International Journal of Scientific Research & Engineering Trends
Volume 9, Issue 4, Jul-Aug-2023, ISSN (Online): 2395-566X

Investigation into Possibility of Rejuvenating Aged Asphalt Binder Using Mustard Oil

D.Anusha , Modugu Naveen Kumar
Dept. Of Civil Engineering
Holy Mary Institute Of Technology & Science
Keesara, Bogaram, Telangana – 501301

Abstract- Incorporation of high content of Reclaimed Asphalt Pavement (RAP) into fresh asphalt mixtures make them prone to thermal cracking and fatigue failure. Rejuvenators are usually recommended to overcome this problem by restoring the aged asphalt binder properties. This study aims to investigate the feasibility of using Mustard oil as a rejuvenator and to evaluate its effectiveness as a rejuvenator by determining the extent to which it restores the chemical and physical properties of aged asphalt binder extracted from RAP. The effect of Mustard oil on physical, rheological, chemical and thermal properties of aged asphalt binder was studied by employing Rotational Viscometer, Dynamic Shear Rheometer, Bending Beam Rheometer, Fourier Transform Infrared Spectroscopy, Thermo gravimetric analysis, Gas Chromatography-Mass Spectrometry and Rolling bottle equipment. Results indicated that Mustard oil effectively restores the properties of aged asphalt binder and can be used as a suitable rejuvenator. Ten per cent of Mustard oil is recommended as an optimum dose for rejuvenation of aged asphalt binder. This dose is based on restoring the RAP binder to match the properties of neat binder having PG64 and is specific to the stiffness of RAP material being used.

Keywords-Des, Preprocessing, Sampling, False Alarm Rate, Feature Extraction

I. INTRODUCTION

Expanded cost alongside the shortage of asphalt materials and ecological advantages has urged the asphalt business to utilize Recovered Black-top Asphalt (RAP) in asphalt development. Stone Network Black-top (SMA) is hole reviewed bituminous combination, that grew only to improve rutting obstruction and sturdiness of asphalts. Numerous scientists inferred that the consolidation of RAP is muddled and, expands the solidness of the blends, which antagonistically influences the exhibition.

The restoring specialist is by and large used to decrease the solidness of bituminous combinations consolidating RAP. This examination plans to assess the plausibility of consolidating high RAP content in the SMA blend utilizing different rejuvenators. To accomplish this examination goal, efficient research center tests are performed by changing RAP content at four levels 10, 20, 30, and 40 % and utilizing four distinct rejuvenators (Squander Vegetable Oil, Squander Motor Oil, Squander Oil, and Palm Oil Ooze) and one dissolvable (CH3)2CO). The presentation boundaries assessed in this exploration incorporate Marshall solidness, dampness vulnerability tests, and crack qualities. Further, the collaboration of RAP with various rejuvenators is assessed through microstructural portrayal.

Presentation:

The asphalt business is one of the biggest normal total and bitumen-consuming areas on the planet. Throughout the long term expanding populace and industrialization required nonstop development and improvement of streets. This rising interest has brought about rising costs and a shortage of regular materials. Then again, expanded asphalt development expands the destruction squanders, which further causes removal issues. Thusly, asphalt ventures are attempting to foster economic advancements to decrease the utilization of normal materials in asphalt development. One such innovation broadly acknowledged is the reusing of Recovered Black-top Asphalt (RAP).

A few analysts found that joining of RAP will upgrade the exhibition of the bituminous blends, for example, rutting opposition, dampness obstruction, and elasticity (Chen et al., 2014; Al-Qadi et al., 2007; McDaniel et al., 2000; Kandhal and Mallick, 1998), which will be advantageous. Throughout the long term, bituminous blends have developed, and many kinds of combinations are grown in particular: bituminous concrete, permeable combinations, flimsy overlays, Stone Lattice Black-top (SMA) combinations, and so on.

1. Foundation

The consolidation of RAP into a bituminous blend is not another subject. Be that as it may, numerous moves should be addressed to deliver an exhaustive combination. The RAP contains matured fastener covering the totals, which

are presented to the ecological circumstances during its administration life (Copeland, 2011; Kandhal and Mallick, 1998). The matured folio is valuable concerning the economy since it can diminish the utilization of the virgin fastener. Because of changes in the attributes, the matured folio doesn't mix well with the bituminous combination and expands the firmness which might prompt execution disappointment of the bituminous combinations.

2. Exploration Scope:

1. Various investigations on the creation of SMA combinations and RAP are done independently. In any case, very little is realized about RAP consolidated SMA combinations.
2. The degree issues that happen during the RAP consolidation into SMA blends are required to have been tended to.
3. The effect of the RAP fuse on the blend configuration, administration life, security, and strength. Furthermore, the toughness properties of the SMA blend are not completely considered. Further, the impact of rejuvenator expansion on RAP consolidated SMA combination is neglected.
4. No standard technique is accessible for the microstructural characterization of RAP-integrated restored black-top blends. Quantitative examination at the miniature level is further developing the certainty of rejuvenator expansion in RAP consolidated black-top blends.

3. Goals

This exploration intends to integrate RAP into SMA combinations with various rejuvenators, with the accompanying primary targets.

1. To concentrate on the possibility of consolidating high RAP content in SMA combinations utilizing rejuvenators.
2. To assess the impact of RAP content, rejuvenator type, and their measurements in the blend plan and assess the presence of combinations.
3. To decide the measurable meaning of RAP content, rejuvenator type, and dose on the presentation of blends.
4. To assess the degree of connection between the RAP and the rejuvenator utilizing microstructure portrayal.

II. LITERATURE REVIEW

Bituminous combinations are one of the fundamental cleaning materials in street development. As of now, all around the world, 90 % of the streets are cleared with bituminous combinations (Chong et al., 2018; Mangum, 2006) due to their economy, fantastic execution, mature innovation in development and support, and so forth. Around 9 million km (approx.) in length in the USA and Europe, 8 million km (approx.) in length in Asia, around 0.35 million km (approx.) length in South America, and 0.1 million km length (approx.) in Australian streets with bituminous combinations (EAPA, 2011, 2016). Bituminous combinations are indeed comprised of two materials, i.e., bitumen and totals. The bitumen displays a rate subordinate reaction and ties the totals together (Bukowski, 1997). The totals are comprised of regular stone, rock, or sand, and are hard materials, which give strength and solidness to the asphalt. Be that as it may, the development of asphalts requires a huge amount of bitumen and totals, which are nonrenewable and costly. Accordingly, measures ought to be taken to diminish the utilization of bitumen and total (Giustozzi et al., 2015; Huang et al., 2005).

1. Development of RAP

The development of RAP consolidation into bituminous combinations was begun during the 1970s, as displayed in Fig. 2.1. Because of the expansion in the bitumen and total costs, the analysts are doing a broad examination to utilize RAP. According to the Public Black-top Asphalt Affiliation (NAPA) and European Black-top Asphalt Affiliation (EAPA) reports, around 90 % of RAP is consolidated in the bituminous combinations in both the US and Europe. In a couple of created nations, the use of RAP in bituminous blend is extremely well known and they are executing their own blend plan rules. In emerging nations, the use of RAP has not accomplished a lot of consideration because of the absence of a blended plan, rules, mixing interaction, and assembling methods. Nonetheless, the expansion in the examination and improvement might expand the act of RAP joining in bituminous blends.

2. RAP Mixing process

Notably, RAP contains matured cover over totals; the presence of matured fasteners builds firmness. During development and administration life, the bituminous blends are presented with different ecological circumstances and go through the maturing system (Navaro etal., 2012). The maturing of bitumen is connected with five significant instruments oxidation, volatilization, polymerization, thixotropy, and syneresis. Bitumen goes through two sorts of maturing systems, specifically momentary maturing and long-haul maturing. Momentary maturing happens during the hour of development when bitumen is presented with high temperature, which changes the thickness, rheology, and physicochemical properties viz., shear modulus and bond.

3. The exploration inferred that low RAP content

Combinations displayed properties nearer to finish mixing, while high RAP content combinations showed halfway mixing. A couple of specialists presumed that the main 80 - 90 % of matured cover partakes in the mixing system and the excess will be latent (Huang et al., 2005; Oliver, 2001; Stephens et al., 2001). Liphardt et al. (2015) found that all-out mixing is expected assuming the level of mixing is higher than 85 %. As a general rule, mixing is a communication between RAP and virgin material and gives homogeneity in the blend. It is a mind-boggling

cycle to accomplish, as a result of fluctuation in the material properties (Chen et al., 2014).

Hence, a legitimate determination of RAP content is required to create a steady blend. Huang et al. (2005) expressed that an inappropriate mixing interaction would influence the presentation of the bituminous combinations. A few exploration studies have shown that the level of the mixing system relies upon the RAP content, blending cycle, time, and temperature. For the most part, the expansion in the blending time and temperature will improve the mixing system and produces a steady combination (Zaumanis et al., 2015; Groves et al., 2014; McDaniel et al., 2012). Nonetheless, the higher temperature ought to be kept away from, it because it will prompt further maturing of the matured folio. Hence, a satisfactory temperature is expected to further develop the mixing system.

3. Rejuvenators

A rejuvenator is an added substance that goes about as an impetus and disintegrates/weakens the matured folio (Mangiafico et al., 2016; Terrel, 1989). Lately, rejuvenators are effective because of their phenomenal exhibition. To produce or choose an exhaustive rejuvenator, it needs to meet explicit fundamental models like it ought to diffuse with the matured fastener right away, ii) it ought to work on the usefulness, iii) give a uniform covering and homogenous blend, and iv) it shouldn't filter from the asphalt during administration life (Arambula-Mercado ' et al., 2018; Craftsman et al., 1980).

A few specialists guaranteed that the rejuvenator's dissemination cycle will oversee the rutting and weariness obstruction. Rejuvenators will diffuse into the bituminous combinations in two phases: present moment and long-haul dissemination processes (Mallick and Straightforward, 2016). The momentary dispersion happens quickly during the blending and compaction process. It relaxes the matured folio and decreases its thickness. Momentary dispersion should be finished before permitting the traffic.

Use of rejuvenator

The proper blending interaction will guarantee uniform covering and homogeneity. Conversely, ill-advised blending will lessen the viability of rejuvenators and insome cases lead to agglomeration. At this point, numerous nonexclusive blending processes are followed (Nabizadeh et al., 2017; Liphardt et al., 2015). A couple of scientists followed the immediate use of rejuvenators to the RAP as a superior choice, wherein the rejuvenators can without much of a stretch coat the RAP total consistently (Su et al., 2015; Dony et al., 2013). It is trusted that the use of a rejuvenator to the consolidated total at the blending temperature is the best cycle and this can be handily presented in the assembling system (Baghaee Moghaddam 9 and Baaj, 2016). Aside from the blending system, the blending temperature and time are similarly significant. At blending temperature, the matured fastener loses its bond property and eliminates the RAP total. Further expansion of the rejuvenator will forestall the deficiency of the matured fastener and increase the covering instrument. Overheating ought to stay away from since that prompts untimely oxidation of the matured folio (ArrMaz, 2017; Tran et al., 2012).

2.1 Execution of RAP combinations

It is influential to know the field and lab exhibitions of the RAP blends because occasionally the research facility execution might vary from the field execution (Kandhal and Mallick, 1997). A few scientists effectively integrated RAP into bituminous blends and reasoned that the exhibition of RAP combinations is like virgin bituminous combinations (Zaumanis and Mallick, 2015; Chen et al., 2009; McDaniel et al., 2000). The asphalt test areas with 45 % RAP content were decided to assess execution, and the outcomes showed just 3 mm of rutting in the following two years. (Kandhal and Mallick, 1998) assessed the field execution of asphalt test segments with 10 - 25 % RAP content and announced no indication of rutting and exhaustion breaking. The lab studies are essential to get to the rutting, warm breaking, dampness, and weariness obstruction of the RAP combinations West (2009). Al-Qadi et al. (2007) showed that the mechanical properties of the RAP blend are practically identical to the regular combination.

The strong modulus values of up to 20 % RAP content are practically equivalent to the virgin blend (Stimilli 13 et al., 2017; Pradyumna and Jain, 2016). In any case, a couple of scientists noticed that RAP combinations neglected to further develop the exhaustion obstruction and total strain rate (Poulikakos et al., 2014; Sebaaly et al., 2-14; Huang et al., 2005). It is noted from past examinations that the greater part of the announced research center execution tests is directed at thick evaluated combinations. 2.4 Stone Network Black-top In 1960, German designer Dr. Zichner concocted the SMA combination to further develop the rutting opposition and administration life under weighty traffic load on the asphalt.

2.2 Stone-on-Stone contact

The blending plan of the SMA combinations is practically like the thick reviewed combinations. Nonetheless, slight changes are made in the degree, volumetric properties, folio content, channel down, and at times the Marshall properties moreover. Every nation for the most part follows its blend plan methodology, created concerning traffic, natural and geological circumstances. Germany fostered a strategy given assessing volumetric properties viz., Voids in Mineral Total (VMA), unit weight, Va, and fastener content. The Va and fastener content are utilized as the determination prerequisites to decide the OBC esteem (Sarang et al., 2014). In the US particulars, the SMA blend configuration depends on guaranteeing stone-

on-stone contact of the coarse totals (Brown and Mallick, 1994).

III. METHODOLOGY AND MATERIALS

The methodology is a systematic way to achieve the stated research objectives and this research is intended to incorporate RAP in the SMA mixtures using different rejuvenators along with several constituent materials and the mixtures performances are evaluated experimentally. The materials used to manufacture the laboratory specimens are: i) RAP ii) VA iii) stabilizing agent iv) rejuvenators and v) bitumen. In this research, all the specimens are prepared in the laboratory by blending, mixing, and compacting all the constituent materials. Detailed descriptions of methodology and materials characteristics are presented in this chapter. 3.1 Methodology Fig. 3.1 shows the flow chart of the methodology adopted in the research. The research work started with the collection of the materials by conducting a preliminary investigation. In the first stage, research is carried out to determine the volumetric properties and OBC of each mixture combination. In the second stage, the performances of all mixture combinations are evaluated.

The performance tests conducted in this research are Marshall 24 stability (MS), moisture susceptibility tests viz. boiling test, RMS and TSR, and Semi-Circular Bending (SCB) test which evaluates TS, FE, and FI. In the third stage, the microstructure characterizations are performed to evaluate the rejuvenator's effectiveness. Finally, a cost analysis is carried out to evaluate the savings obtained by the utilization of RAP and rejuvenators in SMA mixtures. A sum of 65 blends are thought of and to improve on the ID, combinations are separated into three gatherings viz. CM non-endlessly revived combinations. Note: even though CH3)2CO is utilized as a dissolvable in this examination, it is alluded to as a rejuvenator as well as CH3)2CO revived blends for the simplicity of perusing.

3.3 RAP:
The RAP is obtained from a close-by quarry at Vandaluru quarry, Vengambakkam timberland zone, Chennai. It is processed from the asphalt segment and put away in the bituminous plant as a store as displayed in Fig 3.2. A solitary wellspring of RAP material is utilized in this examination. The visual review showed that RAP contains a few pollutants like glass, paper, plastic sherds, dried leaves, and so on, thusly, it is screened before use. The bigger lumps are separated into more modest sizes, to meet the total degree. The actual properties of the RAP are examined concerning degree, water assimilation, explicit gravity, strength, and sturdiness. The RAP is air-dried at room temperature at 25 ± 2 C for 5 - 7 days and sifter examination is performed broadcasting in real time dried example according to IS 2386 section 1.

3.3 Bitumen:
In this exploration, Consistency Grade (VG) - 30-grade bitumen is utilized. This bitumen level is reasonable for high-traffic volume streets in tropical climatic circumstances. The consistency of the bitumen is assessing its smoothness and protection from the stream at a 29 predetermined temperature. The infiltration test is directed to decide the consistency and application temperature of bitumen. The conditioning point test is performed utilizing a ring and ball contraption to assess the temperature at which the bitumen relaxes. The malleability test is deciding the cement and plastic twisting properties of bitumen.

3.6 Stabilizing agent
A pelletized cellulose fibre (TOPCEL cellulose fibre), which is made up of natural cellulose, is used as a stabilizing agent (shown in Fig. 3.4). The physical properties of the cellulose fibre are tested as per IRC SO 79-2008 specification.

3.7 Rejuvenator
Rejuvenators are utilized to lessen the firmness of the matured cover andto work on the usefulness of the bituminous blends. In this exploration, four distinct rejuvenators and one dissolvable in particular WVO, WEO, WG, POS, and CH3)2CO are utilized separately. The WVO, WG, and POS are natural-based items, though, WEO is a petrol-based item, and CH3)2CO is a compound item.

IV.COST ANALYSIS

Pavement performance enhancement and economic and environmental benefits have encouraged the pavement industry to incorporate RAP into SMA mixtures. This analysis aims to showcase the direct economic benefits of RAP incorporation into SMA mixtures. In this cost analysis, the manufacturing and construction costs of CM with non rejuvenated and rejuvenated mixtures are compared. The outcome of these cost analyses is useful for researchers, policymakers, and field engineers.

The cost analysis has given trivial information related to materials and mixtures. So, it is substantial to consider relevant factors of cost analysis and opting an appropriate method of analysis. Accordingly, materials along with transportation, necessary machinery, labor, and miscellaneous costs are considered. Production cost includes the hiring of equipment, transportation of materials, fuel, contractor profit, and miscellaneous charges. The standard conditions to produce bituminous mixtures are assumed in this cost analysis. The average production capacity and running time of the plant are taken as 75 TPH and 6 hours respectively as per the literature review and field survey. Therefore, an average of 450 tons of bituminous mixture is produced from a plant per day. Accordingly, the production, transportation, and laying costs are evaluated for 450 tons of bituminous

mixture. The material, labor, transportation, manufacturing, laying, and contractor profit are taken as per SSR (CPWD- SSR, 2019).

V.CONCLUSION

The extent of this examination is to consolidate high RAP content in the SMA combination by utilizing rejuvenators. To documents, orderly research facility tests are performed by differing the RAP content (at four levels 10, 20, 30, and 40 % by weight of the 35 total), restoring specialist and its measurement (0, 3, 6, and 9 % by weight of the folio). To assess the adequacy of rejuvenators on the RAP integrated SMA combinations four different reviving specialists viz. WVO, WEO, WE, WG POS, and one dissolvable CH3)2CO are utilized. Through these tests, the cooperations of RAP and rejuvenators with virgin materials are concentrated on execution-based properties and microstructural portrayal. The presentation-based properties assessed in this examination incorporate channel down, volumetric properties, Marshall properties, dampness weakness, and break qualities.

The Marshall properties estimated the strength and adaptability of the combinations including MS, FV, and MQ values. The crack attributes are assessed as the break properties of combinations utilizing TS, FE, and FI values. The break properties showed up by directing the SCB test on 100 mm distance across Marshall examples. In this examination, three dampness vulnerability tests viz. the bubbling test, RMS test, and TSR test are performed. The outcomes from the microstructure investigation further assisted with fortifying the ends drawn from execution-based properties. In conclusion, an expense examination is performed to look at the immediate money-saving advantages of RAP and rejuvenator joining. The result of the exploration uncovers that the fuse of the RAP has improved the exhibition of the SMA combinations. Yet, blends with RAP content up to 20 % with no rejuvenators have performed uncommonly well and introduced great dampness and breaking obstruction.

Notwithstanding, combinations with RAP content past 20 % 118 have shown irregularity in execution on account of an expansion in firmness. Consequently, reviving specialist is expected to decrease the solidness and that allowing high RAP content in the blends. Anyway, the proper dose of rejuvenator is essential to create stable blends. Both over and under measurements decrease the exhibition of the combination. It is feasible to integrate up to 40 % RAP content into the SMA combination with a 6 % rejuvenator dose. In general, it is seen that 30 % RAP satisfied with a 6 % rejuvenator dose is an ideal mix to create a prevalent combination. The accompanying significant ends and suggestions are drawn from the current exploration work:

- It is attainable to consolidate RAP (up to 40 %) in SMA without sabotaging the degree and stone-on-stone contact.
- The joining of RAP and rejuvenators altogether decline the OBC esteem.
- Among four rejuvenators, WVO and WEO can allow up to 40 % RAP content, while WG and POS are fruitful with up to 30 % RAP content. CH3)2CO further develops the dampness opposition yet neglects to give adaptability to the blends, which might prompt embrittlement of the SMA combination.
- The expansion of rejuvenators works on the dampness and crack obstruction of the RAP consolidated SMA combinations.
- The rejuvenator measurement is at risk on RAP content; the higher the RAP content, the higher the rejuvenator dose as well as the other way around. Draining of the rejuvenator is noticed for 9 % of measurements, which ought to be deflected.
- In this examination, 6 % of WVO, WEO, WG, and POS, and 9 % of CH3)2CO is considered as 30 % RAP content and 6 % WVO blend is awesome among all combinations.
- Crack obstruction of the blends presumed that WVO and WEO combinations performed well and further developed the break attributes though, WG and POS blends have worked on the FE yet neglected to improve the FI worth, and that can prompt execution issues. Subsequently, the determination of the best-performing rejuvenator type and its measurement should depend on each of the three reaction factors (TS, FE, and FI).
- Microstructural studies show that rejuvenators modify the compound synthesis and upgraded matured folio ease. The WVO and WEO rejuvenators showed better execution towards the equivalent when contrasted with the other rejuvenators.
- It is reasoned that rejuvenator measurements are subject to many factors, for example, rejuvenator type, nature of rejuvenator, and RAP content. Even though a rejuvenator is great, its ill-advised measurements will decrease its presentation. The expense examination shows that a net direct saving of around 12 % can be accomplished by utilizing 40 % RAP satisfied with a 9 % measurement of WVO or WEO.

Future degree

1. Every one of the tests is performed on the single wellspring of RAP and rejuvenators, it is proposed to direct on the various sources, to comprehend the consistency in the experimental outcomes.
2. It is prescribed to review the microstructure with other RAP sizes to check the consistency in the experimental outcomes.
3. The microstructure concentrates on the RAP particles under 75 µ ought to be investigated to know the rejuvenator adequacy and maturing conduct of the RAP. Since the 75 µ are extremely fine particles and that might give a few important bits of knowledge.

4. The presentation tests for properties, for example, rutting obstruction and exhaustion conduct can be led to dissect the combination conduct towards something very similar.
5. The exploration of the CH3)2CO as a rejuvenator is required to have been assessed solely since the expansion of CH3)2CO has shown a few intriguing outcomes.
6. Long-haul field-scale research is fundamental for reinforcing the trial finding of RAP joining in SMA combinations.

REFERENCES

[1] Foroutan Mirhosseini, Ali, Seyed Amid Tahami, Inge Hoff, Samer Dessouky, and Chun-Hsing Ho. "Performance Evaluation of Asphalt Mixtures Containing High-RAP Binder Content and Bio-Oil Rejuvenator." Construction and Building Materials 227 (December 2019): 116465. doi: 10.1016/j.conbuildmat.2019.07.191.

[2] Dinis-Almeida, Marisa, João Castro-Gomes, Cesare Sangiorgi, Salah E. Zoorob, and Márcia Lopes Afonso. "Performance of Warm Mix Recycled Asphalt Containing up to 100% RAP." Construction and Building Materials 112 (June 2016): 1–6. doi: 10.1016/j.conbuildmat.2016.02.108.

[3] Hussain, Arshad, and Qiu Yanjun. "Effect of Reclaimed Asphalt Pavement on the Properties of Asphalt Binders." Procedia Engineering 54 (2013): 840–850. doi: 10.1016/j.proeng.2013.03.077.

[4] Saride, Sireesh, Deepti Avirneni, and Sarath Chandra Prasad Javvadi. "Utilization of Reclaimed Asphalt Pavements in Indian Low-Volume Roads." Journal of Materials in Civil Engineering 28, no. 2 (February 2016): 04015107. doi:10.1061/(asce)mt.1943-5533.0001374.

[5] Al-Saffar, Zaid Hazim, Haryati Yaacob, Mohd Khairul Idham Mohd Satar, and Ramadhansyah Putra Jaya. "The Tailored Traits of Reclaimed Asphalt Pavement Incorporating Maltene: Performance Analyses." International Journal of Pavement Engineering (September 23, 2020): 1–14. doi:10.1080/10298436.2020.1824294.

[6] Li, Xinjun, Mihai O. Marasteanu, R. Christopher Williams, and Timothy R. Clyne. "Effect of Reclaimed Asphalt Pavement (Proportion and Type) and Binder Grade on Asphalt Mixtures." Transportation Research Record: Journal of the Transportation Research Board 2051, no. 1 (January 2008): 90–97. doi:10.3141/2051-11. [

7] Huang, Baoshan, Guoqiang Li, Dragan Vukosavljevic, Xiang Shu, and Brian K. Egan. "Laboratory Investigation of Mixing Hot-Mix Asphalt with Reclaimed Asphalt Pavement." Transportation Research Record: Journal of the Transportation Research Board 1929, no. 1 (January 2005): 37–45. doi:10.1177/0361198105192900105.

[8] Xie, Zhaoxing, Hashim Rizvi, Caitlin Purdy, Ayman Ali, and Yusuf Mehta. "Effect of Rejuvenator Types and Mixing Procedures on Volumetric Properties of Asphalt Mixtures with 50% RAP." Construction and Building Materials 218 (September 2019): 457–464. doi: 10.1016/j.conbuildmat.2019.05.093.

[9] Milad, Abdalrhman, Aizat Mohd Taib, Abobaker G. F Ahmeda, Mohmed Solla, and Nur Izzi Md Yusoff. "A Review of the Use of Reclaimed Asphalt Pavement for Road Paving Applications." Jurnal Teknologi 82, no. 3 (April 6, 2020). doi:10.11113/jt.v82.14320.

[10] Cao, Xinxin, Hao Wang, Xuejuan Cao, Wei Sun, Hongzhou Zhu, and Boming Tang. "Investigation of Rheological and Chemical Properties Asphalt Binder Rejuvenated with Waste Vegetable Oil." Construction and Building Materials 180 (August 2018):