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# RECYCLED ASPHALT PAVEMENT: A SYSTEMATIC LITERATURE REVIEW

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**Abstract.** The use of infrastructural and industrial wastes has gained attention in every day civil engineering practice. The incorporation of these wastes into civil engineering projects are significantly promoting sustainability in the industry. The fast depletion of natural resources used in the construction of highways will reduce if the construction of highway pavements and other civil engineering structures take advantage of wastes with good engineering properties. This review paper aims to build an insight into the interaction between new and aged asphalt binders in Reclaimed Asphalt Pavement(RAP). The research discusses the review of different properties of asphalt when Reclaimed Asphalt Pavement(RAP) is incorporated as aggregates and also compares the result with the use of natural aggregate. The literature review shows that stability, stiffness, workability, durability, resistance to moisture damage, and fatigue resistance are all affected by gradation. This study has also shown that there is limited research on RAP content variability and the results are inconsistent. Although the rutting performance of pavements is satisfactory, the result of the effect on thermal performance is found to be inconsistent, particularly at higher RAP content percentage. This research also studies the microstructure of RAP.

**Keywords**: Reclaimed Asphalt Pavement(RAP), Fine Aggregate, Coarse Aggregate, Concrete, Bitumen, aged asphalt binders.

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## 1 Introduction

There is a high increase in urbanization across the globe which has left people in search of a comfortability even in line with roads that serve both functional and structural requirements. This increased urbanization has as well increased the number of road users thus, the introduction of heavy traffic may not have been considered at the point of the design of certain roads in certain locations, thus leading to early deterioration of roads and subsequent failure.

To keep up with the desired highway standards, the natural resources around with good engineering properties are used for the construction of such roads. This activity has contributed significantly to the deterioration of natural resources such as fine aggregates(sand), coarse aggregates (different sizes of gravel and or stones), the incessant use of these materials in the construction industry has generated erosions, landslides, and other natural disasters. To effectively reduce these side effects from man's use of these materials, the innovative use of construction wastes has been explored by many engineers in practice and engineering companies. One of these is the use of Recycled Asphalt Pavement in partial or complete replacement as aggregates for use in different layers of the roadway. This paper presents an overview of recent studies on the use of RAP as an alternative resource.

RAP is asphalt and aggregates extracted from the pavement and reprocessed. Some of the reasons that necessitate the removal of asphalt already laid are to have access to buried utilities, for reconstruction which is the major reason for massive removal and to resurface. Studies according to Nabil et al (2015), there are no specific standards set for the application of aggregates(RAP) thus, wastes from demolition in the United Kingdom are being recycled and only used for low-grade roads. Generally, the RAP that is produced is being used at the same location as fill for embankment, landfill and even at the sub-base which makes it timely and at the same time much more affordable.

This article provides a holistic picture of both the properties of RAP Aggregates compared to the natural aggregates. The Mechanical, chemical and Physical and Physical attributes of these materials are all being explored in-depth about their specific applications.

## 2 Background of the study

Studies have shown that since the 1930s RAP had been in use and are important concerning the reduction of cost of road construction from the rising prices binders and virgin aggregates and the minimization of the issues related with indiscriminate disposal of the removed asphalt and at the same time conserving natural resources that are rapidly being depleted.

A study by the Federal Highway Administration (FHWA) in the United States of America states that every year, about thirty million tons of Recycled Asphalt Pavement (RAP) are being recycled. This makes it the material that is most recycled in the United States of America. A subdivision of the FHWA established a method of the usage of RAP, based on past experiences, an interim guide on the use of RAP was developed. The guide suggested that between 15% to 25% on an increment on both low and high-temperature grade, virgin binder grade be decreased. Blending charts were however produced to determine the quantity of RAP to be utilized at 25%. Superpave performance shows no significant difference between at low RAP content usage of about 10%. The difference however is significant at higher RAP content of about 40%.

### 2.1 Advantages of using RAP in road construction

According to Jie et al (2011), there are a number of advantages using RAP, some of them have been listed below:

**Full-depth reclamation:** This requires a technology that produces an upgraded homogenous material by pulverizing the full asphalt pavement thickness of the base course or sub-base, in some cases, other materials are being added when necessary and blended.

**Hot mix asphalt (in-place recycling):** This process does not require processing before the actual operation of the recycling process.
To repave, specified heating, scarifying, laydown, rejuvenating and the compaction processes are being achieved first. About a hundred percent recycling of the existing pavement is completed with in-place recycling.

**Cold in-place asphalt:** This process does not require processing before the actual operation of the recycling process. The milling process of the existing pavement surface is achieved to a depth of about 150mm, processed and then, asphalt is mixed with emulsion, it is then placed, and then the process of compaction is achieved in just one pass.

**Cold mix asphalt (central processing facility):** Cold mix asphalt other than that the graded mixture. The method here is comparable to the hot mix asphalt, aside from the fact that the mix is paved as a substitute for aggregate particles by a combination of cold mix. The RAP material is being reused without the application of heat but just by reprocessing and addition of binder.

**Asphalt cement supplement and asphalt concrete:** RAP has both aggregates and binders, thus when used as a substitute for aggregates it likewise serves as a cement binder in asphalt.

**Embankment or fill**: Stockpiled RAP could be effectively used in both backfill and embankment construction. Nonetheless, the use of this content is restricted on the embankment as it does not reflect the most acceptable usage for economic reasons Jie et al., (2011).

**Stabilized base aggregate:** RAP is crushed, undergoes screening, mixed appropriately with reagents to achieve stability, in a sufficiently compacted base or sub-base, thus gaining sufficient strength.

**Conservation of energy:** About 25 to 40% of energy could be saved while using RAP as aggregates. However, leaching of carcinogens from bitumen when the material is either in service or stockpiled is a major disadvantage of RAP. Nonetheless, the use of suitable procedures and plants in the production recycled hot mix asphalt is ousted. It is argued whether leaching produces dangerous chemicals to the atmosphere, however, a study conducted by Allan & Timothy (1996), aimed to determine the toxicity leaching for environmentally friendly RAP, it demonstrates that the RAP is not hazardous or leaches chemical compounds outside its limits in groundwater.

**Economic benefit:** There is significant growth in concern on the availability of high-quality virgin aggregates for use in flexible pavements globally. There is significant depletion of natural resources along with the high rise in demand for these materials. The cost of petroleum products is also on the rise thus, RAP reduces significantly the number of virgin materials, thus making construction more economical.

**Technical benefit:** Research has shown that a well-designed and properly mixed recycled hot mix asphalt can be compared with traditional hot mix asphalt in terms of weathering fatigue cracking, rutting, and raveling in structural and functional efficiency. Both, both are equal in quality.

## 3 Removal and recovery of asphalt binder

It is very important to ascertain the characteristics of asphalt binder, Los Angeles value, gradation, asphalt content, coarse aggregate angularity(CAA), fine aggregate angularity(FAA), and other properties of RAP aggregates.

Separating the aggregates from the asphalt binder mix is the only way to determine these properties. The most common methods of separating these materials are the ignition method, the pycnometer method, and the automatic recordation method (Jie et al., 2011).

## 4 Blending of virgin binders with RAP

The degree to which new and aged asphalt are mixed is one of the main issues with the performance of hot mixed asphalt. There is a negligible difference in the change in binder grade when RAP content used is just at about 10%, at a higher percentage of about 40% or more, the RAP effect is much more pronounced in the mix. (Jie et al., 2011), also provides a detailed procedure for mixing RAP at various stages. A schematic representation of the process is presented below.

A study by (Al-Qadi et al., 2009), shows that aged binders do not have the same behavior as black rock, neither is it at full blending between virgin and aged binders. Huang et al., (2006) did a study through a controlled experiment that analyzed the mixing process with virgin mixtures for the various screened RAP contents (percentages). The study indicated that the layered system in RAP showed great potentials in helping to minimize the concentration of stress on HMA mixtures and at the same time also enhances the overall performance of the pavement. It further revealed that some portions of mix formed coating around RAP aggregates that are stiff, RAP functioned thus as a composite black rock.

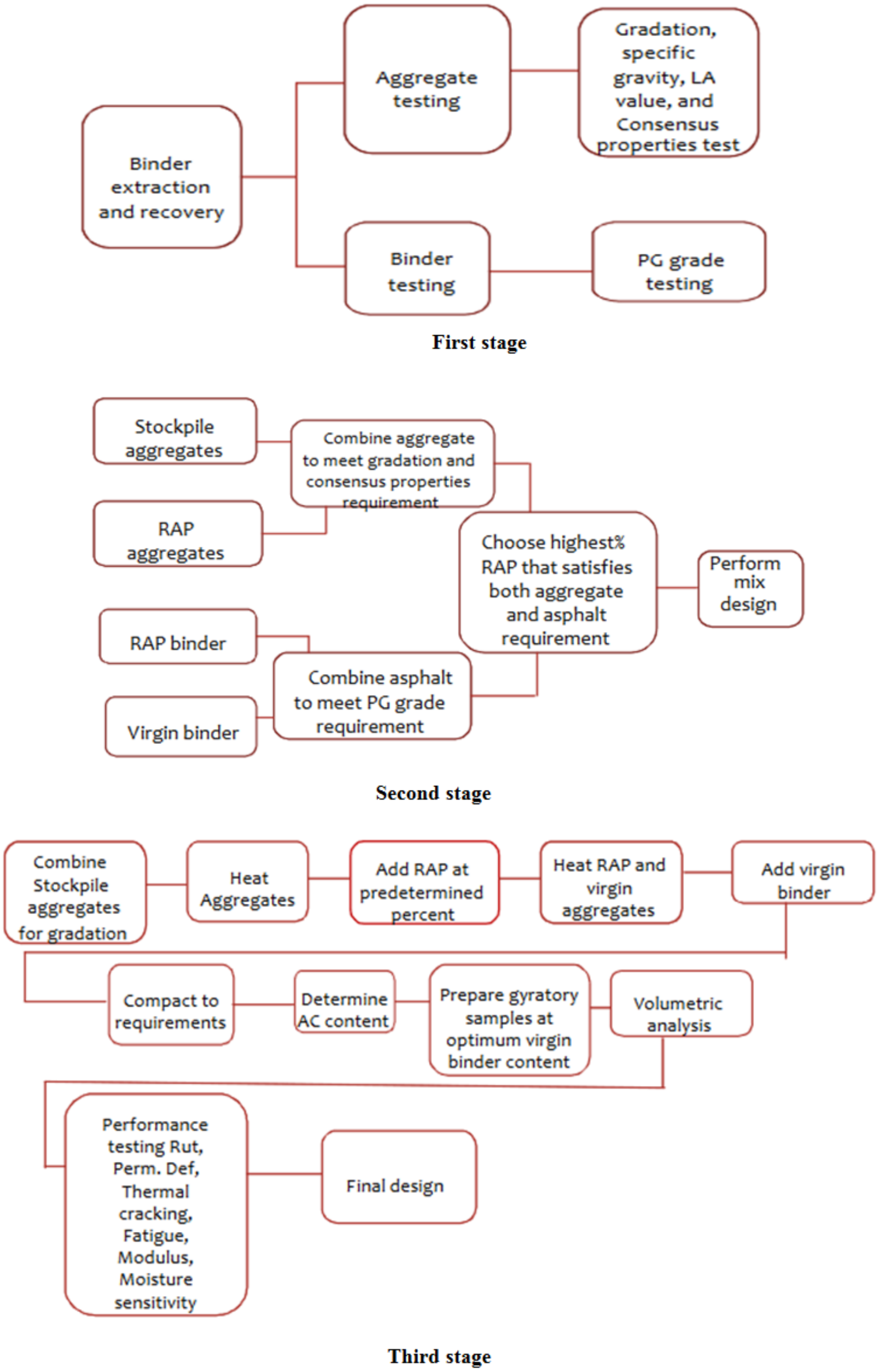


**Figure 1:** Blending Processes of RAP.Source: (Jie et al., 2011)

# 5 Volumetric and mechanistic change in properties after RAP inclusion

A study by Chowdhury & Button (2001) which was aimed at determining the change in both volumetric and mechanistic properties of concrete upon the addition of RAP. The RAP types used in the study were the processed and unprocessed rock types. The mix was in 15, 25, and 40% increment of RAP and was compared to mix with virgin materials. The Voids in Mineral Aggregate and the Void in fine aggregates values for the processed RAP with 25 and 40% were found to be higher than those with a 15% mix. On the other hand, the unprocessed had an increase in the Voids in Mineral Aggregate values as RAP was increased percentage-wise. At 15 percent, the mix stiffness improved, while there was a decrease in creep compliance. The higher stiffness demonstrates that the mixture would be much more deformation resilient thermal cracking and fatigue. At the mix of 25% and 40% RAP content, creep compliance and dynamic modulus were the same almost to those of the conventional materials. At 25% of RAP, the gradation was finer with higher asphalt content than the mix with conventional materials, at 40% however, the mix gradation was finer than that of RAP content at 25%. Furthermore, the Voids in Mineral Aggregate and Voids in fine Aggregate values were seen to be higher than the mix at 15% RAP content mix and that of conventional materials.

# 6 Chemical properties of RAP

RAP contains about 3-7% of hardened asphaltic concrete and 93 -97% by weight of mineral aggregates. Comparatively, the chemical composition of RAP is the same as that of natural mineral aggregates. Noureldin et al., (1998) studied the properties of RAP and concluded that oxidation occurs which converts oils to resins and resins are then further converted to asphaltenes in aged asphaltic concrete which produces age hardening and viscosity that is higher. when RAP gets exposed to the environment. A study by Widayanti et al., (2018) indicates that the major chemical compounds of RAP are similar to those of natural mineral aggregates, these compounds are CaO, $Fe_2O_3$, and $SiO_2$ by percentage weight.It is considered that the main determinant factor of RAP is the asphaltenes as against oils and or resins. Hence, this property benefits in reducing the alkali-silica reactions in mineral aggregates. On the increase in the RAP content, viscosity also increases, however, due to the asphalt film presence in RAP, the workability of the asphaltic concrete decreases. To obtain better workability of this concrete, the viscosity can be lowered. The creep and shrinkage properties are however affected by the addition of RAP (Chen et al., 2018).

# 7 Physical and mechanical properties of RAP

The constituent materials of RAP and concrete mix are the major determinant factors of the properties of RAP, considerable differences can be witnessed between asphalt mixes in size, consistency, and aggregate quality. Aggregate degradation can be caused by both crushing and milling. Tambake (2014), noted that RAP has the potency to replace virgin aggregates in the construction of a road up to about 40%-60% with a satisfactory performance. The stiffness modulus and tensile strength of cold asphalt mix with RAP meet the specification for road construction at the base course Tambake (2014). Although RAP is highly advocated for use in road construction, Mang et al (2016), suggests that RAP properties of asphalt mix are not satisfactory as compared to the use of new aggregates, the cold mix method of asphalt also lags in comparison with the hot mix asphalt method.

**Table 1:** Chemical Properties of RAP. Source: (Jorisa et al., 2019)

| **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 |
| $K_2O$ | 1.73 |
| MnO | 0.585 |
| SrO | 0.37 |
| CuO | 0.13 |
| $V_2O_5$ | 0.11 |
| BaO | 0.2 |
| $Re_2O_7$ | 0.06 |
| $ZrO_2$ | 0.055 |
| ZnO | 0.045 |

**Table 2:** Typical distribution range for reclaimed RAP. Source: (Jie et al.,2011)

| **Sieve Size** | **Percent Finer after Processing or Milling** |
|---|---|
| 37.5 mm (1.5 in) | 100 |
| 25 mm (1.0 in) | 95 – 100 |
| 19 mm (3/4 in) | 84 – 100 |
| 12.5 mm (1/2 in) | 70 – 100 |
| 9.5 mm (3/8 in) | 58 – 95 |
| 75 mm (No. 4) | 38 – 75 |
| 2.36 mm (No. 8) | 25 – 60 |
| 1.18 mm (No. 16) | 17 – 40 |
| 0.60 mm (No. 30) | 10 - 35[a] |
| 0.30 mm (No. 50) | 5 - 25[b] |
| 0.15 mm (No. 100) | 3 - 20[c] |
| 0.075 mm (No. 200) | 2 - 15[d] |
| a. Usually less than 30 % | |
| b. Usually less than 20 % | |
| c Usually less than 15% | |
| d. Usually less than 10% | |

A study by Taha et al (2020), found that, maximum dry density, unconfined compressive strength and the optimum moisture content of RAP will generally increase in addition of cement and aggregates. Although it is seen as viable material in replacing partially conventional materials, it has the potency for use in both base and sub-base regions of a pavement, however, RAP at 100 % could only be used as a conventional material in the base course only if it is cement stabilized. In another study, it is found that t is found that aged bitumen presence in RAP affects the physical characteristics of concrete such as: specific gravity, absorption, gradation and shape, the study concludes that those factors are responsible for the decrease in the bulk density of RAP Taha et al (2020). Mahitha & Aswini (2018) found out that the general physical properties of concrete increased when blended with RAP. The type of aggregates in a concrete and the moisture content determines the unit weight of RAP, studies suggests that the unit weight of RAP falls between 1940-2300 kg/m3 (Jirayut et al., 2019; Nabil et al., 2015).

Typically, the specific gravity of conventional aggregates falls between 2.6 to 2.8. According to Al-Mufti & Fried (2018), the specific gravity determines the quantity of aggregates for a particular concrete mix, the RAP aggregates have specific gravity that is less than that of conventional aggregates. Mechanical properties such as abrasion resistance, impact and crushing when compared with natural aggregates are within acceptable limits as natural aggregates especially when used for rigid pavement applications. Studies have shown that the Los Angeles resistance value for coarse aggregates in RAP is less than 38%, this suggests that RAP aggregates does not have a uniform hardness (Subhash et al., 2010).

Some of the findings from different literature on gradation of RAP suggests that on a general note, there is an increase of fine aggregates in RAP as degradation occurs from crushing or milling effect. The result of sieve analysis of RAP differs from those of the natural aggregates. The angularity of the coarse aggregates RAP is higher than natural aggregates (Subhash et al., 2010). This property increases the resistance to friction of RAP aggregates (Al-Mufti & Fried, 2018). By the action of weathering and oxidation, RAP aggregates become a lot harder when exposed to the environment.

# 8 RAP aggregate gradation

This helps to determine the particle sizes of aggregates, this is a very important property of aggregates, either coarse or fine, it is influential in controlling hot mix asphalt mixes. A study by Roberts et al (1996) indicates that stability, durability, stiffness, workability, fatigue resistance and permeability are all affected by gradation in the hot mix asphalt. The ASTM C136 and AASHTO T27 are the standard gradation and sieve analysis of both coarse and fine aggregates. As a result of mechanical degradation, the gradation of aggregates in RAP in the hot mix asphalt is finer than the conventional materials at the points of removal of pavement and processing of RAP. It has been seen that aggregates from RAP largely meets the ASTM benchmark on the premise of ASTM D1073 for fine aggregates and ASTM D692 for coarse. The type of equipment and aggregates used in the manufacture of RAP determines the particle size distribution of aggregates obtained by milling. All RAP that are produced by either crushing or milling below 1.5 inches or even less and a maximum allowable size at the top of between 2 inches and 2.5 inches. Gradation has shown to be responsible for the hardened and fresh concrete properties (Jorisa et al., 2019).

## 8.1 Flexural strength of RAP in concrete

The flexural strength of RAP in concrete has shown similar characteristics as the compressive strength values. According to Mang et al., (2016), there is a significant decrease upon increase in RAP percentages. However, there is an increase in load absorption when RAP is increased. The RAP concrete elastic modulus decreases flexural strength of concrete with RAP attributed to the prevalence of asphalted film, thus, making aggregates fails slowly as compared to the that of concrete with natural aggregates that fail explosively (El Euch et al., 2018; Nabil et al., 2015; Singh et al., 2019). Brajash (2015), found that the flexural strength of RAP is within permissible limits and should be used in the construction of highways.

Mubaraki et al (2019) studied the flexural behavior of two different RAP with 20% and 40% RAP content respectively, "The research findings have shown, for the two forms of RAP, the flexural strength and mode I fracture strength of the flexible pavement with 40 percent RAP are greater than the flexible pavement with no RAP." In another study the flexural strength of concrete produced from RAP as coarse aggregate was lower than that of the conventional aggregate (Okafor, 2010).

### 8.2 Compressive strength

Larbi et al (2020), conducted a study to that aimed at improving the compressive strength of RAP concrete with Silica Fume (SF), the mineral admixture showed that the compressive strength of both RAP and conventional concrete increased. In the same light, a study that comprised of 0, 20, 40, 60, 80 and 100% by weight for use as fine aggregates showed improvement in compressive strength at an optimal value of 40% (Sani et al., 2016). The unconfined compressive strength was observed to have increased in laterite treated RAP. (Huang & Burdette, 2018) found that RAP concrete has lower compressive strength than natural aggregate for use at the base course of the pavement.

Studies have shown that soft asphalt film is a possible cause for stress concentration which may eventually result in aggregates micro cracks, this results in reduction of the strength parameters of such RAP concrete. When tested under compressive loading, RAP aggregates show less cracks at failure in comparison with control mix of natural aggregates. This is mainly attributed to asphalt motor coating of the aggregates. In general, studies have shown that asphaltic concrete containing both fine and coarse RAP aggregates produce strength at 28 day of curing which is less than 44MPa (Sani et al., 2016). The compressive strength of RAP as aggregates falls within satisfactory limits and is recommended for use in road construction (Brajash, 2016).

### 8.3 Los Angeles test of RAP

This property determines aggregate toughness and the resistance to abrasion which is enough in preventing crushing and disintegration when placed and compacted and exposed to traffic load. Aggregates without this attribute could contribute to a faster deterioration of roads. According to Wu et al (1998) the far more popular method is the Los Angeles Abrasion Test, although other methods exists. The average Los Angeles value is between 25% to 55%. (Jie, 2011). According to a study by (Brajash, 2004) on abrasion and degradation, Aggregates deteriorated by aggregates size were found to still have substantial strength in abrasion and wear resistance. A study that was aimed at aggregates extracted from by full- depth recovery. In the same view, the study also indicated that scrapping and milling causes degradation of aggregates, the latter causes more aggregate degradation in comparison to the full depth recovery. A study by (Brajash, 2016) found that the Los Angeles values were within satisfactory limits and recommended for use at the base, sub-base courses of roadways.

### 8.4 Angularity of fine aggregate

This is a very important and it determines the degree of fineness and angularity of fine aggregates. Fine aggregates that have an excessive round shape results to rutting. This is measured by evaluating the uncompacted loosely placed void content of samples of fine aggregates. It provides a strong aggregate blend with suitable structure and or angularity that can withstand rutting. While the rounded sizes seem to have the advantage of easy compaction, the angular ones tend to possess more resistance to compaction but at the same time more durable. It is assumed that if other parameters are satisfactory, the aggregates with higher angularity would produce a more stable Hot Mix Asphalt. A study by Chowdhury & Button, 2001) found that for high volume traffic roads, cubical fine aggregates with fracture may not meet permissible limits. This necessitated the development of several other test methods for angularity of fine aggregates.

### 8.5 Angularity of coarse aggregates

The angularity of coarse aggregates is basically known by manually visualizing a sample of the coarse aggregates, these samples are separated based on those with fractured and unfractured faces, then counting the number of aggregates that are fractured (Fager, 1990). Particles that possess angularity produces better results because they interlock better and at the same time more resistant to deformation and rutting during the service life of the road. Coarse aggregate angularity helps in ensuring adequate interlocking and prevents extreme deformation. According to Jie et al (2011), ASTM D5821 and AASHTO TP61 are the standard tests used in ascertaining the percentage of particles that are fractured in a collection of coarse aggregates.

# 9 Identified gaps

Studies have shown that different RAP percentages have been used in different projects across the world, however, there is no specific optimal value across researches, this is due to the fact that there are different RAP properties from origin and other factors such as viscosity, binder content, age etc. These factors and more could be further investigated, this study shows that; there is no definite optimal RAP percentage recommended for different purposes, thus, more studies are encouraged in order to narrow the broad scope of RAP for different purposes. Furthermore, the establishment of corrective factors for different factors should be prioritized by appropriate bodies.

# 10 Microstructure of RAP

Most research activities aimed at exploring the effect on laboratory work performance assessment of the addition of RAP to asphalt mixes But it has shown limited interest in the microstructure of the RAP mixtures to be given to the spatial blend of its aggregates, materials, air vacuum, and asphalt mastic. It is common knowledge that distribution pattern of the components of a composites can affect its material properties significantly (Chowdhury & Button., 2001). Recent methods have been used to evaluate the distribution of the mixture phases of the asphalt and to calculate representative volume elements (El Euch., 2018). Although the impact of recycled content on the mixture is to be measured using a rigorous and practical method.

According to a study by Lekhaz et al (2020), based upon volumetric information, three-phase pavement pictures were produced. Such 3-phase pictures were found to provide a more accurate and practical image of the asphalt, suggesting that these images could be used for precise geometry generation simulation in after-scale study. Estimations of the connection between two and three points were made on the aggregate, pavement mastic and air vacuum phase of the asphalt beams produced in three phases. The findings suggest that the spatial distributions in phases do not substantially impact the introduction of RAP into traditional asphalt of up to 40%. Consequently, the main mechanical performance changes in RAP mixtures are related only partially to improved space distribution of the mixture of asphalt, asphalt mastic and air void. According to Kandhal et al., (1995) practitioners may use the suggested research technique to determine the asphalt in the forensic inspections pavement. The volumetric characteristics developed during the mixing design can be checked fairly quickly and adjustments.

Lekhaz et al (2020), in a research, Waste Engine Oil (WEO), Waste Vegetable Oil (WVO) and Waste Grease (WG) were used as rejuvinators at different doses. Rejuvenation-RAP interaction is analyzed by microscopic examination, Fourier transform infrared (FTIR) spectroscopic analysis and X-ray diffraction (XRD) assessment. The microscopic analysis supported the alignment and distribution of the aggregate, showing the substantial rise in aged binder coating on the RAP with the rise in the rejuvenation dose. The FTIR and XRD tests indicate that rejuvenation preserved the RAP's asphalt and maltene ratio and fluidity. WG has improved the asphalt and maltene ratio relative to WEO and WVO. However, microscopic analysis shows that the WG has higher agglomeration. All in all, it is suggested that WVO is a good dosage to improve RAP fluidity. can be made as required.

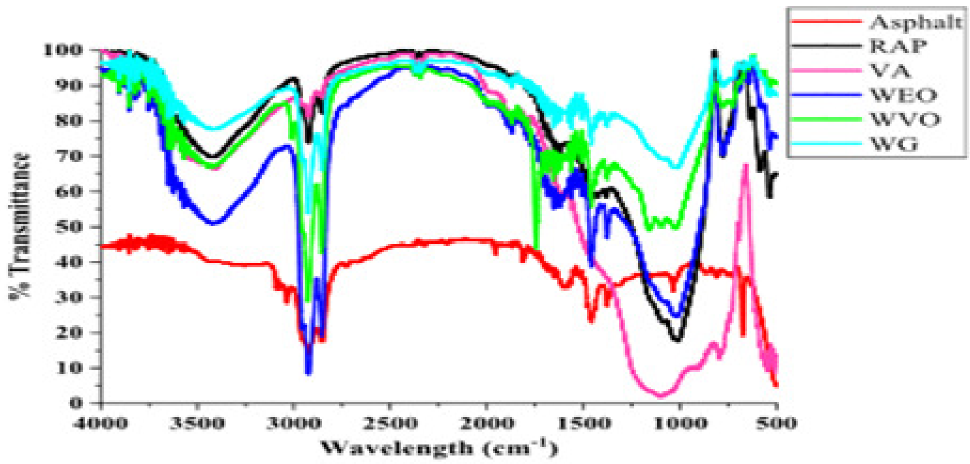


**Figure 2:** Fourier transform infrared (FTIR) results of the better performed dosages of WEO, WVO and WG. Source: (Lekhaz et al., 2020)

In a study by Falchetto, (2014), this paper discusses the effect of applying RAP, Manufacturer Waste Scrap Shingles (MWSS) and Tear-off Scrap Shingles (TOSS), from aged roofs, exposed to solar radiation and for a long time to high temperatures, with lower temperature properties of mixtures as-phalted. Originally, microstructural analysis of these mixtures and the subsequent analysis. The rheological characteristics of changes were examined accompanied by asphalt binders. Asphalt mixing specimens (Bending Beam Rheometer BBR projections in two dimensions) Correlation features, micro - structural and digital image processing characteristics were analyzed. Since there were no important shifts between two and three-point correlation functions, the spatial distribution of the process was not influenced by the recyclable materials added to the mixtures.

## 11 General RAP performance in pavements

The effects of RAP have been evaluated by many researchers, research institutions and engineering companies, some of the findings are presented here in this section. An evaluation of some projects based on binder properties, structural analysis, serviceability and mix by the Louisiana Department of Transportation and Development in the United States (Paul, 1996). The research indicates a satisfactory performance as compared to the use of conventional materials, about 20 to 50% of RAP was used on these projects.

A number of projects completed using RAP with percentages ranging between 8% to 79% were evaluated by the Washington State Department of Transportation (1985) and found that out of 16 projects, the first two initial projects performed well at the time of assessment. The remaining were completed at about 2.5 years before the study, the results indicated a promising result. However, the results indicated that pavement with RAP showed more longitudinal cracking distresses. A study by Jorisa et al (2019), using 30% RAP and evaluated after 6 years showed that pavement roughness was low, no rutting noticed and viscosity was higher than that of control asphalt mix.

Kandhal & Kee, (1997) assessed the performance of RAP in five projects with service years of about 1.5 to 2,5 years using a varied RAP content of between 10-25%. The result showed no difference between RAP and virgin materials. A similar study also indicated the same result except that longitudinal and transverse cracks were observed the materials have the same properties. Fager,(1990) found similar results on the comparison of the performance of RAP with conventional aggregates however, 1% cracking was observed in the study.

## 12 Summary and Conclusion

There is significant increase in the cost of asphalt binder and there is notable depletion in the source of aggregates all over the world. A number of projects have been delayed as a result of the cost of asphalt. With the increased price in purchasing asphalt, the use of high percentage of RAP would be highly beneficial.

Furthermore, there are noticeable conservation of energy, technical benefit, economic benefit in of using RAP in the construction of highways. In addition, to the conservation of binder and aggregates and landfills, it is environmental friendly. The literature review shows that stability, stiffness, workability, durability, resistance to moisture damage and fatigue resistance are all affected by gradation. It has also shown that there is limited research on RAP content variability, there is also an inconsistent result. Furthermore, volatilization, oxidation, thixotropic, polymerization and separation are found to affect the rheological properties of RAP binder. Although studies have shown that the rutting performance of pavements is satisfactory, the result of the effect on thermal performance is found to be inconsistent, particularly at higher RAP content percentage. This study has also shown that research on the microstructure of RAP is limited, researchers are encouraged to take up on the microstructure of RAP and other properties in order to fully understand the material.

**Conflict of Interest:** This work is original, has not been submitted to any other journal. Furthermore, the authors of this article states that there is no conflict of interest.

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