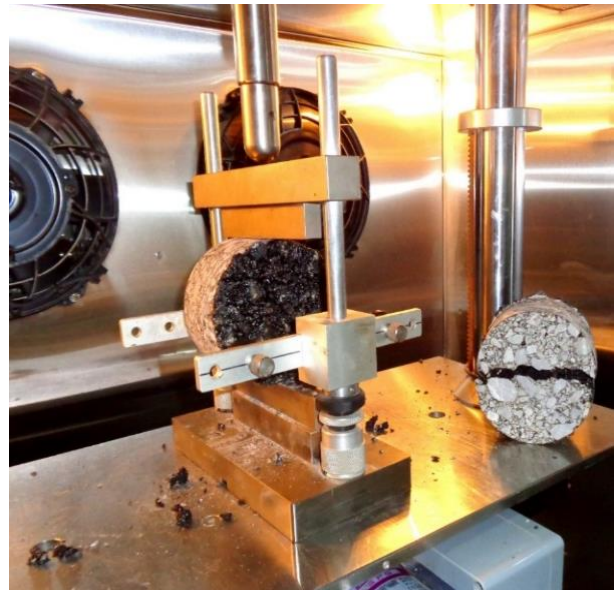


Fig. 6 – UTM Tested Sample

Permanent deformation (Wheel tracking test results)

Wheel tracking tests were conducted on specimens prepared for rutting under wet condition. For wheel tracking 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 % Sasobit addition these samples have less rut resistance than that of samples having 2 % Sasobit. But samples with higher contents of RAP that is 25 %, 35 % and 50 % showed higher rut resistance at 3% Sasobit. All of the specimens passed the wheel tracking test criteria of 12.5 mm rut depth at a temperature of 45 °C, 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 tracking tests results are tabulated in Table 5 and graphically presented in Figure 7.

Moisture Damage (ITS Test Results)

Moisture susceptibility testing was carried out on asphalt mixtures according to ALDOT. For the twenty different mixes a total of 120 gyratory samples at 4 % air voids were prepared and tested for Indirect Tensile Strength (ITS). Thus six samples per mix were prepared, three of them were tested unconditioned by only placing in water at a temperature of 25 °C for one hour right before testing, while the other three specimens per mix were soaked in warm water at a temperature of 60 °C for 24 hours followed by placing in water at 25 °C 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 mixes increases.

Tab. 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

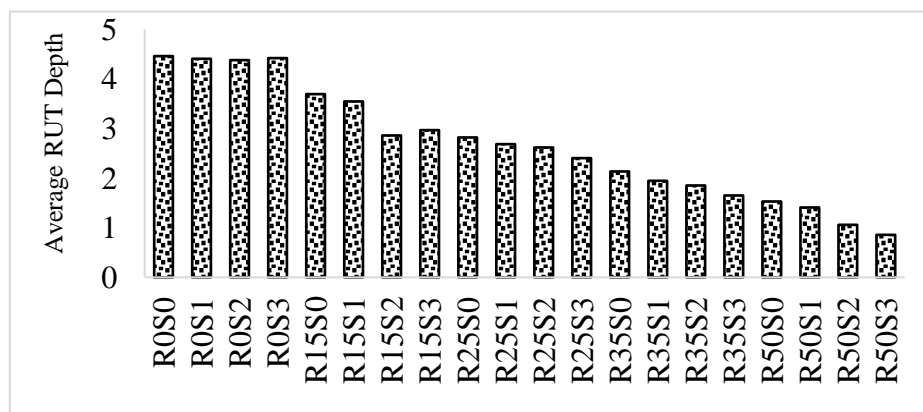


Fig. 7 – Average Rut depth from HWTD testing

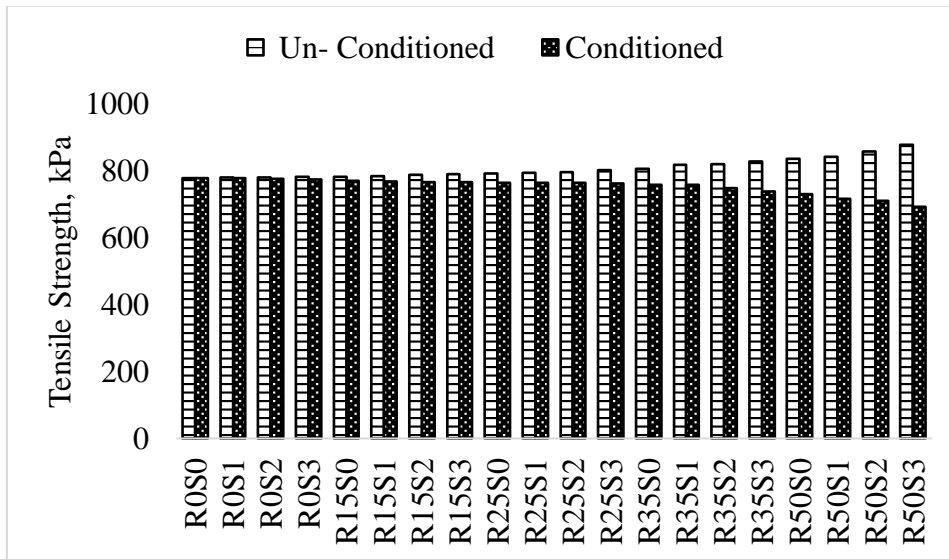


Fig.8 – Tensile Strength of different mixes

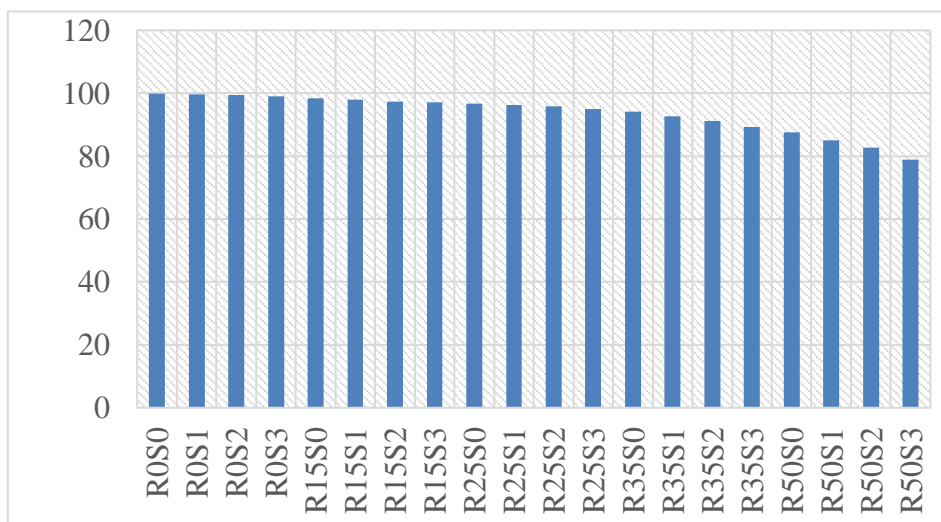


Fig. 9 – Average TSR for different mixes

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 ITS values show that all the conditioned samples give strength value lower than that of unconditioned samples, showing that, Sasobit increases the moisture susceptibility of an asphalt mix. Figure 10 shows Gyrotary Samples Before and After Testing.

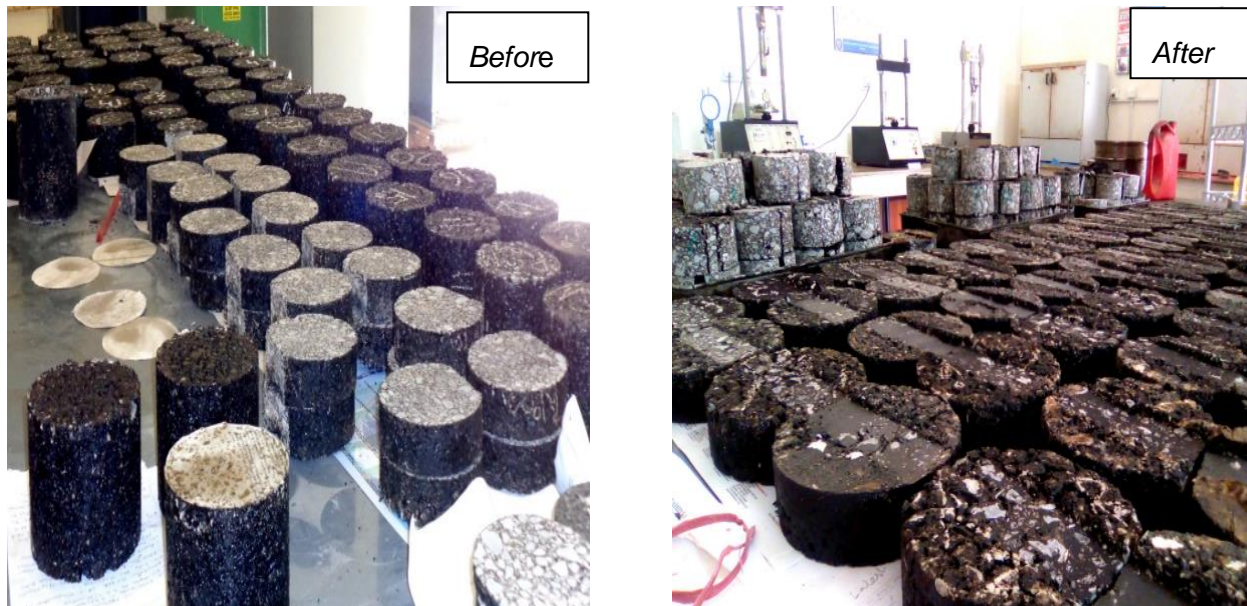


Fig. 10 – Gyratory Samples Before and After Testing

CONCLUSIONS

The conclusions drawn from laboratory tests are listed as follows:

- 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. The increase in rut resistance is due to decreased production temperature and this may be associated more to the reduced binder aging.
- Asphalt mixes having low contents of RAP i.e. up to 15 % give best rut resistance at 2 % Sasobit addition and then decreases unlike for mixes with higher contents 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 the reason that sasobit form 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 control specimens, which is the reason of reduced mixing and compaction temperatures and 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 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 close to the lower limit as well.

- As far as rutting resistance and moisture susceptibility is concerned to be the most prevalent forms of asphalt concrete distresses in our region and also in most of developing countries with no control on wheel axle loads, the recommended contents are 3 % Sasobit and 30-40 % RAP for adequate resistance to rutting and moisture damage. Further it is recommended that it is 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 mixture 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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