Effective Utilization of Reclaimed Asphalt Pavement by Using Rejuvenator in Stone Matrix Asphalt for Wearing Course

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Abstract: ***Stone Matrix Asphalt (SMA) is a gap-graded asphalt mix which provides high rut resistance to the permanent deformation during its service life. SMA consists of 70-80% course aggregates, 8-12% filler, 6-7% binder and 0.3% fibre. The higher percentage of course aggregates and bitumen makes the SMA construction costlier. In order to make SMA mix economical Reclaimed Asphalt Pavement (RAP) consisting of aggregate and bitumen can be used for SMA mix. In the present study an attempt has been made on the use of RAP materials for SMA mix with waste engine oil as rejuvenator. A RAP replacement were carried out in varying percentages with and without rejuvenator and laboratory test including Marshall Stability was conducted to find the optimum RAP replacement. Performance tests were carried out for optimum RAP replacements. From test results RAP with rejuvenator showed improved performance characteristics compared to RAP without rejuvenator.***

Keywords: Stone Matrix Asphalt; Reclaimed asphalt pavement; Rejuvenator; Waste engine oil; Fatigue

1. Introduction

Write In India, with the increase in population, there is also an increase in traffic approaching to the road network. This has led to an increase in traffic load on the pavement. Due to the overloading, flexible pavements are subjected to different types of distress failures such as rutting, raveling, potholes, longitudinal cracks etc. Rutting has been found to be major distress failure in flexible pavements. This may be due to the insufficient compaction of base/sub-base layer or bituminous layers during construction or improper mixing etc. Stone Matrix Asphalt (SMA) is a stable, tough and rut resistant mix which was developed in Germany in 1960s. It is a gap graded mix consisting of a higher percentage of coarse aggregates to form a stone skeleton-like structure and higher binder content. Generally, SMA is more expensive than conventional bituminous mixes because SMA requires high asphalt content, more durable aggregates and fibers as a stabilizer. Studies have been conducted on the use industrial by-products such as electric arc furnace steel slag (EAF) and copper mine tailings (CMTs) as aggregates in SMA (Ebenezer Akin Oluwasola and Mohd Rosli Hainin, 2016). They found that with the incorporation of EAF steel slag and CMT exhibited superior performance than the control samples, there were improved performance characteristics and increased rutting resistance of the SMA mixes. Use of crumb rubber modified bitumen as stabilizers for the SMA mixes showed similar rutting and fatigue characteristics as compared to SMA prepared using patented fibres (Pawan Kumar et al, 2006). Studies carried out on the use of basalt and basalt-limestone as coarse and fine aggregates on the rutting characteristics of SMA mix (Erol Iskender, 2013) and observed decreased rutting resistance with the incorporation of limestone aggregates for SMA mix.

Economic considerations and need for protecting the environment researchers focused on the use of Reclaimed Asphalt pavement (RAP) in pavement industry (Reyes-Ortiz O et al, 2012). They studied on the mechanical properties of dense-graded HMA mixes with the partial and total replacements of RAP aggregates. Highest ITS and resilient modulus values were observed for specimens with 100% replacement of natural aggregates by RAP material. Recycling of RAP also reduces the use of depleting natural aggregates and solves the disposal issues of reclaimed asphalt material generated from pavement rehabilitation (Dr. Umesh Sharma et al, 2018). They studied on the mechanical properties of RAP aggregates for their suitability using in bituminous pavement construction. The use of RAP aggregates (100%) resulted in the increase of Marshall Stability, Flow and Bulk density value of BC-II mix. Some researchers studied on the cracking resistance of HMA mixes with varying percentages of RAP contents. RAP replacement was carried out at 0%, 10%, 20%, and 30% and there was an increase in stiffness and indirect tensile strength with RAP inclusion. The properties of mixture changed at 30% RAP content (Baoshan Huang et al, 2011). Study on the different aged RAP indicated that increase in the age of RAP increases the resilient modulus due to the stiffened binder present in the RAP (S. Chakravarthi and S. Shankar, 2018). High RAP content (e.g., 50%) makes HMA mix brittle and causes premature failure (Zhaoxing Xie et al, 2019). Use of high RAP content leads to low temperature cracking poor mix workability due to stiffened RAP binder. Recycling agents improves the binder stiffness and improves the mix quality (Hamed Majidifard et al, 2018). Rejuvenators decrease the viscosity of aged bitumen and also increase the use of RAP in HMA mix (Martins Zaumanis, 2014). Research has been carried out to optimize the waste vegetable oil as a rejuvenator for BC mix containing 20% RAP. Rejuvenator was added by 5%, 10%, and 15% by weight of RAP binder and tested for marshall stability, ITS and TSR. Waste vegetable oil of 10% was found to be optimum dosage for 20% RAP (Ms. Ayushi Jain et al, 2017). HMA prepared with RAP content of 0%, 25% and 40% and three waste oil contents of 0%, 2%, 5% was studied to know the influence of waste engine oil on RAP replaced mixes. Results indicated that the stiffness due to the aged RAP binder can be offset by using WEO and observed reduced optimum binder content, reduced rut resistance, and limited improvements on fatigue life for mix containing RAP and WEO (Xiaoyang Jia, et al, 2015). The main objective of the research is to study the feasibility

2. Materials and Methods

a) Reagents

Natural aggregates which are required for the present studies were collected from KMS crushers, Bagalur Tamilnadu. CRMB-55 procured from MD constructions; Bengaluru. Baghouse which is left after washing stone dust during the production of M-sand was used as a filler material. Cellulose fibre was used as a stabilizing additive procured from Strategic Marketing and Research team (SMART), Peenya, Bengaluru. Waste engine oil from local available garage was used as a rejuvenator. RAP material scarified from NH 206 Gangavaram was used for the study. The slab form RAP was brought and processed manually. The slabs were broken down to separate the aggregates and then sieved to get the required size of aggregates. The processed aggregates were stored for future use. The properties of materials used for the present study are given in the Table 1, Table 2 and Table 3. SMA specimens were prepared for the gradation obtained by trial and error method as shown in the Figure 1 and laboratory tests including Marshall Stability test, Draindown test and performance tests such as Indirect Tensile Strength (ITS), Fatigue, and Rutting tests were conducted for prepared SMA specimens.

b) Mix design

The 13mm SMA designation was selected for the study. Mix design was carried out for conventional SMA mix, SMA mix with RAP replacements of 10%, 20%, 30%, 40%, 50%, and 60% without using rejuvenator and also for higher RAP replacements of 50%, 60%, 70% and 80% RAP with Waste engine oil (WEO) as rejuvenator. WEO was added during specimen preparation. Binder content present in the RAP has been found out to be 3% by the extraction method and the virgin binder required was calculated and added for the mix.

3. Experimental Studies

a) Marshall properties of SMA mixes

Marshall Stability test was carried out in order to determine the marshall properties for conventional SMA mix, SMA mix with RAP replacements of 10%, 20%, 30%, 40%, 50%, and 60% without using WEO as rejuvenator. Specimens were also casted for higher RAP replacements of 50%, 60%, 70%, and 80% with 10%, 15%, 20%, 25% and 30% Waste Engine Oil (WEO) as a rejuvenator to find optimum WEO content. The cellulose fibre of 0.3% by weight of the total mix was added to avoid asphalt drain down. Specimens were casted by applying 50 blows on each side.

b) Draindown test

The drain down test was carried out for un-compacted SMA mix according to ASTM D 6390. To avoid the drain down of asphalt from the mix cellulose fibre was added at a rate of 0.3 % by the weight of total mix for all the SMA mixes. Draindown percentage was observed to be 0.014, 0.010, and 0.013 for conventional SMA, SMA mix with optimum RAP replacement without rejuvenator and SMA mix with RAP and optimum rejuvenator.

c) Moisture Susceptibility test

The bituminous mixes are tested for long term stripping susceptibility through the Indirect Tensile Strength (ITS) test. The specimens are tested for the change in diametrical tensile strength due to the effects of water saturation and accelerated stripping phenomenon observed due to freezing and thawing. ITS test was carried out for the specimens having air voids of 7+/- 0.5% for 6 sets of compacted asphalt mix among which 3 specimens are tested in a dry condition and the other 3 specimens are tested after subjecting to a freeze-thaw cycle. Test was conducted according to AASHTO T 283 for conventional and RAP replaced SMA mixes and the results are tabulated below.

3.4. Fatigue test

Test equipment used for fatigue testing is a computer-interface based data acquisition system. Loading magnitude, frequency, and data collection are done through the computer. The fatigue test is performed to determine the number of load repetitions that a specimen withstands before it fails. Fatigue specimens were prepared for air void content of 6.5-7% and tested for 1 Hz frequency, 20 kg/cm2 pressure, 10% stress level and predetermined failure deformation of 3mm.

3.5. Rutting test

Rutting is the permanent deformation in the asphalt layers that is observed under wheel paths. The rutting in the bituminous mixes is studied by conducting immersion wheel tracking test. The rutting test was carried out for 40mm and 50mm thick specimens through treaded wheel for a tyre pressure of 5.6 kg/cm2 and speed of 25 passes/minute.

Table 1: Physical properties of natural aggregates and RAP aggregates

Properties	Natural aggregates	RAP aggregates
Combined flakiness & Elongation indices, %	11.19	16.83
Aggregate Impact value, %	16.08	16.27
Los Angeles abrasion value, %	17.52	19.84
Water absorption, %	0.2	0.55
Specific gravity		
20 mm down	2.68	2.62
12 mm down	2.69	2.66
6 mm down	2.71	2.69
Stone dust	2.72	-
Stone polishing value,	57	58

Table 2: Properties of CRMB-55

Properties	Result	Test methods
Penetration value at 25 ˚C (mm)	57	IS 1203-1978
Softening point (˚C)	56	IS 1205-1978
Specific gravity	1.03	IS 1202-1978
Flash Point (˚C)	279	IS 1209-1978
Elastic Recovery in ductilometer at 15˚C, (%)	68	-
Thin Film Oven tests and test on residue:		
a) Percentage loss in mass	0.115	IS – 9382
b) Increase in softening point value, (˚C)	4	IS – 1205
c) Reduction in penetration of residue, at 25 ˚C, (%)	33	IS – 1203
d) Elastic recovery in ductilometer at 25 ˚C, (%)	56	-
Separation difference in softening point, max, (˚C)	2.85	-

Table 4: Marshall Properties RAP replacement SMA mixes.

Mix Properties	% RAP replacement										
	0	10	20	30	40	50	60	70	80	90	100
Marshall Stability, kN	8.59	8.31	9	11	12.3	10	9.54	11.1	9.24	8.16	6.75
OBC, %	6.1	6.07	5.9	6.1	6.1	6.3	6.2	6.14	6	6.2	6.4
Air voids, %	4	4	4	4	4	4	4	4	4	4	4
Flow, mm	3.8	3.5	2.56	3.1	3.4	3.8	3.1	3.28	3.34	3.6	3.9
Voids in Mineral Aggregates, VMA, %	18	17.87	17.58	18	17.9	18.42	18.16	18	17.74	18.08	18.48
Voids Filled with Bitumen, VFB, %	77.9	78	77	77.7	78	78	77.8	77.9	76.92	77.79	78.28

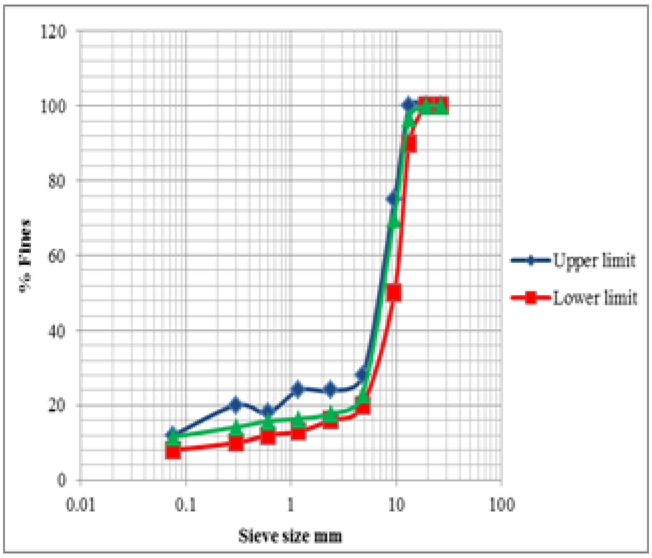


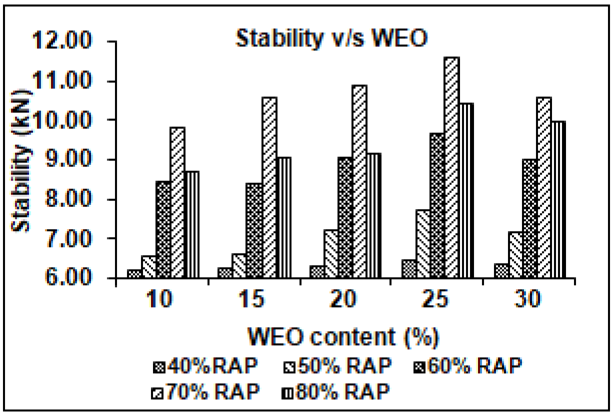
Figure 1: Gradation curve obtained for SMA mix.

4. Results and Discussion

4.1 Marshall Properties of SMA mixes

Marshall properties of RAP replaced SMA mixes are given in Table 4. Optimum Binder Content (OBC) was selected at 4% air voids and was found to be 6.1% for conventional mix and 6.07%, 5.9%, 6.1%, 6.1%, 6.3%, 6.2%, 6.14% and 6.0% for RAP replacement mixes. For conventional SMA mix Stability, VMA and flow values for obtained OCB were found to be 8.59kN, 17.89% and 3.8 mm which are within the standard values. The air voids percentage and stability obtained for 40 % RAP replacement is 4% and 12.3kN. The highest stability value is obtained for 40% RAP replacement when compared to other RAP replacements and remaining marshall properties are within the specified limits.

Hence optimum RAP replacement up to 40% without rejuvenator was found to be effective and considered for further performance tests. Marshall properties were studied to determine the optimum waste engine oil for higher percentages of RAP replacement. The graphical representation of results is shown in Figure 2. The stability value of 11.62 kN and air voids percentage of 3.99 was obtained for 70% RAP with 25% waste engine oil. The stability obtained for 70 % RAP with 25% waste engine oil was found to be higher than other RAP replacements and remaining parameters like VMA and flow values were also within the standard values. Results indicated that optimum waste engine oil of 25% is effective for 70% RAP replacement for SMA mixes. Hence 70% RAP with 25% waste engine oil was considered for further performance tests.



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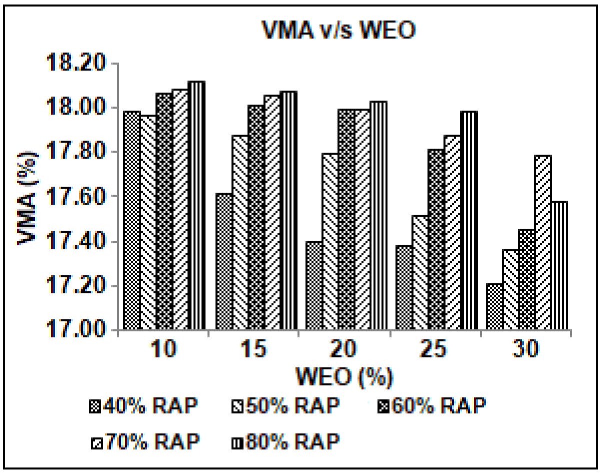

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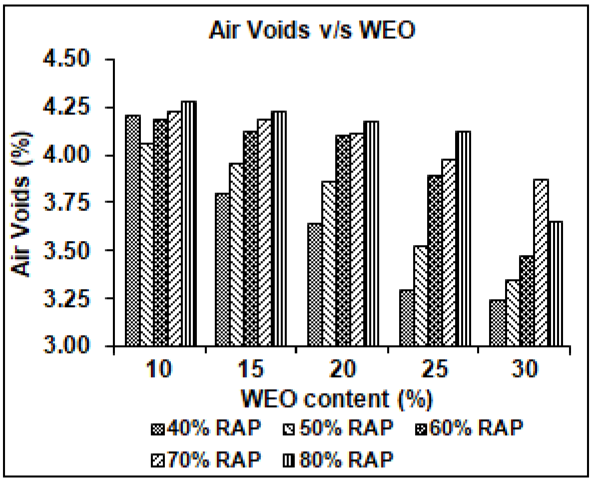

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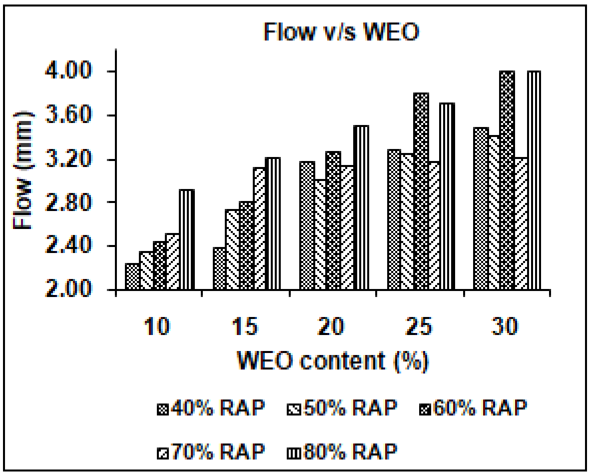

(d)

Figure 2: Marshall properties for RAP replacement SMA mixes with WEO as rejuvenator. (a) Stability graph (b) VMA graph (c) Air voids graph (d) Flow graph

4.2 Moisture Susceptibility test

As shown in Table 5 the tensile strength ratio for conventional SMA mixes and SMA mix for 40% RAP without rejuvenator and 70% RAP with 25% rejuvenator were found to be 88.14%, 90.90% and 97.49 % respectively. Test results showed higher TSR values for SMA mix with 40% RAP and 70% RAP with 25% rejuvenator than the conventional SMA mix. The values obtained are greater than the specified value of 85% as prescribed in MORT&H.

Table 5: Moisture susceptibility test results for SMA mixes.

Mix Type	Samples	Tensile strength (St), kPa	TSR (%)
Conventional SMA mix	Unconditioned	349.87	88.14
	Conditioned	308.39	
40% RAP replacement without WEO	Unconditioned	505.61	90.9
	Conditioned	459.59	
70% RAP replacement with 25 % WEO	Unconditioned	414.15	97.49
	Conditioned	403.75	

4.3 Fatigue test

Fatigue test is carried out to know the number of repeated load a bituminous mix can withstand without failure. Figure 3 shows the number of repeated load of 5967, 4801 and 5972 at 10% stress level for conventional SMA mix, 40% RAP replaced SMA mix without WEO and 70% RAP replaced SMA mix with 25% WEO.

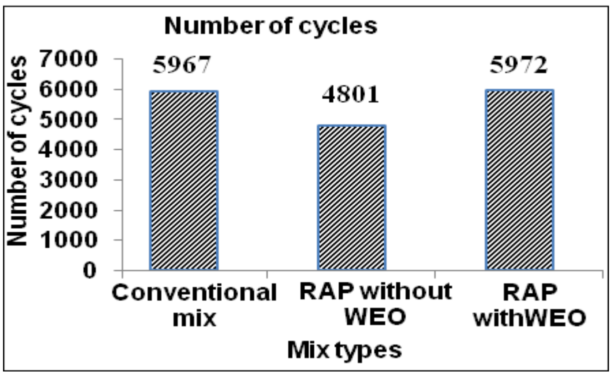

Figure 3: Variation of Fatigue life of SMA mixes

4.4 Rutting test

From the Figure 4 and Figure 5 rut depth values for 40mm specimens was found to be 5.84, 4.45 and 4.11 mm for conventional SMA mix, and SMA mixes for 40% RAP without WEO and 70% RAP with 25% WEO. For 50 mm specimens rut depth values was found to be 4.48mm for conventional SMA mix and 3.48 and 3.21mm for SMA mixes with 40% RAP without WEO and 70% RAP with 25% WEO respectively. Results indicated that SMA mix prepared with optimized RAP and rejuvenator had more resistance to rutting when compared to conventional SMA mixes.

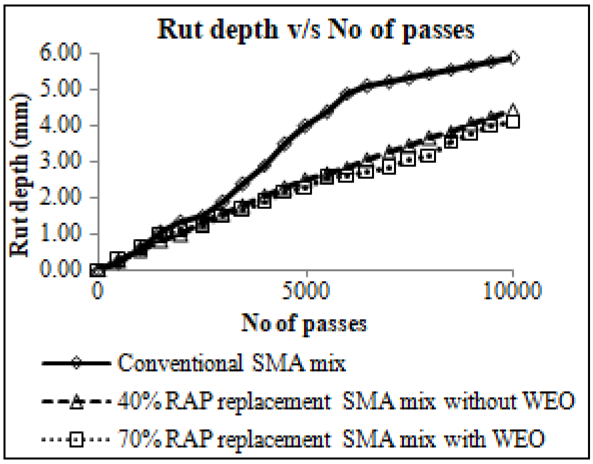

Figure 4: Graph showing rut depth values for 40mm slab specimen

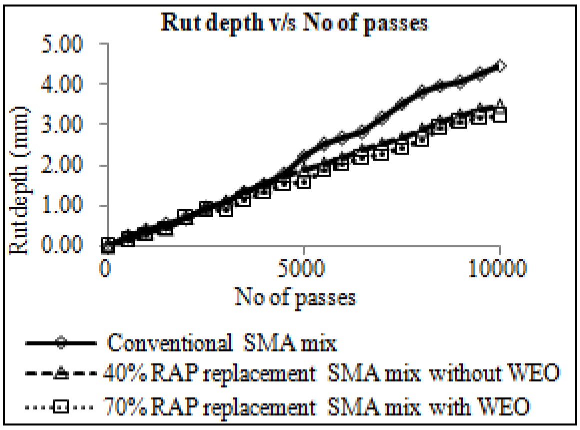

Figure 5: Graph showing rut depth values for 50mm slab specimen

5. Conclusion

The following conclusions are drawn from the present study

1) It was observed that with the inclusion of 40% RAP in the SMA mix, stability increases up to 1.53 times than the conventional SMA mix and also satisfies other SMA mix requirements as per the MORT&H.
2) RAP replaced SMA mixes with rejuvenator showed less stability values when compared to the RAP mixes without rejuvenator but the values obtained are within the specified limits for both the mixes. This may be due to the effect of waste engine oil used as rejuvenator on the aged binder present in the RAP materials.

3) The drain down test values obtained for conventional SMA mix, 40% RAP replaced SMA mix without WEO and 70% RAP with 25% WEO as rejuvenator found to be within in the limits as per the MORT&H.
4) It was observed that TSR value increases by 1.10 times for 70% RAP replaced SMA mix with 25% rejuvenator than the conventional SMA mix.
5) The test results indicated that SMA mix with 40% RAP without rejuvenator and 70% RAP with 25% rejuvenator were more resistance to the rutting when compared to conventional mix.
6) The fatigue life of conventional SMA mix and 70% RAP replaced SMA mix with 25% waste engine oil are found to be similar whereas the mix with 40% RAP replacement without waste engine oil showed less fatigue results compared to these two mixes.
7) From the above results, it can be concluded that SMA mix prepared using optimized RAP and waste engine oil along with the baghouse dust showed better performance when compared to conventional SMA mix.
8) The usage of RAP materials and waste engine oil in the bituminous pavement helps in reduction of scarcity of natural aggregates and also solves the disposal problems of these materials.

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