Springer

Chinese Society of Pavement Engineering

International Journal of
Pavement Research and Technology

Journal homepage: www.springer.com/42947

A study on the effect of rejuvenators in reclaimed asphalt pavement based stone mastic asphalt mixes

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Received 27 January 2018; received in revised form 23 July 2018; accepted 18 September 2018

Abstract

The present paper focuses on the behavior of Stone Mastic Asphalt (SMA) mixes incorporating rejuvenated Reclaimed Asphalt Pavement (RAP) materials. The RAP materials were tested for its physical properties and later were rejuvenated using various rejuvenators such as waste cooking oil, waste engine oil and shredded plastics. The rejuvenated RAP materials were incorporated in the SMA mixes at various replacement levels i.e. 0%, 30%, 50% and 70% (by weight). Various binder properties such as viscosity, rheological properties and chemical composition were evaluated for the aged and rejuvenated material. The rejuvenators were incorporated at different dosage levels i.e. 2%, 4% and 6% (by weight of binder). The optimal rejuvenation dosage for each type of rejuvenator was identified and mix design for the SMA was optimized for evaluating its physical and mechanical properties. Based on the results, the optimum rejuvenator dosage was identified at 6% for waste cooking oil and waste engine oil, while 2% for shredded plastics. It was observed that the addition of rejuvenators improved the performance of RAP based SMA mixes.

Keywords: Reclaimed asphalt pavement; Rejuvenators; Stone mastic asphalt; Mechanical properties; Eco-friendly

1. Introduction

Fossil fuels are the most common sources for extraction of asphalt binders for use in pavement applications. With augmented construction activities and increased demand for virgin raw materials, there is a necessity for looking out development of potential alternatives to replace the conventional raw materials [1–7]. Bitumen is a non-renewable material which is obtained by distillation of crude oil. This complex organic material is strongly recommended for the construction of the pavement structure. Every year, hot mix asphalt roads are rehabilitated by milling and replenishing with new hot mix asphalt. As a result, 100 million tons of milled materials are generated annually. This may cause environmental damages if not properly disposed and landfills required are of large area. Aged asphalt in Reclaimed Asphalt Pavement (RAP) may be considered as a possible alternative for partially or completely replacing conventional materials in hot asphalt mixes. However, great efforts have been made to build an eco-friendly sustainable pavement system with the use of RAP materials [8–11]. Various studies have restricted the use of RAP materials in new asphalt mixes up-to 30%. The performance studies on pavements incorporating RAP have reflected similar properties to that of pavements constructed with traditional raw materials [9–11]. However, several studies have indicated interaction between aged asphalt and new binder is major setback for usage of higher percentages of RAP materials. One of the major concerns of using the RAP materials in new mixes is the formation of stiffer mix leading to lower viscosity and thus affecting the workability that making asphalt more prone to cracking. The use of rejuvenators, softening agent, modifiers, extender etc have proved to overcome the drawbacks of direct usage of RAP in asphalt mixes [12–14]. The use of Rejuvenators such as bio-oils, plastics, used engine oils etc along with RAP are known to improve the physical and chemical compositions asphalt mixes. The rejuvenator, when used with the aged binders under goes a process of diffusion, wherein the rejuvenator penetrates into the stiffer asphalt layer leading to its softening [15]. The recycling of RAP materials proves to be beneficial both economically and

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Peer review under responsibility of Chinese Society of Pavement Engineering.

ISSN: 1996-6814 DOI: https://doi.org/ 10.1007/s42947-019-0002-7
Chinese Society of Pavement Engineering. Production and hosting by Springer Nature

ecologically since the usage of usage of virgin raw materials is significantly reduced. This also leads to the conservation of natural resources, along with reduced landfills problems due to waste disposal.

Stone Matrix Asphalt (SMA) is a gap graded wearing course mix fraction held together by a rich mixture of asphalt cement, filler, and stabilizing additive. The aggregates in the mix interlock to form a stone to stone skeleton and exhibit a higher resistance to permanent deformation. About 70-80% of coarse aggregates, 10-12% of filler, 6-7% of binder and about 0.3% of fibers forms to be the mix composition of SMA mixes. Studies have reported an increased durability up to 30% in SMA mixes compared to the conventional dense graded asphalt mixes. Associated advantages of using this mix are resistance to reflective cracking and reduction in traffic noise [16-18].

The incorporation of rejuvenated RAP materials in SMA mixes is a relatively new concept and not much work has been reported in this area. The present research focuses on the study of behavior of rejuvenated RAP incorporated in SMA mixes for application in pavements. The aged binder in RAP is rejuvenated using various rejuvenating agents namely cooking oil, engine oil and plastics etc., The rejuvenated RAP is then used in SMA mixes at different replacement level i.e.,0%, 30%, 50% and 70% (by weight). Binder properties of aged RAP and rejuvenated RAP are studied. The physical and mechanical properties of SMA mixes are also evaluated.

2. Materials and methods

2.1. Materials

The materials used for the study included procurement of reclaimed bitumen, standard virgin bitumen along with various types of rejuvenators.

2.1.1. Reclaimed Asphalt Pavement (RAP) and bitumen binder

The milled materials from the pavement surface layer were collected from an expressway in Bangalore region, India which had served for 8 years and another sample of RAP were procured from Hubli region, India that had served for 15 years, were considered for the study. The properties of Virgin Viscosity Grade 30 (VG30) binder was set as reference and the values are presented in Table 1. For the mix design, SMA gradation with VG30 grade bitumen was used.

2.1.2. Rejuvenators

Rejuvenators used in the study are Waste Cooking Oil (WCO), Waste Engine Oil (WEO) and waste shredded plastic (SP). These rejuvenators samples were collected from local sources. The WCO and WEO were prepared by means of a simple filtering process. In this process, the filter paper was used to separate the suspended particles from WCO according to ASTM D4124 [19].

Table 1
Standard requirements for VG30 asphalt.

Tests	Specifications as per IS-73-2006 [16]
Absolute Viscosity (60°C), cP	2400
Kinematic Viscosity (135°C), cP	350
Penetration at 25°C, 5 sec, 0.1 mm	50-70
Softening point (Ring and Ball), °C	47

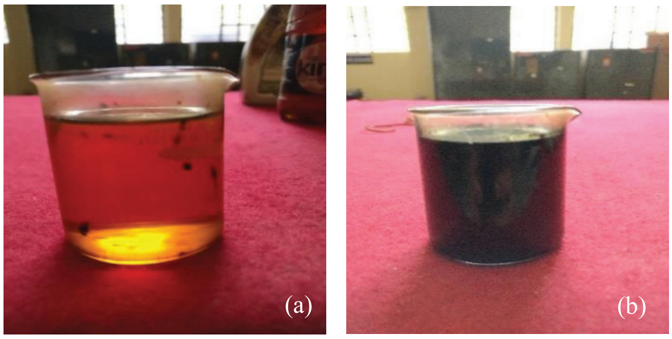


Fig. 1. Images showing the samples of filtered (a) waste cooking oil and (b) waste engine oil.

The filtered WCO and WEO are illustrated in Fig. 1. The chemical properties in filtered WCO and WEO are the fundamental characteristics to control the behavior of the rejuvenated bitumen. Therefore, the chemical compounds in WCO and WEO are measured using gas chromatography mass spectrometry. From the chemical test results, the predominant chemical compounds in the WCO were found to oleic acid, palmitic acid followed by linoleic acid. Similarly, chemical compounds such aliphatic and aromatic hydrocarbons were predominantly identified the WEO.

2.2. Methodology

Two types of RAP samples, one aged 8 years (RAP 1) and the other aged 15 years (RAP 2) were used for the present study. Rolling Thin Film Oven (RTFO) tested was carried out to determine the short aging properties. The rolling thin film oven test provides the aging of binder during the mixing and compaction. Basic properties of conventional binder (VG 30), RTFO aged binder and rejuvenated RAP binder were evaluated and compared. The mix design for Stone Mastic Asphalt (SMA) was evaluated using VG30 grade bitumen with addition of RAP materials and rejuvenators at varying percentages. The rejuvenators were added at dosages of 2%, 4% and 6% of binder mass for the extracted RAP binder and properties were checked with conventional binder and RTFO aged binder. Addition of rejuvenators to extracted RAP binder shows the softening efficiency and allows determining the required dose to satisfy binder specification requirements. SMA gradation is considered for evaluating performance of binder. RAP materials are added in percentages of 30%, 50% and 70% (by weight) to conventional aggregates and binder. The optimum binder content is determined and tensile strength test is performed.

2.2.1. Binder sample preparation

Binder was extracted from RAP using benzene according to ASTM D2172 [20]. After sufficiently heating the binders, RAP binder samples were blended with 2%, 4%, and 6% of each rejuvenator separately and properties were evaluated.

2.2.2. Viscosity test of binder

The viscosity test was carried out on virgin binder, RTFO aged binder, RAP and rejuvenated binder as per ASTM D4402 [21] using Brookfield viscometer apparatus to determine the high-temperature rheological properties related to mixing workability at 135°C. The binder sample is heated to a temperature of 75 to 100°C

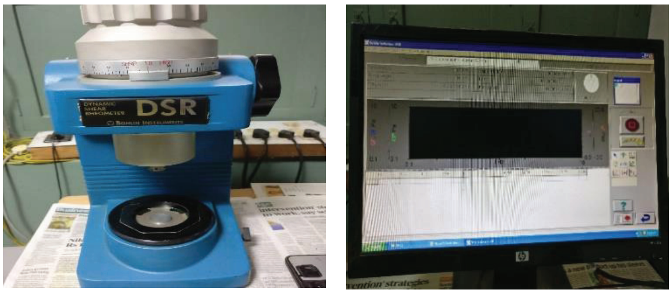


Fig. 2. Dynamic shear rheometer setup.

and allowed to settle at room temperature initially. After the sample settles, it is transferred to a thermos container of a known volume. As the sample attains the test temperature, the rotating spindle is immersed in the thermostat container to measure the consistency. The test temperature of 135°C (kinematic viscosity) was maintained throughout the experiment and as the spindle rotates at the required RPM, the torque is generated and viscosity is measured.

2.2.3. Visco-elastic behavior of binder

Dynamic Shear Rheometer (DSR) apparatus as shown in Fig. 2 was used for determining high temperature and intermediate temperature properties using 25 mm and 8 mm plates with 1 mm and 2 mm gap between plates respectively.

The DSR test provides the information regarding the applied stress and resulting strain developed within the material at various temperatures. The relationship between the applied stress and resulting strain is used to compare complex modules (G*). The time lag between the applied stresses to the resulting strain is the phase angle (δ). The rutting (G*/sin δ) and fatigue (G* sin δ) parameter are determined considering complex modulus and phase angle. The complex modulus and phase angle parameters can be used to relate the rheological performance of the binder in terms of rutting and fatigue resistance.

The test is conducted according to AASHTO M T315 [22]. A computer is connected to the DSR test apparatus and two separate diameter plates of 8 mm and 25 mm are used for short term aged binder and long term aged binder, respectively. The temperature is set as per the standards considering the rheometer plates. Initially, the temperature has to be controlled to the required test temperature, including all distinctions to be provided. After the constant temperature has attained, the sample is placed in the specified plate and sandwiched and allowed for 10 minutes to initiate the test. The stress, plate gap, oscillation parameters and the temperature is set. Software intruded to the rheometer controls the stress level and temperature automatically. The test temperature for fresh and aged binder varied from 40-82^{O}C and 10-40^{O}C respectively, and for every 6^{O}C interval the phase angle (δ), complex modulus (G*), elastic modulus, viscous modulus, complex viscosity is measured which is system integrated. With the test results obtained, the rutting (G*/sin δ) and fatigue (G* sin δ) parameters are evaluated. The data system automatically reduces the data acquired and evaluation of rheological parameters is easier by using the required equations.

2.2.4. Fourier Transform Infrared Spectroscopy (FTIR)

The FTIR spectroscopy is used to identify and quantify functional groups in bitumen responsible for aging characteristics. FTIR helps to analyze the chemical composition of bio-oil, which provides an important insight into the nature of this rejuvenator. FTIR represents absorption peaks corresponding to vibration frequencies between the atomic bonds of compounds in binder. In this study, spectra were collected in range of 4000 cm^{-1} to 400 cm^{-1} and peak values are integrated of their functional groups.

Table 2
Gradation of aggregates for stone mastic asphalt mix as per IRC: SP 79-2008 [16].

IS Sieve size (mm)	Percentage passing (%)	Mid gradation (%)	Weight retained (%)	Weight retained (gms)
26.5	100	100	-	
19	90-100	95	5	60
13.2	45-70	57.5	37.5	450
9.5	25-60	42.5	15	180
4.75	20-28	24	18.5	222
2.36	16-24	20	4	48
1.18	13-21	17	3	36
0.6	18-Dec	15	3	36
0.3	20-Oct	15	3	36
0.075	12-Aug	10	4	48

2.2.5. Mixture sample preparation

The method for characterization of bituminous mixes recommended is Marshall Mix design and test is conducted as per ASTM D6927-15 [23]. The optimum binder content is determined on the ability of mix to relate to stability, volume changes and flow.

For the present study, the aggregate gradation adopted is SMA recommended by IRC SP-79 2008. The mid-point gradation of aggregates generally used in bituminous mixes is considered and is presented in Table 2. The mid gradation method is adopted for aggregates blend with RAP material for varying percentages of 30%, 50% and 70% (by weight) respectively and as per guidelines the layer gradation requirement is considered.

The bitumen used for preparation of Marshall mix is VG30 grade bitumen for hot SMA containing 30%, 50% and 70% RAP materials and the addition of various rejuvenators is done at 2%, 4% and 6% (by weight of binder). The Marshall stability tests was carried out for specimens as per the guidelines.

3. Results and discussions

3.1. Viscosity

The viscosity results for virgin VG30 binder, RTFO aged binder, RAP binder aged for 8 years (RAP 1) and RAP binder aged for 15 years (RAP 2) are tabulated in Table 3.

From Table 3, it is observed that viscosity of RTFO aged binder is 2925 centi-poise without rejuvenators, while viscosity of 8 years aged RAP binder (RAP1) is 625 centi-poise without rejuvenators and for the RAP sample aged 15 years (RAP2), the viscosity observed is 825 centi-poise. With addition of WCO, WEO at varying percentages (2%, 4% and 6%), the viscosity is found to be decreasing in all the types of binder. The viscosity is governed by the presence of aromatic and saturated hydrocarbons in large proportions in the binder. The loss of aromatic and saturated hydrocarbons with aging results in oxidation of the binder, thus making the binder stiffer, resulting increased viscosity. The

Table 3
Viscosity test results of various binder materials.

Property	Without rejuvenators	With rejuvenators WCO			WEO			Shredded plastic		
Viscosity (cP)	RTFO aged									
	0%	2%	4%	6%	2%	4%	6%	2%	4%	6%
	2925	1230	825	425	1085	805	410	5325	7050	9650
	8 years aged RAP (RAP1)									
	0%	2%	4%	6%	2%	4%	6%	2%	4%	6%
	625	568	515	485	543	492	455	1175	1450	1785
	15 years aged RAP (RAP2)									
	0%	2%	4%	6%	2%	4%	6%	2%	4%	6%
	825	795	685	650	765	724	680	915	1223	1525

addition of WCO and WEO, which contain aromatic and saturated hydrocarbons, reverses the oxidation process. Asphaltenes, which have higher molecular weight, dissolve in rejuvenator oily medium having low molecular weight and these asphaltenes and maltenes present in binder causes changes in viscous behavior [24]. However, with the addition of shredded plastic, the viscosity is found to increase at all dosage levels which may be due to the formation of stiffer binder mix. It was observed that the all the binders with or without rejuvenators, satisfied the minimum kinematic viscosity specified is 325 cP and the values obtained are within the limits as per specification.

3.2. Rutting and fatigue parameter

Dynamic Shear Rheometer (DSR) test was conducted as per AASHTO T315 [22] guidelines and the rutting; fatigue resistance parameters of binders are evaluated. The limiting values of the resistance to rutting parameter (G*/ sin δ) should be more than or equal to 2.2 kPa and the resistance to fatigue parameter (G* sin δ) should be equal or less than 5000 kPa [25]. Fig. 3 provides the variation of rutting parameter (G*/ sin δ) with temperature for fresh and RTFO aged binder specimen.

From Fig. 3, it may be noted that virgin binder (VG30) satisfies the rutting parameter of G*/sin δ recording values greater than 1.0 kPa, even at higher temperatures. However, the RTFO aged binder fails to meet the specification rutting parameter above 68°C indicating the material losing its stiffness at higher temperature. The variation of the fatigue parameter (G*sin δ) with temperature of aged binder and rejuvenated binders for varying percentages of rejuvenators are depicted in Fig. 4.

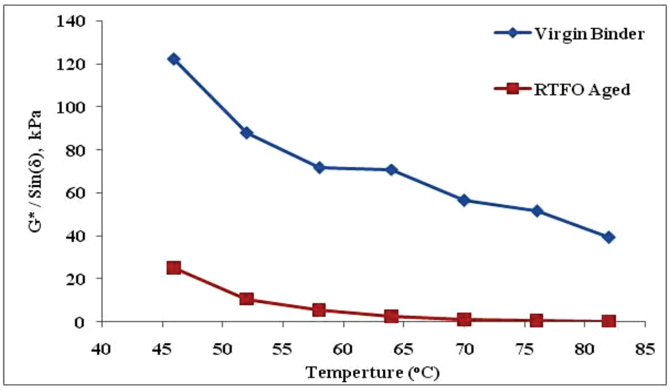
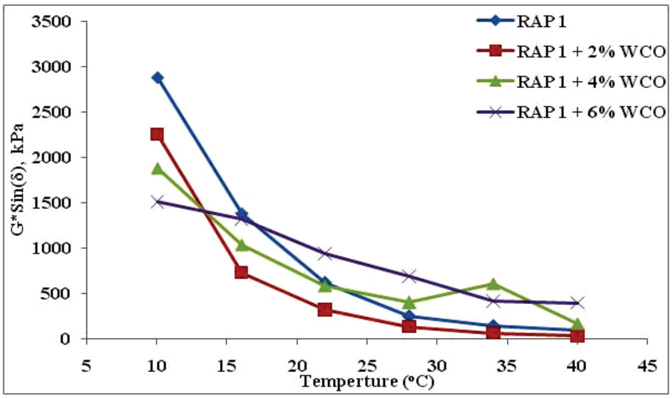


Fig. 3. Variation of rutting parameter with temperature for virgin and RTFO aged binder.

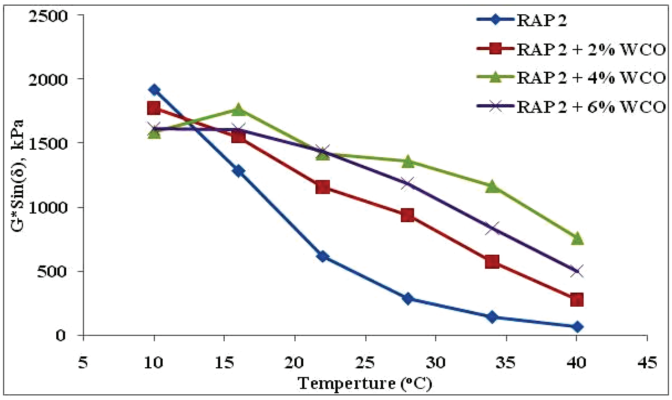
From Figure 4, it may be observed that fatigue parameter values (G*sin δ) for aged binder are quite higher as compared to virgin and RTFO binder (Fig. 3), thus indicating formation of stiffer and brittle binder with aging. However, rejuvenation of WCO and WEO rejuvenators softens the binder materials, thus improving the binder's resistance to fatigue failure. The addition of shredded plastics up to 2% resulted in RAP binders recorded fatigue parameter values (G*sin δ) below 5000 kPa. However, with the addition of shredded plastics beyond 4%, it is observed a fatigue parameter values (G*sin δ) value exceeds the specified limit of 5000 kPa, which may be attributed to formation of stiffer and brittle binder mix. The formation of a stiffer mix with the addition of shredded plastic although reduces the resistance to fatigue failure, it may provide better rutting performance. Based on these criteria, the optimum rejuvenator dosage was fixed at 6% for WCO and WEO while 2% for shredded plastics.

3.3. FTIR spectrum results

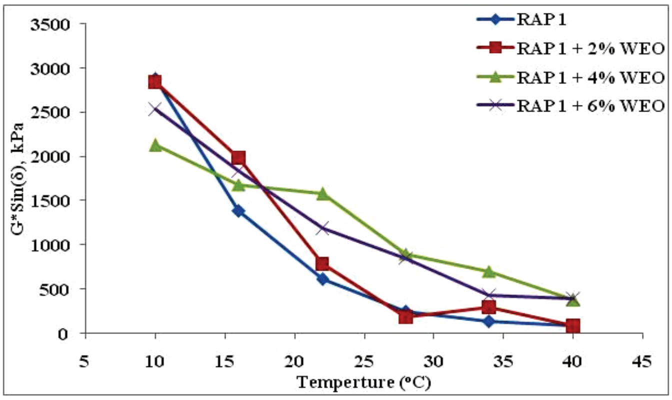
The FTIR spectroscopy test was carried out for determining the aging behavior of virgin binder, RTFO aged, RAP binder without rejuvenators and RAP binder (RAP1 and RAP2) with addition of 6% WCO and WEO and 2% for shredded plastics and the results are depicted in Fig. 5 to Fig. 11. The spectrum obtained relates to the absorbance and wave number and the peak height is observed at the wave number 2918 to 2922 cm^{-1}. The wave number indicates different functional group present in the sample and includes compounds aldehydes, carboxylic acid, ketone and the wave number resolution generally ranges from 400 to 4000 cm^{-1}. The results from the test had similar spectrum having valleys and peaks, with major variation with the addition of plastic. The peak value obtained was in the range of 2845 – 2922 cm^{-1} which indicates the presence of saturated hydrocarbons in large proportion. From Fig. 5 and Fig. 6, it is observed that the intensity at wave number around 1000 cm^{-1} for virgin binder and RTFO aged binder is a lower indicating negligible quantity of sulfoxide group compounds. However at the same wave number, the intensity is a higher in binder reclaimed from 8 years aged material (RAP 1) and 15 years aged material (RAP 2) samples as seen in Figs. 7 and 8, indicating the presence of considerable amount of sulfoxide to cause oxidation leading to the ageing effect. In Figs. 9 and 10, the intensity has reduced by about 35% by the addition of 6% waste cooking oil and by about 30 % by the addition of 6 % waste engine oil. In addition, the area under this range has also spread over a wider area. This reduction in the sulfoxide compounds in the binder mix is because of the presence of



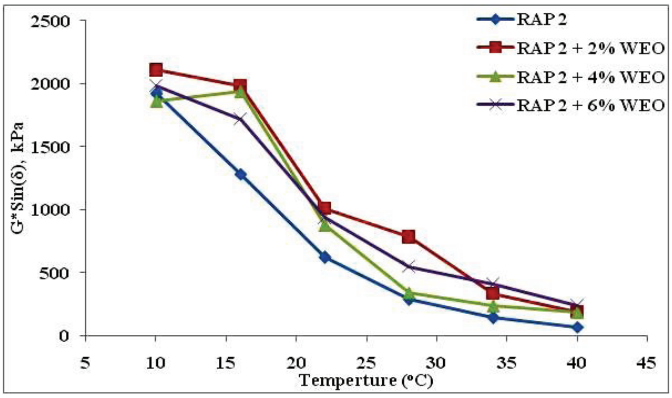
(a) 8 years old RAP with WCO.



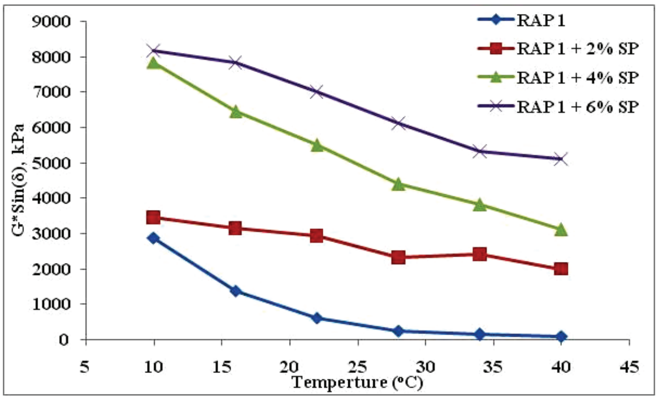
(b) 15 years old RAP with WCO.



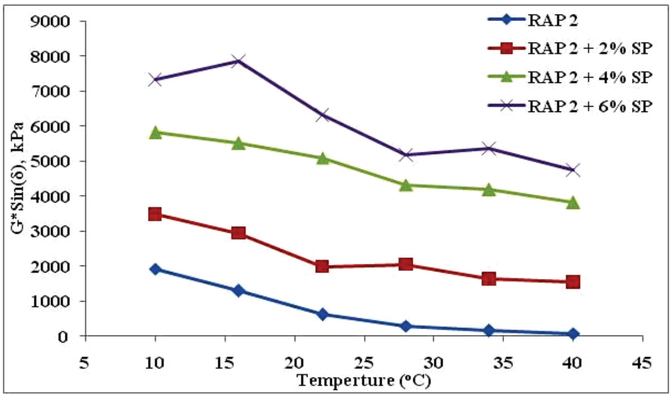
(c) 8 years old RAP with WEO.



(d) 15 years old RAP with WEO.



(e) 8 years old RAP with SP.



(f) 15 years old RAP with SP.

Fig. 4. Variation of fatigue parameters with temperaure forvarious binders.
Note: RAP 1 represented 8 years aged RAP sample while RAP2 represents 15 years aged RAP sample.

aromatic and aliphatic hydrocarbons in waste cooking and waste engine oils that renders the softening to the stiff binder. This happens due to the reduction in the ratio of asphaltenes to maltenes, ensuring more maltenes are present in the binder. However, the similar effect was not found by the addition of waste plastics to the binder as seen in Fig. 11. This may be due to absence chemical reaction between the plastics and binder material in a significant manner to soften the same [26,27].

From the FTIR graphs, the peak areas around spectral bands at 1030 cm^{-1} and 1700 cm^{-1} were considered as these peaks represent the aging process. The peaks obtained from the FTIR can provide a comparison on the effect of rejuvenators to relate the aging in RAP binders. From Figs. 9 to 11, it may be observed that the RAP binders rejuvenated with 2% shredded plastics have lesser sulfoxides and carbonyls as compared to those with WEO and WCO. To better illustrate these peaks, the sulfoxides peak value at around 1031.29 cm-1 for RAP binders rejuvenated with shredded plastics is 0.08 A, where as in case of WCO and WEO it is 0.15A and 0.13 A respectively, displaying a lower peak for shredded plastics. Similarly, the peak values of RAP binders rejuvenated with shredded plastics were found to be lower at different spectral bands. The carbonyls peak values of RAP binders rejuvenated with 2% shredded plastics were also found to be lower as compared to RAP binders rejuvenated with WCO and WEO. The sulfoxides and carbonyls peak values of RAP binders rejuvenated WCO were larger as compared to those rejuvenated with WEO [28].

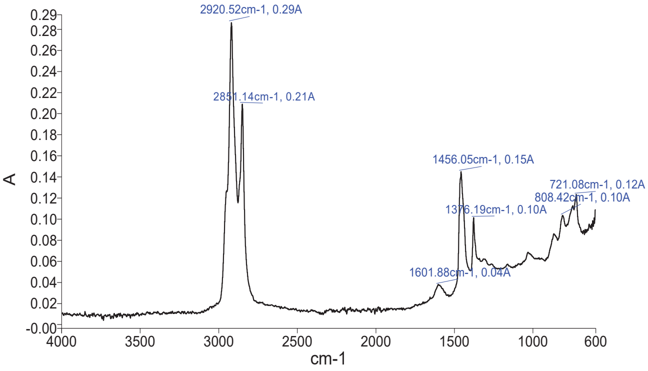


Fig. 5. FTIR Spectrum of Virgin Binder VG 30.

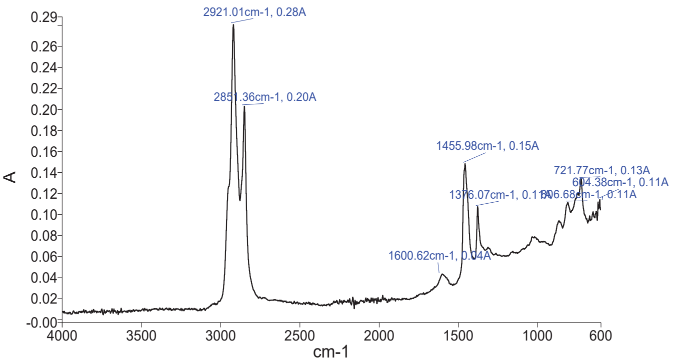


Fig. 6. FTIR Spectrum of RTFO Aged Binder.

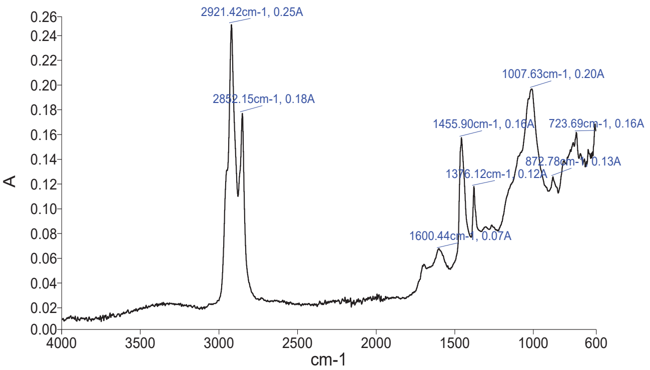


Fig. 7. FTIR spectrum of 8 years aged RAP binder without rejuvenators.

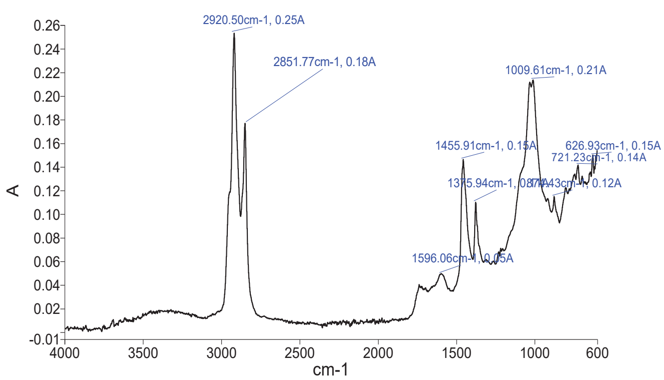


Fig. 8. FTIR spectrum of 15 years aged RAP binder without rejuvenators.

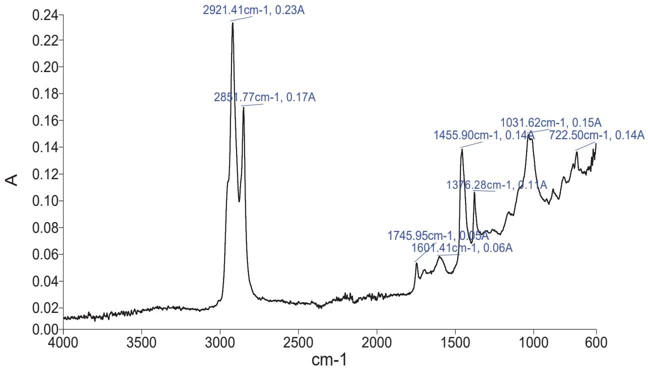


Fig. 9. FTIR spectrum of RAP binder with 6% addition of rejuvenator (WCO).

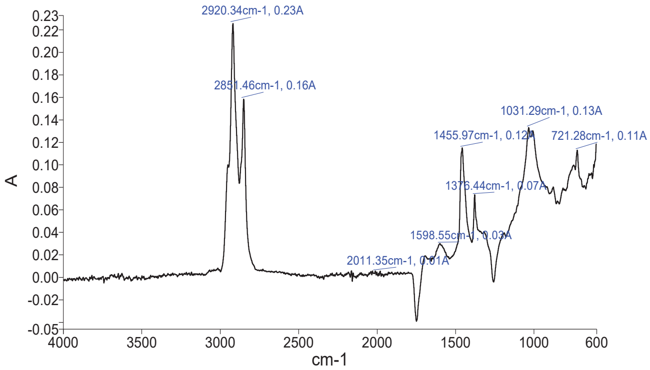


Fig. 10. FTIR spectrum of RAP binder with 6% addition of rejuvenator (WEO).

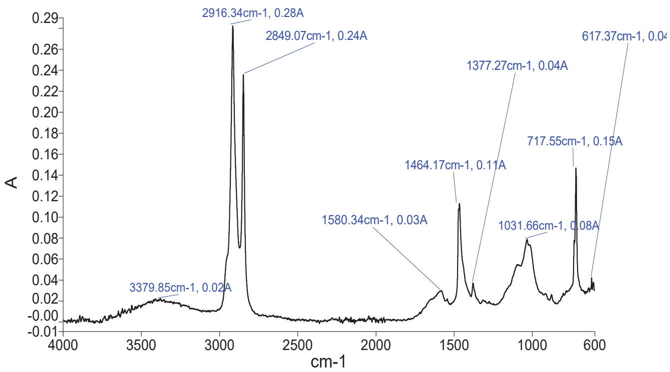


Fig. 11. FTIR spectrum of RAP binder with 2% addition of shredded plastic.

3.4. Marshall stability test results

The Marshall Mix design included the SMA mix using VG30 grade bitumen and the design for virgin aggregate with RAP mixture blended at 30%, 50% and 70% with 6% WCO and WEO and 2% for shredded plastics and the results are tabulated in 4. The gradation considered is as per IRC: SP-79-2008 to determine the optimum binder content by considering various Marshall properties i.e., Voids in Mineral Admixtures, Density, Voids and Flow. The summarized details of Marshall Properties at OBC are presented in the Table 4.The Marshall properties are tabulated as shown in Table 4 considering the optimum binder content from the mix design. The average Optimum Binder Content (OBC) of

Table 4
Properties at optimum binder content for SMA Mix with 6% WCO, WEO and 2% shredded plastic.

Sl. No	Properties	Virgin mix	WCO			WEO			Shredded plastic		
			30%	50%	70%	30%	50%	70%	30%	50%	70%
1	Stability (kN)	14.6	15	15.75	16.2	15.6	16.75	16.4	17.56	18.13	19.3
2	Flow (mm)	5.2	4.25	6.73	5.1	4.27	6.34	5.1	3.85	3.95	4.03
3	Air voids (%)	3.8	4.3	4.4	4.1	4.2	4.4	4	4.3	4.1	3.9
4	Bulk density (g/cc)	2.32	2.31	2.31	2.32	2.31	2.31	2.32	2.31	2.31	2.3
5	Optimum Binder Content (OBC) (%)	6.08	5.8	5.75	5.65	5.8	5.72	5.68	5.78	5.87	5.91

mixtures containing RAP (at any replacement level) using rejuvenators displayed average decreased in magnitude by about7.5%, 6% and 2.7% for WCO, WEO and shredded plastic respectively, compared to that of virgin mix. The reduction in the OBC with addition of RAP and rejuvenators may be due of the differences in the viscosity of binders in the mixtures. From the Table 4, it may also be observed that the stability shows an average increase with the addition of RAP materials (at any replacement level) in the mix by about 11.4%, 14% and 32% for WCO, WEO and shredded plastic. It may be observed that that effect of waste cooking oil and waste engine oil on the mixes is almost similar. It was observed that the increase in the percentage of RAP led to the increase in stability of the mixes. Increased stability with addition of RAP materials may be attributed to the superior adhesion properties developed between the mixes and RAP materials. However, the addition of shredded plastics in the mix displayed better properties due to the formation of crystalline properties rendering the mixture stiffer with higher stability [29]. Similar trend has been observed in the flow values in the tested samples. The results indicated that the air voids and bulk density of the mixes for all the types of rejuvenators used are found to be within the specified limits as per IRC-SP-79:2008 [16]. It is also seen that the addition of RAP in the mix did not have adverse effects on the physical and mechanical properties in the mix at any replacement level.

3.5. *Moisture susceptibility*

The Indirect Tensile Strength (ITS) test was carried out as per ASTM D1075 [30] for the Marshall specimen at OBC of the SMA mixes. Tensile Strength Ratio (TSR) values for various rejuvenated RAP binders with 6% WCO and WEO and 2% for shredded plastics are tabulated in Table 5. The results displayed an average reduction rate of TSR by about 2%, 4.3% by addition of WCO and WEO respectively, thus indicating better anti-stripping properties. However, TSR was found to be well within standard recommended limit of 75% [24]. The addition of shredded plastics has displayed an average increase of 5.7% in the tensile strength ratio. Visual examinations of the testes specimens at 70% of RAP replacement levels also did not exhibit any signs of stripping of bitumen from aggregates irrespective of the type of rejuvenator.

Table 5
Tensile strength ratio values at optimum rejuvenator content.

Sl. No	RAP (%)	TSR (%)			
		Without rejuvenators	WCO	WEO	Shredded plastics
1	0	86.32	-	-	-
2	30	-	84.83	82.62	91.2
3	50	-	82.19	81.85	90
4	70	-	81.08	80.09	88

4. Conclusions

The major conclusions derived from the present study are as follows:

1. The addition of rejuvenators improved the viscosity of the RTFO aged binder, 8year old RAP and 15 year old RAP binders and the viscosity was found to satisfy the minimum viscosity requirements. The use of shredded plastics displayed significant improvement in the viscosity as compared to waste engine oil and waste cooking oil. The RTFO aged binder, 8year old RAP and 15 year old RAP binders reported viscosity of 2925 centi-poise , 625 centi-poise and 825 centi-poise when tested without rejuvenators. However, the values of viscosity started decreasing with increased percentages of rejuvenators irrespective of the type of rejuvenator.
2. The rheological parameters of the aged and rejuvenated binders studied through DSR tests satisfied the requirements for rutting and fatigue resistance. The use of WCO and WEO improved the fatigue and rutting performance at all dosage levels. However, the addition of shredded plastics beyond 2%, failed to satisfy the fatigue parameter. Based on these criteria, the optimum rejuvenator dosage was fixed at 6% for WCO and WEO while 2% for shredded plastics.
3. The relative quantities of different chemical compounds in the asphalt binder were found to provide sufficient evidence for the presence of compounds leading to ageing of binder. The peak value obtained was in the range of 2845 – 2922 cm-1 indicating the presence of saturated hydrocarbons in large proportion. In virgin binder and RTFO aged binder, the intensity at wave number around 1000 cm-1 was found to be lower, indicating negligible quantity of sulfoxide group compounds. However, the at the same wave number, the intensity is a higher in binder reclaimed from 8 years aged material (RAP 1) and 15 years aged material (RAP 2) samples indicating the presence of sulfoxide group compounds responsible for ageing effect. The intensity reduced by about 35% and 30% with addition of 6% WCO and WEO respectively. However, the addition of waste plastics displayed similar intensity as that of aged binder indicating no adverse effects. The WCO displayed better rejuvenating effect as compared to WEO and shredded plastics.

The Marshall properties for SMA mix with rejuvenated RAP indicated higher stability value when compared with that of the conventional mix at all RAP replacement levels. It was observed that increase in percentage of RAP further improved the performance parameters. The addition of rejuvenated RAP to the SMA mixes showed improved resistance to the moisture susceptibility.

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