A Review on Reclaimed Asphalt Pavement (RAP), Rejuvenators and its Effects on RAP

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Abstract: More and more focus is shifting towards the use of recycled materials for construction. Road infrastructure development has increased many folds during the past few decades. Diminishing natural resources, increasing price of raw materials and need to preserve the environment has necessitated the use of reclaimed asphalt pavement (RAP) for the production of bituminous mixes. This review paper discusses the benefits/limitation, the procedure for hot mix recycling, the effect of ageing and rejuvenator on the morphology and chemical composition of bitumen. The paper also throws some light on various types of rejuvenators and their effect on the properties of aged bitumen.

***Index Terms* – RAP, rejuvenator, recycling, ageing, morphology, bitumen**

I. INTRODUCTION

The need to protect the environment has led to increasing use of reclaimed asphalt pavement (RAP) during recent decades. However, the bitumen associated with RAP is aged after being subjected to various processes such as, oxidation, alteration in molecular organization and loss of volatiles as shown in Figure 1 (Cavalli, Partl, and Poulikakos 2017; Lu and Isacsson 2002; Nazzal et al. 2014; Petersen and Glaser 2011; Rinaldini et al. 2014). Addition of softer virgin binder, increasing binder content or using warm mix additives helps in addressing this and increases the amount of RAP that can be recycled into bituminous mixes but not in very high proportions (Farooq and Mir 2017; Im, Karki, and Zhou 2016; West, Willis, and Marasteanu 2013). To counteract the effect of binder hardening, a rejuvenator needs to be used which aids in replacing the oils lost during ageing and help to rebalance the chemical composition of the RAP (Ongel and Hugener 2015). With the help of rejuvenators and warm mix additives, up to 60% RAP can be recycled into warm mix asphalt (Farooq, Mir, and Sharma 2018).

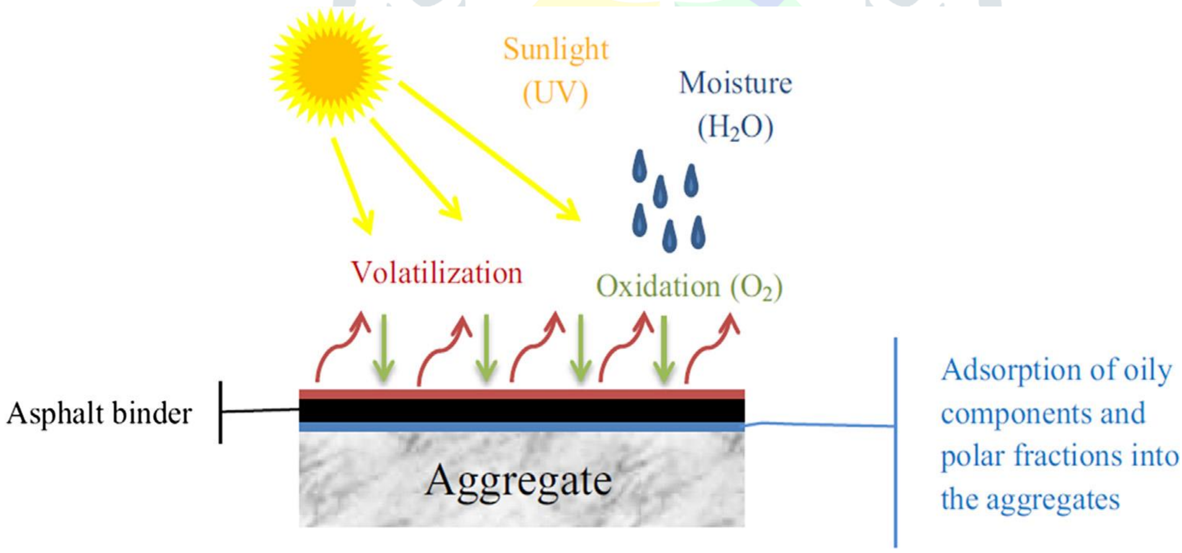

Figure 1. Ageing of bitumen in pavements (Baghaee Moghaddam and Baaj 2016)

II. BENEFITS AND LIMITATIONS OF USING HIGH RAP CONTENT

Generally, there are two main benefits of using RAP, namely cost and environmental. It is clear from Figure 2 that various costs associated with RAP include the cost of RAP material and its processing, testing, etc. However, the utilization of 100 % RAP can result in a 50-70% reduction in the total cost of construction (Zaumanis, Mallick, and Frank 2014). The environmental benefits include reduced emissions, reduced demand for non-renewable resources and reduced landfill space requirement for disposal of RAP (Baghaee Moghaddam and Baaj 2016). Figure 3 shows the reduced emission levels obtained with the use of RAP.

Despite the above advantages, it is very important to properly design the recycled pavements otherwise cost reduction as a result of recycling shall be less than the cost involved with its maintenance, emission, and energy consumption (Waymen et al. 2012).

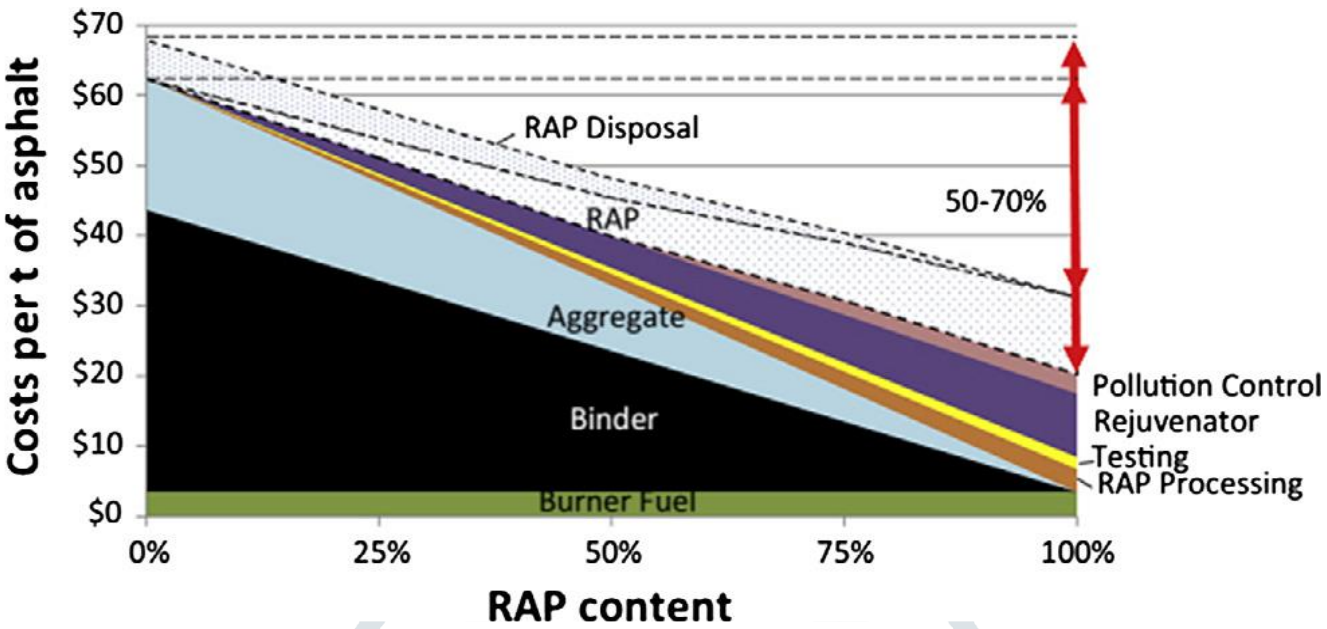

Figure 2. Cost of materials incurred for hot mix recycling (Zaumanis, Mallick, and Frank 2014)

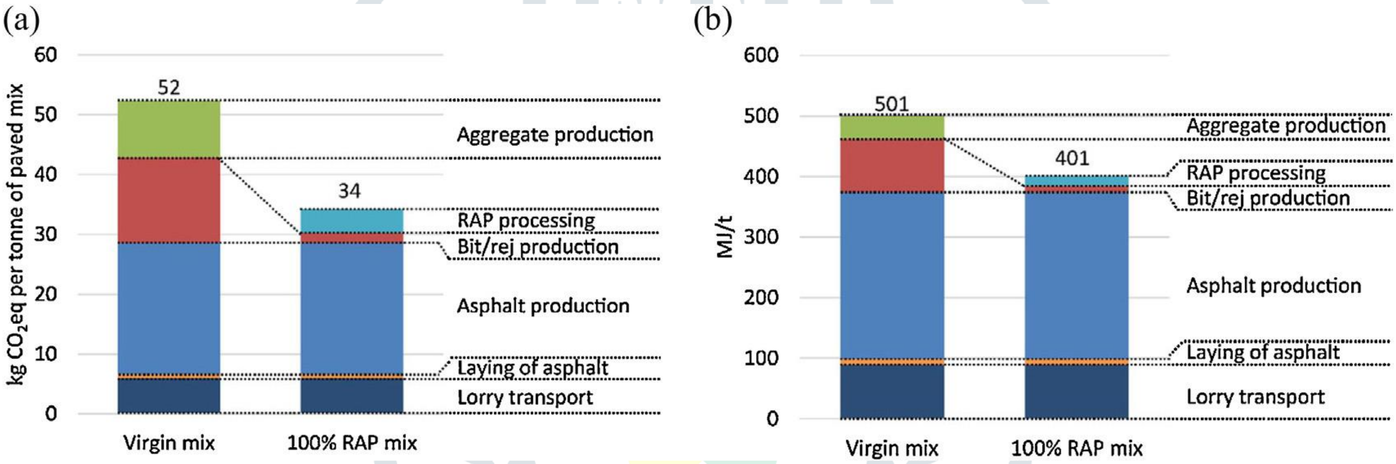

Figure 3. Comparison of CO_2 emissions for virgin and 100% RAP mix (Zaumanis, Mallick, and Frank 2014).

III. HOT MIX RECYCLING PROCEDURE

The process of RAP collection and recovery of bitumen to be evaluated for various properties is shown in Figure 4. The recycling procedure for hot mix using Superpave technology is shown by flow chart in Figure 5.

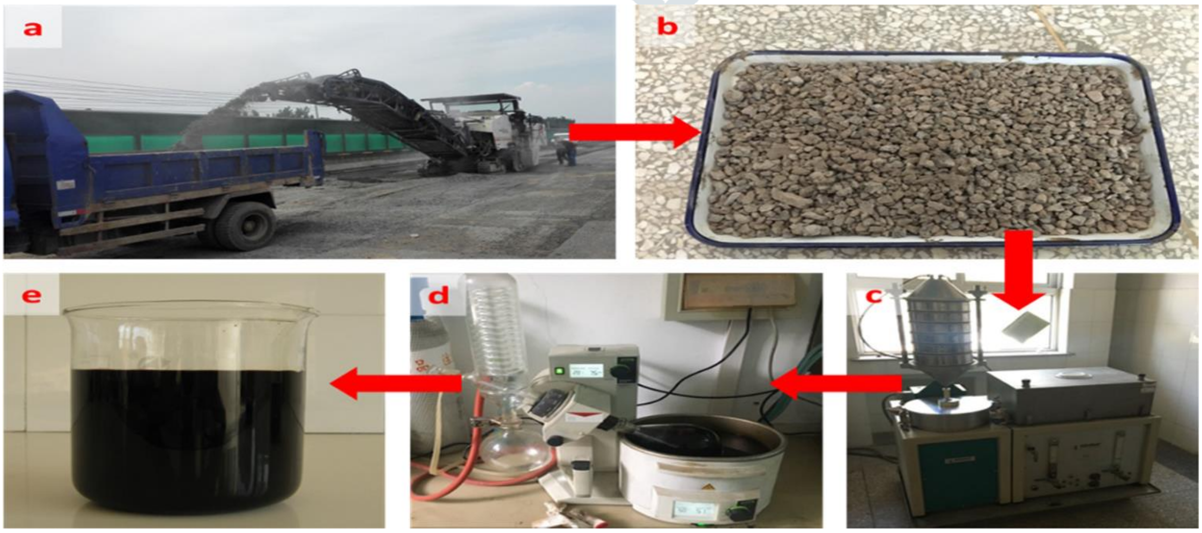

Figure 4. The process of RAP collection and recovery of bitumen (Jiang et al. 2018)

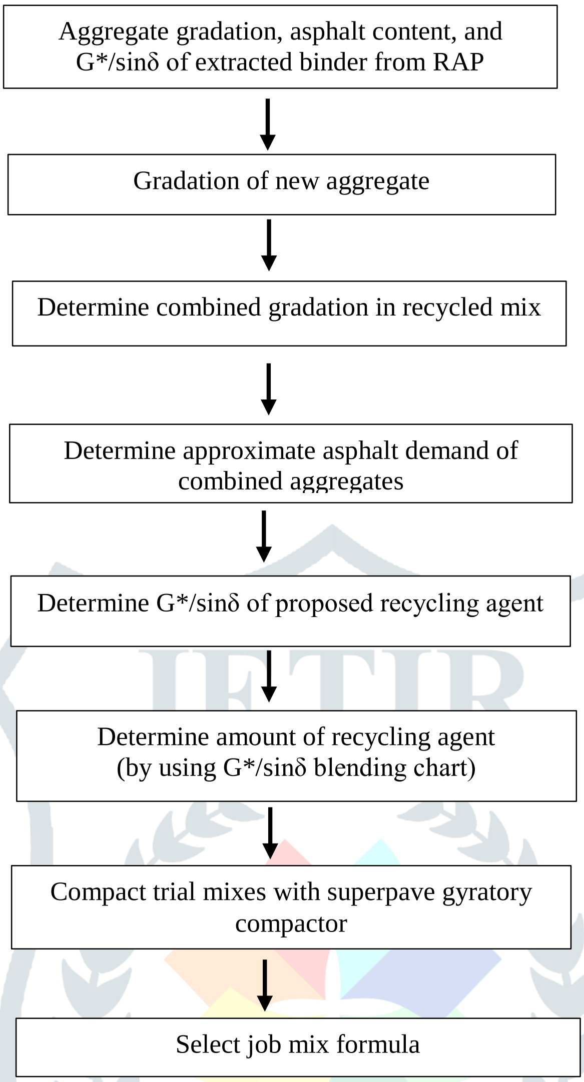

Figure 5. Flow chart of hot RAP recycling (Kandhal and Mallick 1997)

IV. EFFECT OF AGEING AND REJUVENATOR ON BITUMEN MICROSTRUCTURE

The morphology and phase diagrams of virgin and aged bitumen is shown in Figure 6-9 (Chen et al. 2018). The stripes associated with virgin bitumen are called bee phase. The 3D morphology diagram of virgin bitumen shows height fluctuation indicating that the surface of virgin bitumen is uneven. Furthermore, Figure 7 shows that bee phase is coated by a thick layer. Figure 8 and Figure 9 shows the morphology and phase diagram of aged bitumen, respectively and indicate that changes occur in the microstructure of bitumen after ageing in comparison to the virgin bitumen. The coating layer on the bee surface gets thinner or disappears as a result of ageing.

Figure 10 (a), (b) and (c) show the phase diagrams of bitumen rejuvenated with (a) 2% *rejuvenator RA100* (b) 10% *rejuvenator RA100*(c) 2% *rejuvenator RA102*, *respectively*. The morphological diagram was too fuzzy, hence, was not considered. It is evident that the bee-like structure is long and narrow for all three types of rejuvenated bitumen's. The rejuvenators do not change the microstructure of bitumen components. There is no difference in the sizes and quantities of beelike structures for all the three rejuvenated binders indicating that the type and amount of rejuvenator have no effect on the microstructure of rejuvenated bitumen. Hence, rejuvenator must be evaluated in terms of actual performance on aged binders.

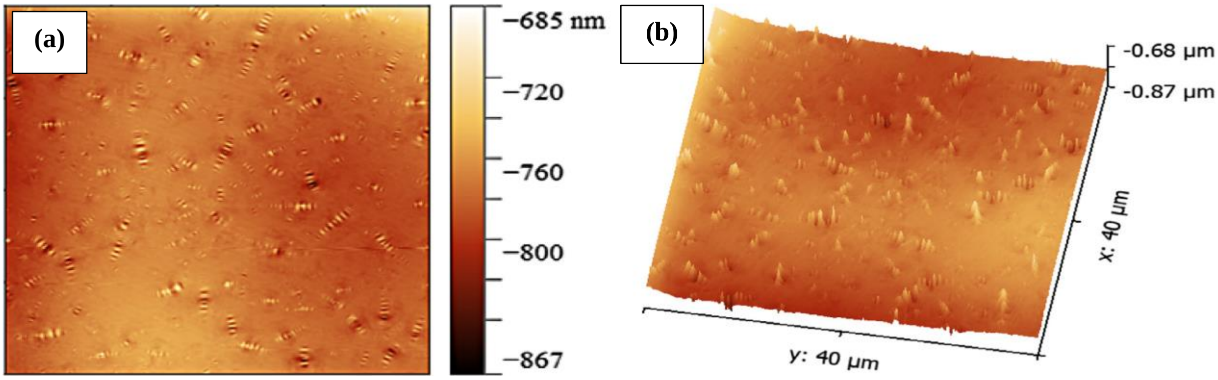

Figure 6. (a) 2D morphology diagram of virgin bitumen (b) 3D morphology diagram of virgin bitumen (Chen et al. 2018)

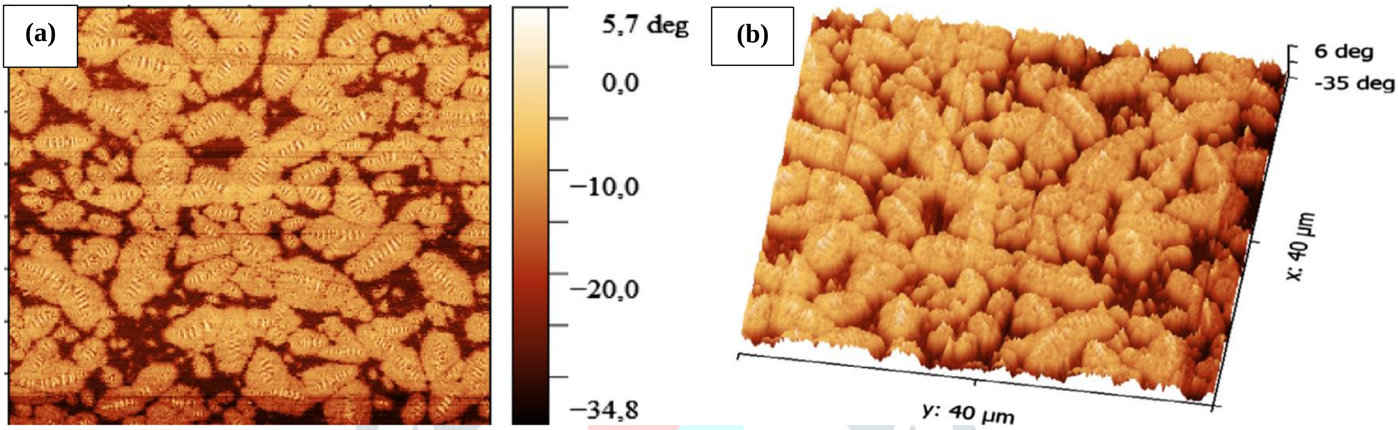

Figure 7(a) 2D phase diagram of virgin bitumen (b) 3D phase diagram of virgin bitumen (Chen et al. 2018)

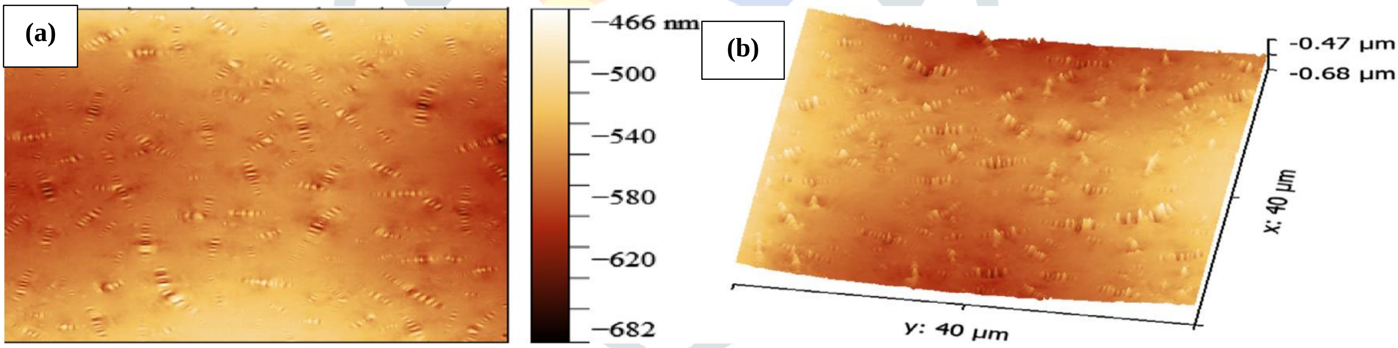

Figure 8(a) 2D morphology diagram of aged bitumen (b) 3D morphology diagram of aged bitumen(Chen et al. 2018)

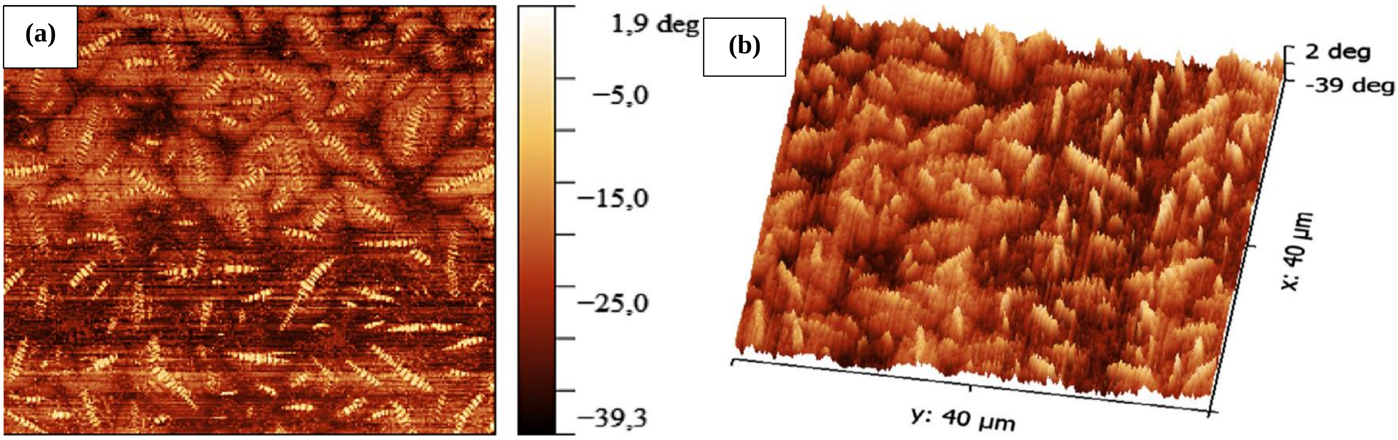

Figure 9(a) 2D phase diagram of aged bitumen (b) 3D phase diagram of aged bitumen(Chen et al. 2018)

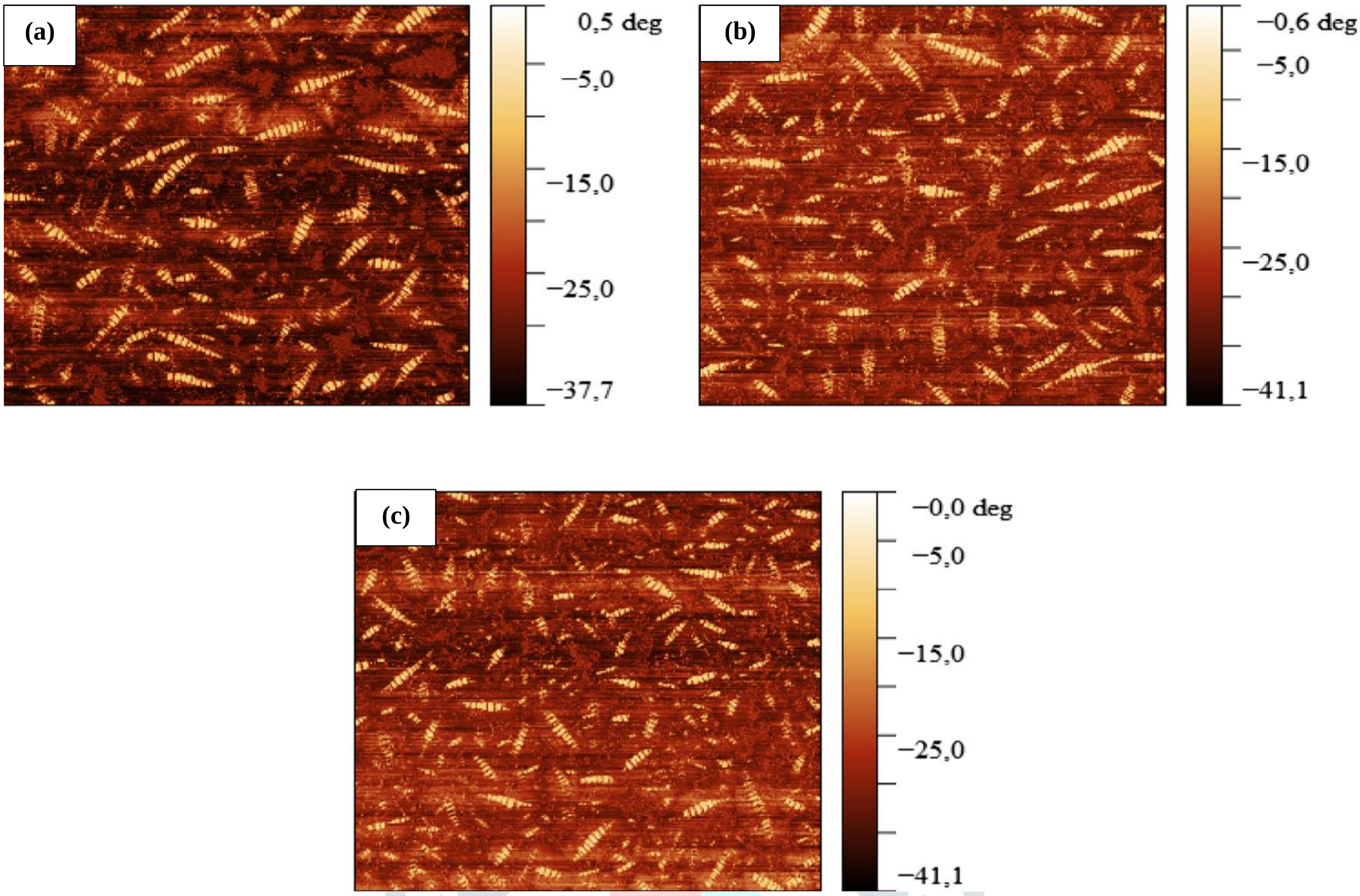

Figure 10. Phase diagrams of three rejuvenated bitumen's (Chen et al. 2018)
(a) 2% rejuvenator RA100 (b) 10% rejuvenator RA100 (c) 2% rejuvenator RA102

V. EFFECT OF AGEING AND REJUVENATOR ON THE CHEMICAL COMPOSITION OF BITUMEN

Figure 11 depicts the alteration that occurs in the chemical composition of bitumen after it ages and on the inclusion of rejuvenator in comparison to virgin bitumen. It is clear from the figure that the aged bitumen very nearly reclaims all of its characteristics.

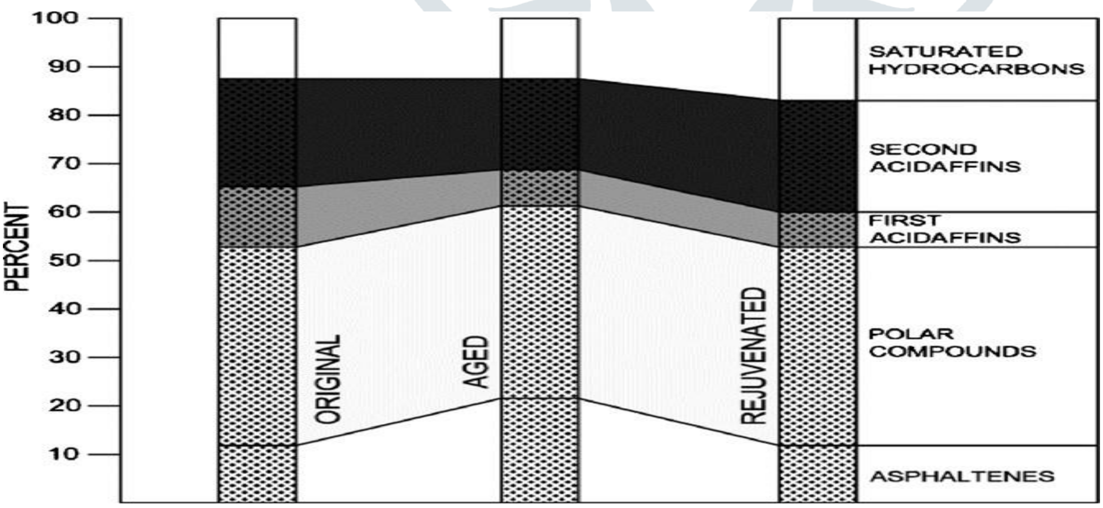

Figure 11. Changes in chemical composition of bitumen after ageing and rejuvenation (Brownridge 2010)

VI. TYPES OF REJUVENATORS AND THEIR EFFECT ON VARIOUS PROPERTIES OF RAP

The various types of rejuvenators/softening/recycling agents include a waste vegetable (WV) oil, WV grease, organic oil, distilled tall oil, waste engine oil, aromatic extract and virgin binder (Zaumanis, Mallick, and Frank 2015). The properties of these are shown in Table 1. The effect of these rejuvenators on rutting, moisture susceptibility, ageing, workability, low-temperature cracking, and fatigue is presented in Table 2.

Table 1. Rejuvenator types and their properties (Zaumanis et al. 2015)

Recycling agent	**Kinematic Viscosity at 135°C (cSt)**	**Specific gravity**	**Engineered or generic**	**Petroleum or organic**	**Refined or waste**	**Molecular structure**	**Polarity**	**Price per litre (US$)**
WV oil	5.17	0.924	Generic	Organic	Waste	Ring and strand	Non	0.58
WV grease	4.28	0.924	Generic	Organic	Waste	Ring and strand	Mild	0.73
Organic oil	5.43	0.947	Engineered	Organic	Refined	Ring and strand	Very	1.57
Distilled tall oil	5.60	0.950	Generic	Organic	Refined	Ring and strand	Mild	1.59
Waste engine oil	3.86	0.872	Generic	Petroleum	Waste	Aliphatic	Slight	0.46
Aromatic extract	9.20	0.995	Generic	Petroleum	Refined	Aromatic ring	Very	1.26
Virgin binder (PG 64-22)	474	1.020	Generic	Petroleum	Refined	Ring and strand	Mixed	0.62

Table 2. Effect of various rejuvenators on various properties of recycled mixes (Zaumanis, Mallick, Poulikakos, et al. 2014)

Property	**Testing method**	**Required value to qualify**	**Virgin mix/ binder**	**RAP mix/ binder**	**WVO**	**WVG**	**Organic oil**	**DTO**	**AE**	**WEO**
Rutting	High PG temperature	≥64 °C	✓	✓	✓	✓	✓	✓	✓	✓
	WTT rut depth	≤12.5 mm	✗	✓	✓	✓	✓	✓	✓	✓
Moisture	WTT inflection point	≥1000 cycles	✗	✓	✗	✓	✓	✓	✓	✓
Ageing	Loss of volatiles	≤1%	✓	✓	✓	✓	✓	✓	✓	✗
Workability	Rotational viscosity	≤3 Pa.s	✓	✗	✓	✓	✓	✓	✓	✓
	Mix workability	≤10 gyr	✓	✗	•	•	•	•	•	•
Low temperature cracking	Low PG temperature	≤-22°C	✓	✗	✓	✓	✓	✓	✓	✗
	Mixture cracking temperature	≤-22°C	✓	✗	•	•	•	✗	✓	•
Fatigue	G*.sinδ	≤5000 kPa	✓	✗	✓	✓	✓	✓	✓	✓
	CAST, 50% stiffness loss	≥3E+09 cycles	✓	✓	✓	✓	✓	✓	✓	✗
✓ indicates pass				✗ indicates fail				•indicates neutral		
WVO: Waste Vegetable Oil, WVG: Waste Vegetable Grease, DTO: Distilled Tall Oil, AE: Aromatic Extract, WEO: Waste Engine Oil										

VII. Concluding remarks

Utilising RAP for the production of bituminous mixes offers a lot of benefits, especially low overall production cost but a high level of quality control must be ensured, otherwise, huge maintenance costs may be incurred. Procedures are available which give detailed instruction regarding the use of RAP using Superpave technology. Microscopic structural analysis shows that although variation is noticed between virgin and aged binder, the type and amount of rejuvenator do not show any difference in the morphology and phase diagrams of rejuvenated bitumen. However, chemical composition analysis clearly depicts that the addition of rejuvenator helps in regaining the characteristics of aged binder to the level of virgin binder. Out of the various types of waste and refined rejuvenators considered in this review; waste vegetable grease, organic oil, and aromatic extract passed all the required tests.

REFERENCES

[1]. Baghaee Moghaddam, Taher and Hassan Baaj. 2016. "The Use of Rejuvenating Agents in Production of Recycled Hot Mix Asphalt: A Systematic Review." *Construction and Building Materials* 114:805–16.

[2]. Brownridge, Jim. 2010. "The Role of an Asphalt Rejuvenator in Pavement Preservation : Use and Need for Asphalt Rejuvenation." *In: FHWA, Editor. 1st Int Conf on Pavement Preservation. Newport Beach, USA: Federal Highway Administration* 51–64.

[3]. Cavalli, Maria Chiara, Manfred N. Partl, and Lily D. Poulikakos. 2017. "Measuring the Binder Film Residues on Black Rock in Mixtures with High Amounts of Reclaimed Asphalt." *Journal of Cleaner Production* 149:665–72.

[4]. Chen, Anqi, Guoqiang Liu, Yongli Zhao, Jing Li, Yuanyuan Pan, and Jian Zhou. 2018. "Research on the Aging and Rejuvenation Mechanisms of Asphalt Using Atomic Force Microscopy." *Construction and Building Materials* 167:177–84.

[5]. Farooq, Mohammad Adnan and Mohammad Shafi Mir. 2017. "Use of Reclaimed Asphalt Pavement (RAP) in Warm Mix Asphalt (WMA) Pavements: A Review." *Innovative Infrastructure Solutions* 2(1):10.

[6]. Farooq, Mohammad Adnan, Mohammad Shafi Mir, and Ankit Sharma. 2018. "Laboratory Study on Use of RAP in WMA Pavements Using Rejuvenator." *Construction and Building Materials* 168:61–72.

[7]. Im, Soohyok, Pravat Karki, and Fujie Zhou. 2016. "Development of New Mix Design Method for Asphalt Mixtures Containing RAP and Rejuvenators." *Construction and Building Materials* 115:727–34.

[8]. Jiang, Hongguang, Jizhe Zhang, Changjun Sun, Shengjie Liu, Ming Liang, and Zhanyong Yao. 2018. "Experimental Assessment on Engineering Properties of Aged Bitumen Incorporating a Developed Rejuvenator." *Construction and Building Materials* 179:1–10.

[9.] Kandhal, PM and RB Mallick. 1997. "Pavement Recycling Guidelines for State and Local Governments-Participant's Reference Book." *Auburn, AL: National Center for Asphalt Technology, Report Number FHWA-SA-98-042.*

[10]. Lu, Xiaohu and Ulf Isacsson. 2002. "Effect of Ageing on Bitumen Chemistry and Rheology." *Construction and Building Materials* 16(1):15–22.

[11]. Nazzal, Munir D., Walaa Mogawer, Savas Kaya, and Thomas Bennert. 2014. "Multiscale Evaluation of the Composite Asphalt Binder in High–Reclaimed Asphalt Pavement Mixtures." *Journal of Materials in Civil Engineering* 26(7):04014019.

[12]. Ongel, Aybike and Martin Hugener. 2015. "Impact of Rejuvenators on Aging Properties of Bitumen." *Construction and Building Materials* 94:467–74.

[13]. Petersen, J. Claine and Ronald Glaser. 2011. "Asphalt Oxidation Mechanisms and the Role of Oxidation Products on Age Hardening Revisited." *Road Materials and Pavement Design* 12(4):795–819.

[14]. Rinaldini, E., P. Schuetz, M. N. Partl, G. Tebaldi, and L. D. Poulikakos. 2014. "Investigating the Blending of Reclaimed Asphalt with Virgin Materials Using Rheology, Electron Microscopy and Computer Tomography." *Composites Part B: Engineering* 67:579–87.

[15]. Waymen, M., Y. Andersson-Skold, R. Bergmen, Y. Huang, T. Parry, and J. Raaberg. 2012. "Life Cycle Assessment of Reclaimed Asphalt." *European Commission*.

[16]. West, Randy, James Richard Willis, and Mihai Marasteanu. 2013. "Improved Mix Design, Evaluation, and Materials Management Practices for Hot Mix Asphalt with High Reclaimed Asphalt Pavement Content." *Transportation Research Board* (752).

[17]. Zaumanis, Martins, Rajib B. Mallick, and Robert Frank. 2014. "100% Recycled Hot Mix Asphalt: A Review and Analysis." *Resources, Conservation and Recycling* 92:230–45.

[18]. Zaumanis, Martins, Rajib B. Mallick, and Robert Frank. 2015. "Evaluation of Different Recycling Agents for Restoring Aged Asphalt Binder and Performance of 100 % Recycled Asphalt." *Materials and Structures* 48(8):2475–88.

[19]. Zaumanis, Martins, Rajib B. Mallick, Lily Poulikakos, and Robert Frank. 2014. "Influence of Six Rejuvenators on the Performance Properties of Reclaimed Asphalt Pavement (RAP) Binder and 100% Recycled Asphalt Mixtures." *Computers and Chemical Engineering* 71:538–50.