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(Review)

A Review of Sustainability by Utilization of Reclaimed Asphalt Pavement in Both Concrete and Pavement Application

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ABSTRACT

Urban expansion and extending road networks to cover larger areas consume many natural resources, as they need aggregate from quarries and bitumen in the case of flexible pavement or cement in the case of rigid pavement. Bitumen extraction is difficult due to the complexity of its extraction process and the consumption of a large amount of oil. This is in addition to the environmental damage, whether from the manufacture of bitumen or cement. In recent years, all countries have been interested in sustainability and preserving natural resources. So, research has been directed to study how to take advantage of the waste and recycle it in engineering. RAP is among the most important wastes, as many studies have been conducted to reuse it in engineering applications, whether pavement or concrete. This research sheds light on RAP based on previous researches, from obtaining it to reusing it. RAP can be used in the road field by partially or completely replacing the new asphalt mixture. To ensure the revitalization of the rap, rejuvenating agents are added during the mixing process. Studies have indicated that using RAP in pavement has 4 different techniques: HMIR, HIR, CIR, and FDR. As for the results of its use in pavement application, it was found to reduce rack resistance, fatigue life,

shear strength of soil, and CBR of soil. On the contrary, it increases the resistance modulus and decreases the rutting. In concrete applications, RAP decreases the workability, compressive strength, flexural strength, and indirect tensile strength; on the contrary, it increases the toughness of concrete.

Keywords: Recycling, RAP, Rejuvenator, Virgin binder.

1- Introduction

Recently, the trend of recycling materials has become necessary to create a balance in the environment and preserve natural resources. As construction expands, road networks increase and upgrade its efficiency, the overall trend of most current research is to find innovative sustainability solutions. Federal Highway Administration (FHWA) states that about 100 million tons of hot asphalt mix are milled annually [1]. In recent years, all worlds have encouraged increased RAP application in both asphalt mixture and cement concrete to provide natural resources and preserve the environment while reducing production cost [2-6]. The use of RAP in new asphalt mixtures is a very economical means as it is possible to utilize the bitumen extracted from the old asphalt mixture and reuse it in new asphalt mixtures, which reduces the percentage of the required new bitumen for the mixture in addition to the possibility of using the old aggregate itself in new mixtures [7-12]. To restore the rheological properties of recycled bitumen (aged bitumen) in the new asphalt mixture, a new softer agent is used during mixtures containing RAP to enhance the mixture's softening and improve the mixture properties [13-14].

2- Reclaimed asphalt pavement (RAP)

2.1- Definition

When maintaining roads, re-paving the surface layer of roads, re-leveling the asphalt surface, or accessing public utilities buried under the road, all of this requires the removal part of the surface layer of the road. The result of that removal is called the reclaimed asphalt pavement. There are two methods to obtain the waste; the first: by milling the surface of the pavement using a milling machine, in which a part of the surface layer is removed by 5 cm in one pass of the machine. The second method is full-depth removal, in which the pavement is broken and torn using a machine called a rhino horn or bulldozer and often the crushing products are transported in trucks to be processed in central facilities and rehabilitated for reuse [1].

RAP is the outcome of the removal of the asphalt paving and is considered the main recycled material in the new asphalt mixture. As shown in Figure 1, the milling machine breaks and crumbles the existing distressed and aged paving layer that is to be removed into separate small pieces by the blades continuously cutting the paving to form RAP, as shown in Figure 2 [15-16].

Figure 1. Asphalt Milling Machine and Dump Trailer [16].

Figure 2. Reclaimed asphalt pavement (RAP) [17].

2.2- History of RAP

Since 1915, RAP has been included in recycled asphalt mixtures, consistent with the general trend to preserve the environment and reduce production costs [18]. In 1970, with restrictions imposed on the supply of Arab oil, which led to an increase in the price of Arab oil, the use of RAP became desirable and required. Accordingly, developing the use of RAP technology and improving its efficiency in asphalt mixtures has become necessary to meet the need for bitumen while reducing the mixture production cost. Until now, most of these methods

of development are still being used. Superpave system made basic principles for developing the use of RAP to improve the SuperPave guidelines. Despite this, in the late nineties, the American State Transportation Departments (ASTD) used RAP in asphalt mixtures for many years before approving the super pave design method [12].

2.3- Extraction process of bitumen for RAP

when using new asphalt mixtures having a large amount of RAP, it is necessary to add materials that refresh the aged bitumen in RAP, which easiest the process of bonding the RAP with the components of the new mixture; these materials are called virgin binder or rejuvenators [19]. The extraction process of bitumen from RAP separates the bitumen existing in the RAP from the constituent materials for the mixture. There are two common methods to conduct the extraction process, namely:

i) Solvent Method

ii) Ignition Method

i) Solvent Method

In this method, the RAP mixture is heated at a temperature of about 100˚c. It is grinned and separated into small pieces to increase its surface area. It is exposed to chemical solvents and then soaked in one of them for a period. This process is repeated several times until the RAP is almost clean of aged bitumen, as shown in Figure 3. After that, the solvent bitumen is treated inside the rota vapour to separate the solvent and recover the aged bitumen as shown in Figure 4 [20].

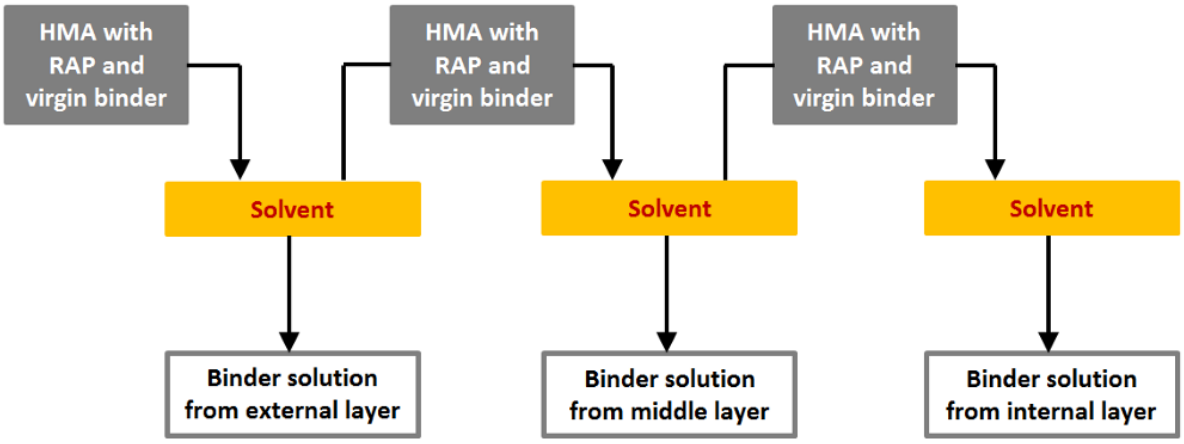


Figure 3. Scheme of the multistep extraction process of HMA with RAP [20]

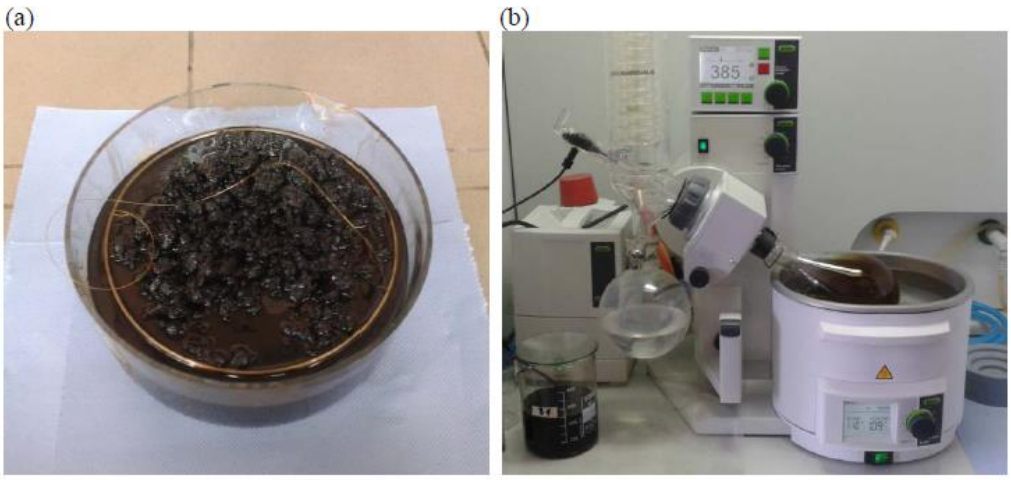


Figure 4. Extraction and binder recovery: **(a)** HMA immersed in solvent, **(b)** binder recovery in rotavapor [20]

Two of the most common of these chemical solvents are methylene chloride trichloroethylene (TCE) and methylene chloride trichloroethane (TCA), but because of the hazards of solvents included Hydrochlorofluorocarbon (HCFC) or chlorofluorocarbon (CFC) in its molecular composition on the environment, the American Clean Air Act and Montreal Protocols require the gradual disposal of these solvents, which makes it difficult for their continuously use and makes it a complicated process. Accordingly, ignition method is used much more than solvent method [21].

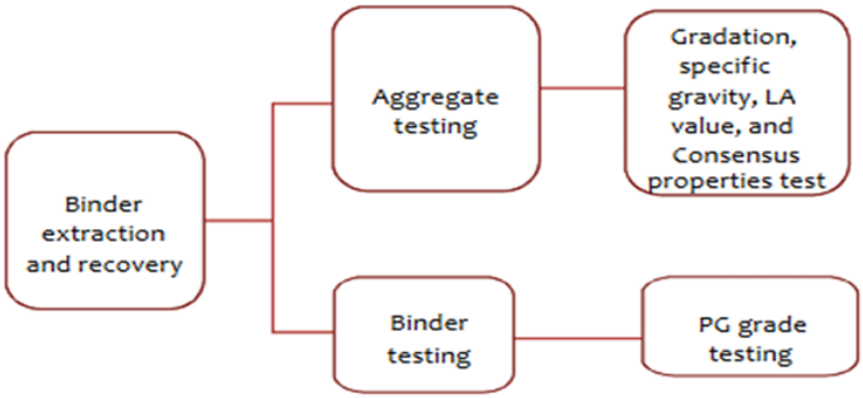
ii) Ignition Method

This method, according to ASTM D-6307, the asphalt RAP is dried at a temperature of 110˚c ± 5˚c. The sample is placed in a test oven, as shown in Figure 5, at a low temperature after being evenly distributed inside the oven container. The weight of the sample is recorded to the nearest 0.1 gm. The oven temperature is quickly raised to the required temperature, which is 540˚c. By means of oven measurements, the weight of the sample is recorded every minute. The weight is approved when the difference between three consecutive weights does not exceed 0.01 gm. Then, the aged binder is calculated as the ratio between the difference in weight before and after ignition and the weight before ignition [21].

Figure 5. Thermolyne ignition oven [21]

2.4- Blending RAP with virgin bitumen

The homogeneity of the mixture between RAP and virgin binder is the most important factor that affects the quality of the performance of the hot asphalt mixture. The effect of using RAP with new asphalt is insignificant and can be neglected if the ratio of the RAP ranges about 10% of the total weight of the mixture. Still, if that percentage increases to about 40% or more, the effect on the performance of the hot asphalt mixture becomes clear [22]. To ensure a good quality and homogeneity mixture, the blending process could be throwing pass three stages as shown in Figure 6 [23]. This effect can be seen in the behaviour of the aged binder as a black rock and does not participate in the blending process, which requires the designer, in some cases, to change the grade of bitumen [24].



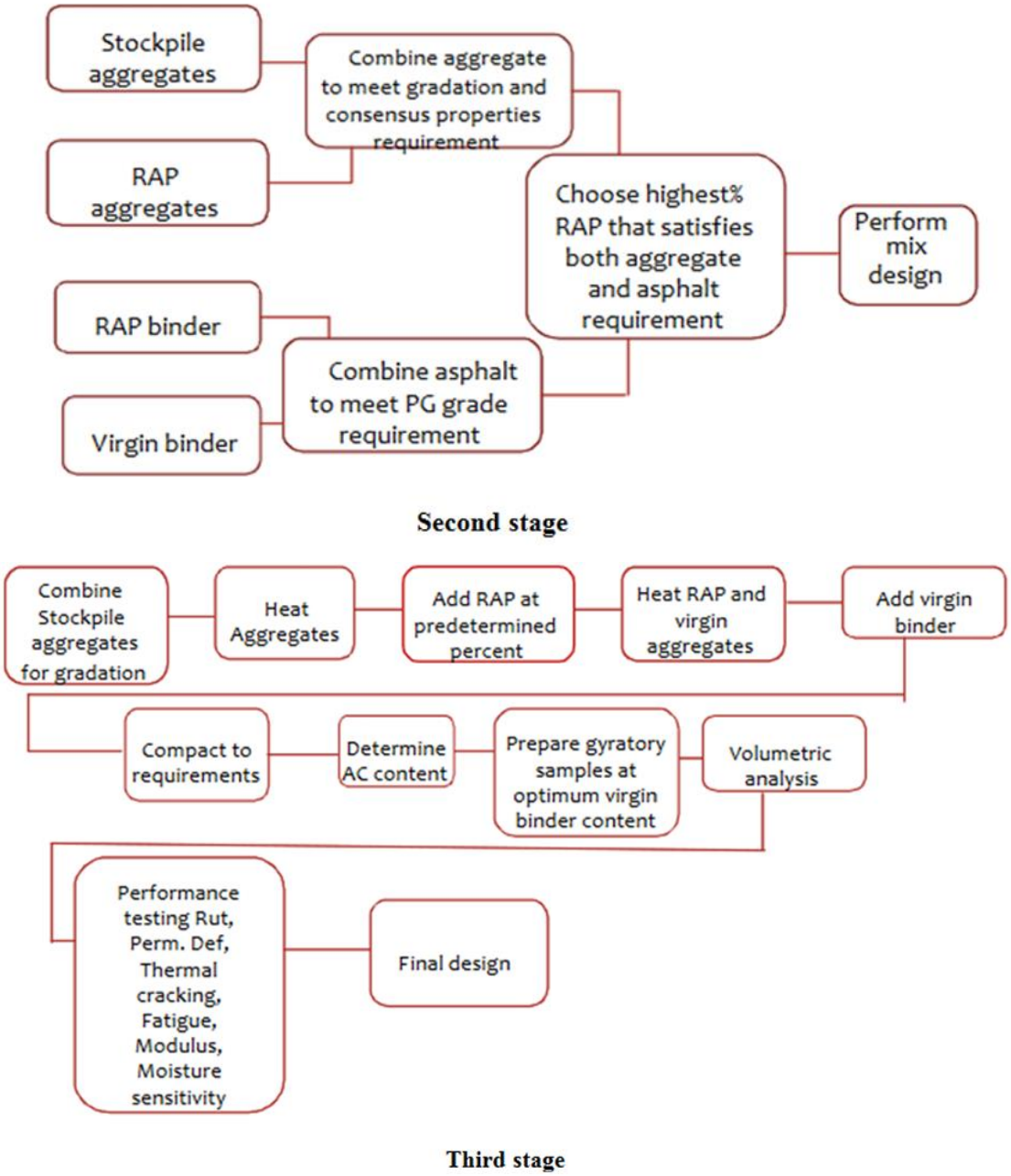


Figure 6. Blending Processes of RAP Source [23].

While blending the RAP with the virgin asphalt, theoretically, the outer membrane of the final mixture should be the product of the union of both outer membranes of the virgin bitumen and bitumen inside RAP. However, what urges is contrary to that; according to previous research at the beginning of the blending process, the virgin bitumen forms an outer membrane around the granules of the RAP without interaction with each other as shown in Figure 7 [20].

During the blending process, dispersion phenomenon, shear force, and friction between all mixture particles help interact with membranes [25-26]. Cause of this problem is still under study, and there are no clear rules for the effect of this partial blending on the properties of the hot asphalt mixture. Therefore, it is necessary to develop the blending process to ensure that the membranes interact and merge completely [20].

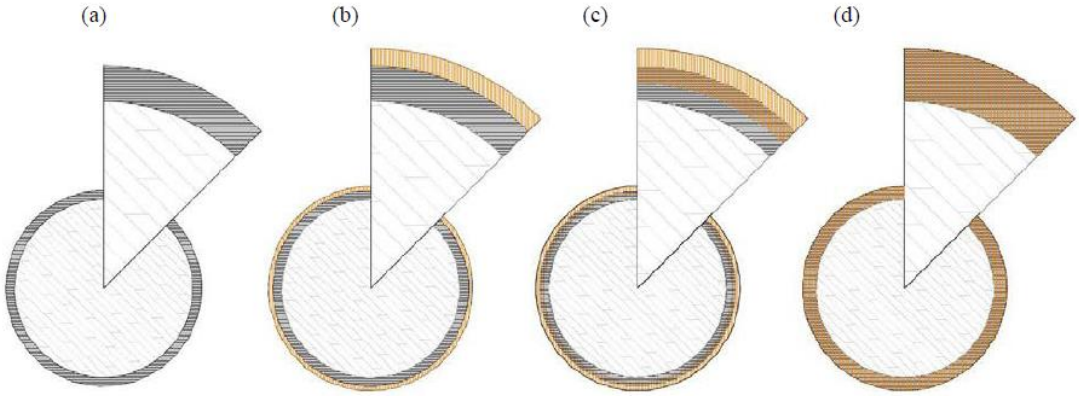


Figure 7. Different stage of diffusion of binder film covering RAP: (a) RAP with only binder membrane; (b) RAP + virgin binder, no blending; (c) RAP + virgin binder, partial blending; (d) RAP + virgin binder, total blending [20]

2.5- Rejuvenators

Rejuvenators refer to organic materials with physical and chemical properties that help aged bitumen restore its lost and required properties [19]. Rejuvenators can be divided into two main categories: bio-based rejuvenators and petroleum-based rejuvenators [27-28]. Bitumen can be described as a composite polymeric material prepared by difficult and complex processes. The bitumen consists of a stable component with high molecular weight, which represents the binder structure called asphaltenes, which spread within a more oxidable oily medium has less molecular weight called maltenes and is responsible for retaining the binder with its strength and flexibility [29-30]. During the stages of road construction, in addition to the operation period, some oils in the bitumen material volatilize. Accordingly, an imbalance occurs in the ratio between the asphaltenes and the maltenes, affecting the mixture's properties, thus decreasing the ductility and increasing the stiffness and viscosity [13]. Many types of rejuvenator agents are used in the market such as Tall oils, Triglycerides, Paraffinic oils, Naphthenic oils, Fatty Acids, and Aromatic extract [31]. Different types of rejuvenator agents can be collected and categorized as illustrated in Table 1.

Table 1. Categorization of rejuvenators into groups (1 to 6) by origin [32]

Origin	Originally manufactured or derived	Recycling of waste
From the petrochemical industry/ petroleum	1- Aromatic extracts and naphthenic oils derived from petroleum	2- Waste-derived oils: recycling of machine oils
Vegetal/biological	3- Vegetal oils from agroindustry 4- Engineered bio-based oils (e.g. tall oil derivatives))	5- Waste-derived oils: recycling of food oils
Residual category	6- Various specifically engineered additives	

The percentage of adding a rejuvenator in the RAP mixture depends on the properties of both the aged bitumen and the type of rejuvenator used to ensure obtaining a homogeneous mixture [32]. There are different stages at which the rejuvenator can be added to the RAP mixture, as shown in Figure 8. Knowing that the common stages in which implementation are carried out in the market are location 10, location 8, and location 3 on Figure 8 [33]. Figure 9 shows the rejuvenator spraying on the RAP in location 3 [34].

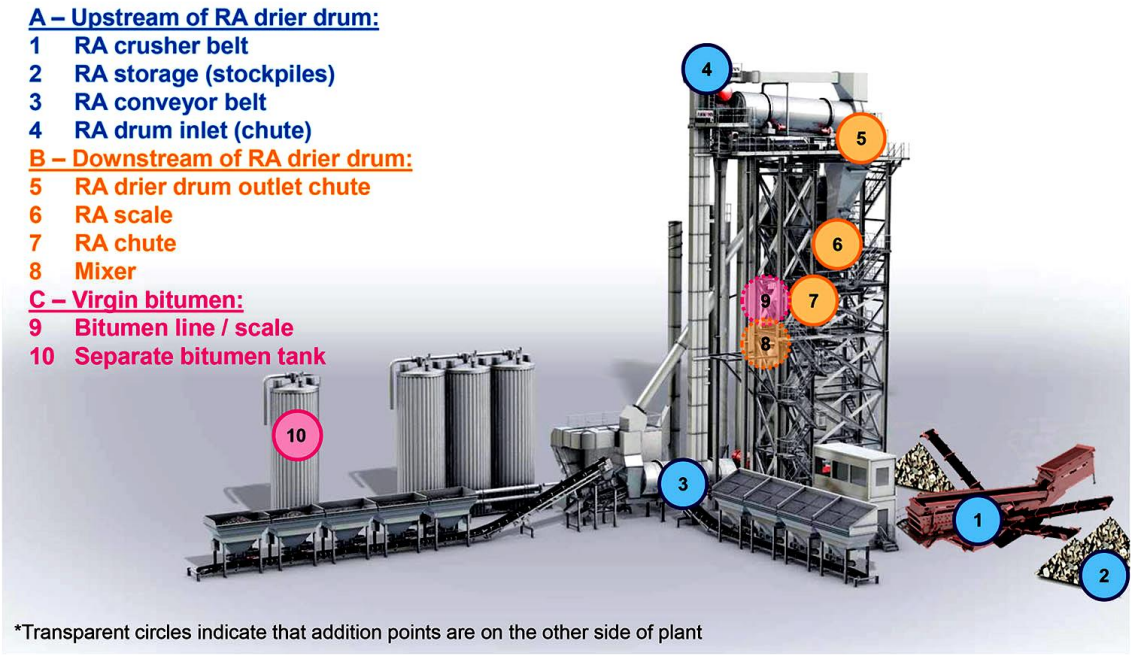


Figure 8. Schematic illustration of the various methods by which, or the locations at which, a rejuvenator can be added during asphalt production [33].

Figure 9: Rejuvenator addition to RA on the conveyor belt utilizing a spraying system [34].

3- RAP Characterization

Over time and the approaching end of the operating period for which the road was designed, both the aggregate and the bitumen inside the rap are still usable. It is possible to conserve environmental resources by reusing the RAP again, either in concrete or in the field of roads, whether in re-paving or using it in the sub-base layers [35]. The properties of the new asphalt mixture that contains RAP depend on the properties of both the aggregate and the aged bitumen present in it, so various tests must be done on the used RAP to know its effect on the new mixture, such as sieve analysis, toughness, specific gravity, moisture content, and sand equivalence [36]. Previous research has shown that the effect of using RAP inside hot asphalt mixes on the mechanical properties of these mixes, such as tensile strength and stiffness, is either the same as or better than the mixture without it [37-38]. Also, using RAP in the hot asphalt mix improves the capability of the mix to fatigue, resilience, rutting, and creep [19].

4- RAP benefits

In 2021, the amount of re-used RAP in asphalt mixtures reached 94.6 million tons, an increase of 8.74% from the previous year, while the number of asphalt shingles used became 630,000 tons, an increase of 8% [39]. The benefits of using rap are not limited to the economic aspect; they can be summarized in terms of economic, environmental, and engineering benefits.

4.1- Economical Benefits

Bitumen is the highest-priced component in the asphalt mixture. Accordingly, the re-use of the aged bitumen in RAP with rejuvenators helps reduce the new mixture's production cost.

The cost can also be reduced further by using a proportion of the rap with the new mixture and revitalizing it with a small dose of virgin bitumen and rejuvenators. All this helps to reduce the cost of producing the mixture. The cost of transportation can also be reduced by new equipment and technologies that do the whole process on-site.

4.2- Environmental Benefits

Bitumen is produced from petroleum distillation in a series of processes that require high energy. The traditional paving method uses hot asphalt mixtures, where the aggregates are dried, and the bitumen is heated, which consumes high energy and emits many harmful pollutants and greenhouse gases. In addition to transporting the aggregate large distances to the mixing stations, transporting the mixture from the mixing stations to the paving site results in the burning of large quantities of fuel and the emission of pollutants. The use of rap provides proportions of bitumen, and new technology helps to complete the work on site, which reduce transportation pollutants [19]. In 2021, the use of rap in asphalt mixtures reduced gas emissions by 2.6 Million Metric Tons (MMT) more than the previous year by 0.3MMT. Also in 2021, 26 million barrels of virgin bitumen were provided, an increase of 2 million barrels over the previous year [39].

4.3- Engineering benefits

The use of rap within asphalt mixtures enhances its mechanical properties. The use of rap improves the performance of the mixture and increases the stiffness and viscosity. It increases the rutting resistance, which reduces the required repairs and maintenance.

5- Applications of RAP

5.1- Using RAP in concrete

While 80% of the RAP is reused in asphalt applications, many researchers study the reuse of the RAP within concrete mixtures as a substitute for the aggregates [40]. The performance of the RAP-concrete mix depends on the quality of the RAP properties, such as crushing strength, Impact resistance, Abrasion Resistance, and density [6]. Several researchers have studied these properties; Table 2 represents an average of these results.

Table 2. Properties of RAP [41-45].

	Properties	**COARSE RAP**	**FINE RAP**
1	Specific Gravity	2.2-2.6	2.2-2.6
2	Absorption (%)	1.8-2.9	1.8-2.8

3	Bulk density (Kg/m3)	1940-2300	1600-2200
4	Crushing value (%)	16-20	-
5	Impact value (%)	4.3-33	-
6	Abrasion resistance (%)	18-30	-

The results show that the specific gravity of RAP is lower than the virgin aggregate, while the absorption is higher. Also, the mechanical properties of RAP are similar with virgin aggregate. Also, according to previous research, the chemical composition of RAP is identical to that of virgin aggregate, as illustrated in Table 3.

Table 3. Chemical composition of RAP aggregates [46].

Element compound	**Test result (% by weight)**
SiO_2	38
Fe_2O_3	26.8
CaO	16.3
Al_2O_3	11
SO_3	2.9
TiO_2	1.8
K2O	1.73
MnO	0.585
SrO	0.37
CuO	0.13
V2O5	0.11
BaO	0.2
Re_2O_7	0.06
ZrO_2	0.055
ZnO	0.045

- Fresh RAP-Concrete properties

The main property of fresh concrete is workability, which is determined by some tests carried out immediately after mixing such as: compacting factor or slump test, which is the common test carried out on site. Based on some previous research, workability increases in concrete mixtures that contain low percentages of RAP, while it decreases with the increase in RAP percentage. It is noted that the workability is less in the case of replacing RAP with fine

aggregate than coarse aggregate [47-49]. Another research studied the replacement of virgin aggregate in the concrete mixture with processed and unprocessed RAP with percentages 25, 50, 75, 100%. The results showed that the slump values were increased to 9.68%, 22.58%, 41.94% and 54.54% with 25%, 50%, 75% and 100% replacement of processed RAP compared to unprocessed RAP. Also, results showed that unprocessed RAP decreases the setting time of the mixture more than processed aggregate [50].

- Hardened RAP-Concrete properties

The hardened concrete can be expressed as mechanical properties such as compressive strength, flexural strength, tensile strength, resilience, and toughness. According to several previous researches, the bitumen casing surrounding the RAP aggregate particles weakens the bond between the aggregate and the cement paste. Also, it increases the stress concentration on these surfaces, which causes the appearance of micro-cracks, so finally, the compressive strength, indirect tensile strength and flexural strength of the concrete is decrease. Also, the results indicated that using rap in the concrete mix as a replacement for coarse aggregate is better than using it as a replacement for fine aggregate despite reducing the compressive, indirect tensile and flexural strength in both cases. Replacement RAP with coarse aggregate reduces compressive strength and flexural strength by 65% and 35%, respectively, while replacing RAP with fine aggregate reduces compressive strength and flexural strength by 80% and 45%, respectively [50-53]. Other research indicated that the toughness of the concrete mixes that contain RAP was in complete contrast to the tensile and compressive strength results. The results showed that toughness increases with the increase in the percentages of the RAP in the mixture. The results indicated that the cracks that occur during the loading process until failure are visible and clear in the case of conventional concrete, unlike the concrete that contains RAP, the cracks are micro-cracks and not visible, and the failure is sudden [54-55]. Table 4 summarises the data on strengths results from different research studies.

Table 4. Tensile strength and Flexural strength characteristics of RAP in concrete mixtures.

Variables	Admixtures	Results
PCC, RAP aggregates	-	• Tensile strength increases [56],[57]. • Flexural strength increases [58]. • Abrasion resistance increase [59]. • Compressive strength increases [60].

OPC, RAP Aggregates	SF, FA & BA	• Tensile strength and durability properties enhanced by SF [61]. • At 50% replacement level, the tensile strength was enhanced by SF and FA mixtures [62]. • Silica fume enhances the flexural strength [63].
OPC, RAP Aggregates	-	• At 50% replacement level of RAP, the flexural strength has reached the required strength [64]. • Coarse RAP aggregates enhance the compressive strength for concrete mixtures [65].
RAP, GGBFS	MS, NS	• Tensile strength enhanced by NS [66]. • Flexural strength at a 30% replacement enhanced by NS [67].
RAP Aggregates	CRP	• CRP improved the tensile strength by 32% [66].
RAP Aggregates	-	• Flexural strength enhance at 25% replacement [59]. • The bond between the aggregates is enhanced as the proportion of RAP decreases, and the flexural strength raised [65].
OPC, RAP aggregates	ZSF	• Flexural strength and abrasion resistance increases [68].

5.2- Using RAP in flexible pavement

Reusing rap in asphalt applications is still uncommon despite the various studies dealing with this topic, especially partially replacing the rap within the new asphalt mixtures [35].

- Properties of RAP-asphalt mixtures

Some studies indicated that the partial replacement of the RAP within the hot asphalt mixtures reduces the fatigue life of the road [69]. An increase in the replacement percentage leads to a decrease in the rack resistance [70], an increase in the modulus of resilience, an increase in the permeability within the mixture, and a decrease in the shear strength [71]. Also, using RAP in soil reduces the value of CBR and decreases soil's bearing capacity [72]. Another research indicated that reusing RAP inside warm asphalt mixtures performs better than reusing it in hot asphalt mixtures, as studies indicated that it is better in reducing rutting, moisture resistance, and higher in fatigue resistance [73].

5.3 - Applications of RAP in pavement maintenance.

Many methods are used in road maintenance, to extend the period of their operation, and to ensure that this happens, the rules for using each method should be followed properly. According to Asphalt Recycling and Reclaiming Association, there are four recycling methods: (1) cold in-place recycling; (2) full-depth reclamation, (3) hot in-place recycling, (4) hot mix

asphalt recycling [35]. The choice of the method depends on the condition of the road and its defects, in addition to the time required for maintenance work. Figure 10 represents the distribution of road maintenance methods according to the serviceability of the road and the duration of its service [74]. Table 5 summarizes the different characteristics of RAP maintenance methods [75-77].

Table 5. Technique Characteristics of road maintenance using RAP [77].

Application Technique	**Evaluation factor**			
	Climate	**Traffic**	**Condition Addressed**	**Contraindication**
Cold In-Place Recycling (CIPR)	Remediation performs well in all weather conditions	Very successful in both high- and low-volume roadways	Reconstruction of old pavements	• Long remaining life, • Extend the service life of roadway pavements by 10-15 years
Hot mix asphalt recycling (HMAR)	Dried treatment sealants perform better in warmer climates	Performance is not significantly affected by different ADT or truck levels	Reconstruction of old pavements	• Extend service life of roads for over 12 years
Hot in-place recycling (HIR)	Dried treatment sealants perform better in warmer climates	Performance is not significantly affected by different ADT or truck levels	Correct shallow-depth HMA surface distress.	• The preservation treatment process is expected to extend pavement life by 10-12 years
Full-depth reclamation (FDR)	Remediation performs well in all climate conditions	Higher traffic bearing capacity	Stabilized base course	• Extend the service life of roadway pavements by 10 years

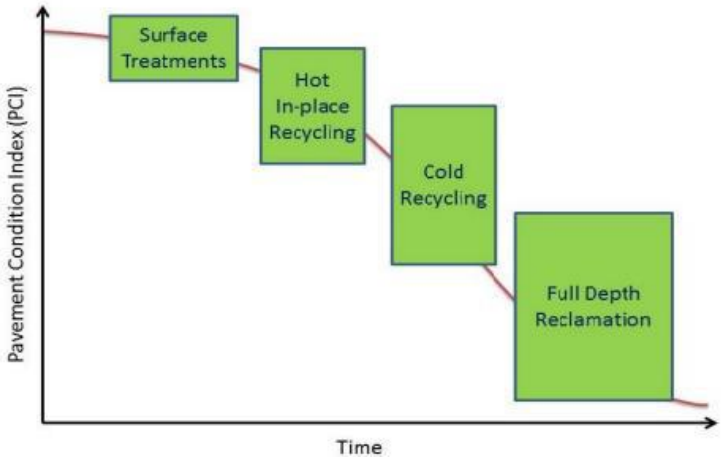


Figure 10. Asphalt recycling and reclaiming strategies for different pavement condition index [74]

- Hot mix asphalt recycling (HMAR)

Mixing in this technique uses the same steps and equipment as in the traditional hot asphalt mix. In this technique, the percentage of the components of the new mixture, whether it is aggregate or a percentage of RAP replaces bitumen after testing it to determine the percentage that maintains the properties of the mixture. RAP resulting from scraping the surface layer of the asphalt road is used, and the mixing process takes place in central mixing stations, after which the mixture is transported to the site required to be re-paved [35]. The main hindrance in the widespread use of 100% recycling is the unproven performance of 100% RAP pavements and lack of a unified and rational system for the selection of materials and mix design. Due to various concerns, many agencies and public administrations authorise low RAP percentages ranging from 10% to 30% in hot recycling [78]. First, there are still unanswered questions about the phenomenon of RAP bitumen mobilization and how it blends and interacts with new virgin bitumen during mix manufacture. Also, the literature lacks basic information regarding the physicochemical phenomena and mechanisms involved in this process. Inaccurate presumptions about the interaction's consequences may affect mix design as well as pavement performance, increasing the final mixture's vulnerability to rutting, moisture damage, cracking, and ravelling. Furthermore, ageing significantly impacts the physical and chemical properties of RAP bitumen, resulting in a general hardening of the bituminous blend [79].

In addition, the production technology and the ability to modify the physicochemical properties of the aged bitumen determine the maximum quantity of RAP that may be reused in

HMA production. Most typical drum plants can handle 50% RAP due to hot in-plant recycling, while batch systems can handle 10% to 30% of reusable RAP. Certain additives are highly advised when producing new HMA containing high percentages of RAP (30% or more) to achieve proper workability and final mechanical performance. The additives ought to be safe and stable across a broad temperature range during manufacturing and use. To ensure optimal performance during the lifetime of the asphalt pavement, they also need to experience no evaporation or exudation [79].

- Hot in-Place Recycling (HIR)

By using appropriate equipment, this technology guarantees the performance of all work on site, which is characterized by many advantages, including interruption of traffic for a short period and treatment of cracks and rutting while saving transportation costs. In this technique, the road's surface is heated to soften the bitumen, which helps in the surface scraping process. A layer of the surface is scraped approximately 20-50 mm. After that, the rap is transferred to the mixing unit in the machine as shown in Figure 11 to be re-mixed with a percentage of virgin bitumen and a percentage of rejuvenating agents, and then re-paving had been after the end of the mixing process [80].

Figure 11. The machines used for hot in-place recycling [80]

Rejuvenating agents are used to restore the properties of aged asphalt because they can decrease the size of asphaltene clusters, increase the amount of maltene constituents, improve the

dispersive power of the continuous maltene phase, and increase molecular mobility. These effects result in decreased viscosity and stiffness of the aged asphalt as well as increased ductility. The number of rejuvenating agents needed is decided based on various factors. These factors consist of the characteristics of old asphalt, the proportion of old asphalt in the mix, the penetration grade of fresh asphalt, the type of rejuvenating agent, and its viscosity and aromatic content [81]. The main rejuvenating agents' effects on mixtures' performance characteristics are summarized in Table 6.

Table 6. Effect of Rejuvenating agent on mixture and binder

Rejuvenating agent	percentages	Effect on mixture and binder
Engine oil [82]	10%–20%	• Compatibility requirements were met by mixtures containing 50% and 60% RAP with dosages of 12.5%–20% and 15%–20% Engine oil, respectively.
Waste engine oil [83]	2%–6%	• WEO improves asphalt's low-temperature performance, while high-temperature performance is negatively impacted. • Using WEO decrease the adhesion of aggregate and bitumen.
Waste vegetable oil [84]	5%–20%	• Improve the workability and fatigue resistance
Waste cooking oil [85]	1%–5%	• 3%–4% dosages enhanced susceptibility to short-term ageing and decreased viscosity compared to a virgin binder.
A by-product of cotton-oil Production [86]	5, 10%	• workability, viscosity, and resistance to rutting were fully regained. • Low-temperature cracking resistance and fatigue resistance were enhanced. • PAV-aged asphalt's content (asphaltene, sulfoxide indexes, and carbonyl content) was enhanced.
Waste wood oil [87]	10, 20%	• Bio-oil can significantly improve the rheological properties, fatigue, rutting, and low-temperature crack resistance of aged asphalt. • 15% bio-oil is recommended for use as a rejuvenating agent.

- Cold In-place Recycling (CIR)

The CIR technology is similar to what happens in the HIR technology in terms of performing work on-site and saving transportation costs. The difference is that the road surface is not heated; therefore, it is distinguished from HIR technology because it saves energy. In this technique, asphalt emulsion is used as a binder agent. This technology treats the pavement surface with a 75-100 mm thickness. This method is distinguished by its environmental friendliness, as it reduces the emissions associated with heating the asphalt [88].

The performance of cold recycled asphalt mixture made of RAP and emulsified or foamed asphalt may not be adequate to carry heavy traffic loads. Therefore, additives like Portland cement, lime, and fly ash are recommended to enhance its performance [89]. In previous researches, a number of factors, including gradation type, bitumen emulsion content, mechanism in the cold recycled asphalt mixture, extra water content, cement content and types, filler types, curing condition, and compaction method, were thoroughly studied in relation to the mechanical and pavement characteristics of CMA. All of these studies are extremely important for the best possible design of CMA's mechanical and pavement properties. By comparing the outcomes, it is possible to determine that the most effective way to increase the tensile strength of CMA is to increase the cement content. However, a high cement component might make CMA less ductile, which raises the possibility of cracking [90-92]. Figure 12 show the machine used for this technique [93].

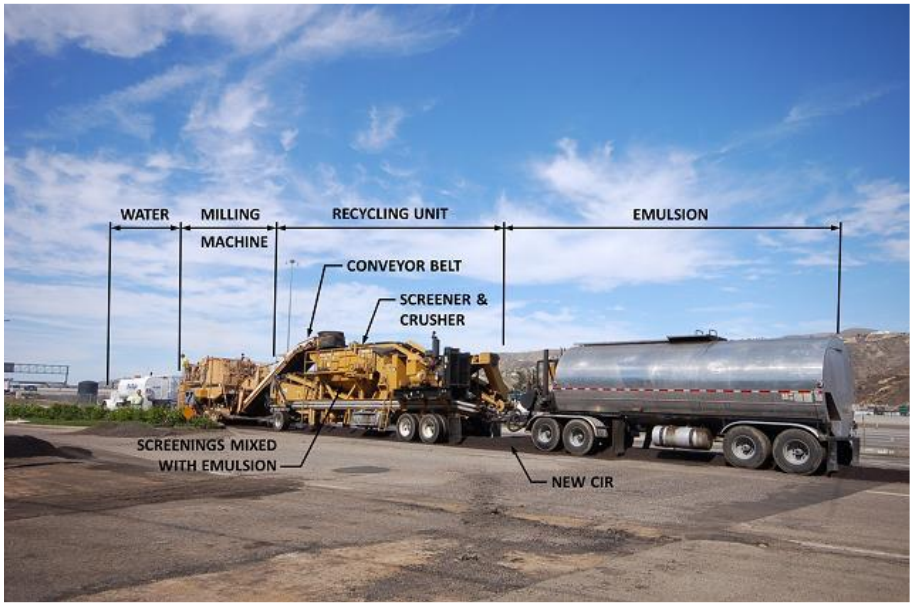


Figure 12. The machines used for hot in place recycling [93]

- Full Depth Reclamation (FDR)

This technique is used if the defects penetrate the surface layer and reach the base layer. Figure 13 illustrates the RAP processing in this technique [94]. In this method, a thickness of about 100-300 mm of the road is removed to reach the base layer and mix the output of the drilling with some additives such as sodium chloride, fly ash, lime, and cement in order to improve the properties of this layer and to increase its strength, which is called the soil stabilization. This process occurs at the site, where the road is milled, crushed, mixed with new materials and additives, stirred well, put back on the road, and then compacted to form the road again [95].

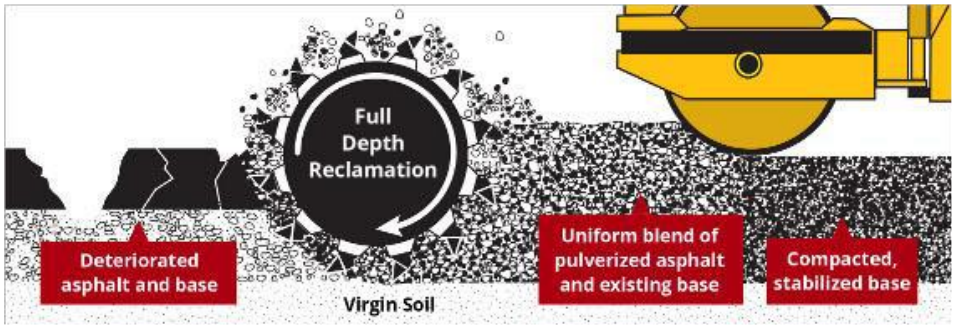


Figure 13. Full-depth reclamation process [94]

The cost savings associated with FDR can be as high as 50% compared to the expenses of removing and replacing a pavement at the end of its service life. Additionally, it has been demonstrated that FDR can reduce energy consumption by up to 70% as opposed to the complete removal and reconstruction of a deteriorated pavement structure [96].

6. Conclusion

1. there are two common methods to extract bitumen from RAP, solvent method and ignition method, but the ignition method is the most used because of the hazards of solvent and the requirement of gradual disposal of it
2. The effect of replacement RAP in new asphalt occurs if the percentage increases than 10%.
3. Using new asphalt mixtures having a large amount of RAP, it is necessary to use rejuvenators.
4. The percentage of rejuvenators in the RAP mixture depends on the properties of both the aged bitumen and the type of rejuvenator used.

5. Workability increases in concrete mixtures that contain low percentages of rap, while it decreases with the increase in RAP percentage.
6. Slump values were increased to 9.68%, 22.58%, 41.94% and 54.54% with 25%, 50%, 75% and 100% replacement of processed RAP compared to unprocessed RAP.
7. Unprocessed RAP decreases the setting time of the mixture more than the processed aggregate.
8. Increased RAP content in concrete, compressive strength, indirect tensile strength and flexural strength of the concrete decreases.
9. Replacement RAP with coarse aggregate reduces the compressive strength and flexural strength by 65% and 35%, respectively, while replacement RAP with fine aggregate reduce the compressive strength and flexural strength by 80% and 45%, respectively
10. An increase RAP percentage in asphalt mixtures decreases the rack resistance while it increases the modulus of resilience
11. Using RAP in the soil increases the permeability while reducing the shear strength, CBR value, and bearing capacity.
12. RAP inside warm asphalt mixtures gives a better performance than reusing it in hot asphalt mixtures, it is better in reducing rutting moisture resistance and higher in fatigue resistance

7. References

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