

## Evaluation of Rheological, Mechanical and Microstructure Performance of Hot Mix Asphalt (HMA) Incorporating with Agricultural Waste: A Review

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### ABSTRACT

*The increasing demand for sustainable and eco-friendly materials in the construction industry has led to the exploration of agricultural waste as an alternative modifier in hot mix asphalt (HMA). Agricultural waste is one of the potential materials that can be used as bitumen modifier due to the abundance of waste being dumped without being utilized properly. This review aims to evaluate the effects of incorporating various types of agricultural waste on the rheological, mechanical, and microstructural performance of HMA. Specifically, it focuses on the influence of materials such as rice husk ash, sugarcane bagasse, Palm Oil Fuel Ash (POFA), coconut and other agricultural by-products on the physical properties of asphalt binder and mix. Additionally, the review highlights changes in the microstructure of the asphalt mixture, observed through scanning electron microscopy (SEM) and other characterization techniques. The findings suggest that agricultural waste materials have the potential to enhance the performance of HMA by improving its mechanical properties, increasing rutting resistance, and promoting sustainability in road construction. However, challenges such as optimal dosage, compatibility with conventional asphalt components, and long-term performance stability are also identified. Therefore, chemical and physical treatment need to be done to promote the compatibility between agricultural waste and bitumen. This paper provides a comprehensive overview of current research, offering valuable insights for future studies and practical applications in the integration of agricultural waste in asphalt pavements.*

*Keywords: Hot Mix Asphalt (HMA); agricultural waste; rheological; mechanical; microstructure*

### INTRODUCTION

Due to axial pressure, high vehicle traffic, and poor road maintenance, Malaysia's road network is deteriorating more quickly. Constant pressure causes the soil beneath the pavement to erode, which in turn affects the top layer of the roads. Plus, excessive weather condition, axial pressure and also viscoelastic properties of bitumen also affect binder's quality. Permanent deformation (rutting) occurs at higher temperatures, while it becomes stiffer at lower temperatures, making it more prone to breaking.

These behaviors demonstrate the binder's temperature susceptibility. Aimed to promote asphalt binder durability, researchers were actively discovering to utilized various additives possible to be used in producing high quality pavement.

Therefore, according to Tayfur et al. (2007), the tendency of pavement cracking and rutting can be reduced through bitumen modification which will extend the pavement shelf life. Moreover, mechanical properties of asphalt mixture like Marshall stability, optimum bitumen content and cohesiveness within bitumen and mineral aggregates can be improved by modifiers (Ali 2013). Issues

like traffic noise, rehabilitation cost and maintenance can be mitigated with the usage of bitumen modifiers (Putman and Amirkhanian, 2004). As the focus has shifted to sustainability, many scholars looked into using waste materials to improve bitumen's qualities. Previous studies have highlighted the advantages of utilizing various agricultural waste, such as rice husk ash (Abo-Shanab et al. 2021), sugarcane bagasse ash (Zia and Khan 2021), palm oil clinker (POC), palm oil fuel ash (POFA), palm oil boiler ash (POBA) (Hainin et al. 2018) and coconut (Shelke et al. 2014).

The issue of accumulation of agricultural waste after being dumped would result in the development of other problems like leachate. Mentioned by Jawjit et al. (2024), developing countries often mismanage waste through improper disposal methods like open dumping, uncontrolled landfills, and burning. This poor waste management leads to environmental contamination and social issues, as organic, inorganic, and hazardous substances pollute the air, soil, and water. Thus, due to the future problem may be caused by the waste generated from agricultural industry, it is crucial to assess their potential as one of green waste materials in pavement industry. It is considered a new and future sustainable industrial material with diverse applications in the pavement production. To give a thorough grasp of the present and potential uses of agricultural waste, this article will concentrate on the characteristics of different agricultural wastes and how it affects the performance of asphalt pavements. The improvement of physical, mechanical and microstructural of asphalt binder and mixture after been added with various agricultural waste will be thoroughly discussed.

However, few study was conducted which addresses the usage of agricultural waste as bitumen modifier and how the interaction of mixture in microstructure view, highlighting a research gap. Hence, this study aims to highlight and analyzed the previous research done in utilizing the usage of varieties crop residue in pavement and also to fill the research gap and obstacles for future studies.

## LITERATURE REVIEW

### FLEXIBLE PAVEMENT

According to Tayfur et al. (2007) and Aziz et al. (2015), 95% of highways in the world used flexible pavement. The two types of pavements that usually used are either rigid pavement or flexible pavement where both are differentiated by the type of material that is applied to the wearing course layer. Material like Portland cement is used for the wearing course layer of rigid pavement, while bitumen is the

material used for flexible pavement. As shown in Figure 1, flexible pavement consisted of few layers which were subgrade layer, subbase layer, base layer and surface layer. The foundation of flexible pavement or known as subgrade layer is composed by natural soil that has been compacted. For the subbase layer, the compacted aggregate is used as the main materials.

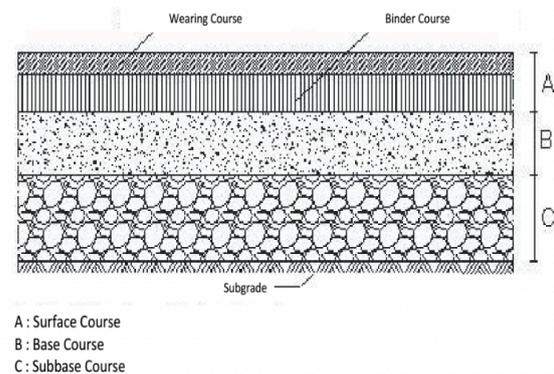


FIGURE 1. Flexible pavement (cited from Hatmoko and Lendra, 2021)

The flexible pavement's structural system on top of the subbase layer is known as base layer. The base layer composed of superior unbound aggregate or a well compacted layer of bitumen-aggregate served to evenly distribute the stresses from the traffic from the surface layer to the foundation of the pavement. Lastly, the upmost layer of flexible pavement's is called surface course which comprises of binder course and wearing course (Arshad et al. 2020). The load from wearing course and binder course will be distributed to the base course which will improve the pavement strength. According to the guideline by JKR (2013), a 50mm thickness is required to produce sturdier pavement where usually binder course is thicker than the wearing course. The surfacing layer provides a smooth, durable, and tear-resistant surface while retaining sufficient friction to guarantee road safety. These layers ought to be sufficiently robust to withstand traffic pressure without rutting.

### PAVING MATERIAL

Asphalt mixture components are comprised of three main materials which includes bitumen, fine and coarse aggregates, and mineral powder, are known as viscoelastic materials. (Butlar et al. 2017). Every material is essential to the production of a high-quality pavement. In order to produce asphalt concrete, bitumen is mostly crucial since it binds the aggregate by covering and coating it.

Aggregate makes up between 90% and 95% of the weight of the asphalt mixture. (Al-Ameri and Putra Jaya, 2022). Gradation and size, durability and soundness, toughness and abrasion resistance, shape and texture, and cleanliness are all important aggregate properties that should be taken into consideration. Supported by Rehman (2019), the size, shape, placement, and compaction method of the aggregates influenced how well the asphalt mixture performed. In Malaysia, Jabatan Kerja Raya (JKR, 2013) had provided the specification for the aggregate with gradation AC10, AC14 and AC28 as showed in Table 1. The numbers for the aggregates AC10, AC14, and AC28 denoted the nominal maximum aggregate size in the asphalt mixture, which are 10mm, 14mm, and 28mm respectively.

TABLE 1. Aggregate gradation limit (cited from JKR, 2013)

Mix Type	Wearing Course	Wearing Course	Binder Course
Mix Designation	AC 10	AC 14	AC 28
BS Sieve Size (mm)	Percentage Passing by Weight		
28.0			100
20.0		100	72-90
14.0	100	90-100	58-76
10.0	90-100	76-86	48-64
5.0	58-72	50-62	30-46
3.35	48-64	40-54	24-40
1.18	22-40	18-34	14-28
0.425	12-26	12-24	8-20
0.150	6-14	6-14	4-10
0.075	4-8	4-8	3-7

Aggregate properties were been tested by conducting various tests like gradation, sieve analysis, aggregate impact value (AIV), Los Angeles Abrasion Value (LAAB) test, and aggregate crushing value (ACV). The gradation and size test are used to measure aggregate particle size distribution, which affects HMA volumetric characteristics, mixture permeability, and workability. AASHTO T27 and ASTM C136 (Sieve Analysis of Fine and Coarse Aggregates) are the standard used for the gradation and sieve analysis tests.

Bitumen is a primary component of pavement mixtures and is employed in bituminous pavement construction due to its strong cement composition, high degree of waterproofing, durability, and adhesiveness. Bitumen, a viscoelastic substance comprising asphaltenes, aromatic hydrocarbons, resins, and saturates, gives combinations of mineral aggregates a controlled degree of flexibility. (Putman and Amirhanian, 2004). It is a usually either black or brown in color viscoelastic complex hydrocarbon.

While bitumen can be found in some natural sources, refineries that process crude oil are the main source of bitumen. (Sehgal, 2019). For flexible pavement, bitumen is used as the binder as it exhibits viscoelastic properties where it poses both liquid and solid behavior depending on the time and temperature poses on it. Three criteria can be used to categorize bitumen: viscosity, performance grade, and penetration grade.

The last component of paving material is called filler. Filler is the leftover particles that pass through a 0.075mm sieve and the durability of hot mix asphalt (HMA) is affected even there were only minimum number of fillers been added in the mixture. As agreed by Zhang et al. (2019), Lima and Thives, (2020) and Choudry et al. (2021), factors like types of filler and the concentration used in mixing will affect the performance of HMA when been imposed to transient load and surrounding. Bianchetto et al. (2007) found that the viscosity of asphalt is not only improved but it ageing is also hindered when filler is been used in the mixture. Supported by Choudry et al. (2020), filler did affect the process of adhesion and cohesion between the materials in the asphalt mixture during the mixing process. Here, filler act to improve the ability for asphalt pavement to resist towards rutting and at the same time promote its inertia and stiffness. Therefore, the life span of the mix is increased by the filler's ability to reduce the proportion of asphalt. (Hafeez, 2010). Hence, even filler has minimum usage, yet it has an important role in improving the properties and strengthen HMA.

Nevertheless, modification must be made due to bitumen that exhibit both viscous and elastic manners while undergoing deformation which will affect the quality of pavement. SáRibeiro et al. (2017) stated that the bonding between the asphalt and aggregate weakened when temperature increased as the bitumen in the mixture expanded and become softer therefore reduced the mixture's stiffness. Water can seep into the asphalt mixture structure through the small air spaces or gaps when it is exposed to high humidity for an extended length of time. These spaces or gaps exist due to the nature of aggregate and bitumen after the mixing process. As water seep through and fill these gaps, it weakened the aggregate-bitumen bond due to the differences in adsorption forces. Materials (aggregate, bitumen and filler) are stick together by forces called adsorption forces. In this case, water has higher adherence towards the bitumen surface compared to the bitumen which means that bitumen will be detached from the aggregate surface therefore degrading the pavement abilities to withstand the loading from traffic. This process will lead to various pavement deterioration like potholes, cracking and rutting. Since this will have an impact on pavement performance, improvements in pavement performance quality must be implemented in order to prevent pavement distress.

## PAVEMENT DISTRESS

The important characteristics that define bitumen are its vulnerability to temperature changes, ageing, and viscoelasticity. This is the reason bitumen lacks good engineering qualities. (Shaffie et al. 2018). Bituminous pavement surfaces must be strong in order to withstand distortion and offer a smooth, yet skid-resistant, surface. For the entire structure to remain stable and strong, it must also be watertight and firmly attached to the course or layer underneath. (Yildirim, 2007; Ali, 2013). Heavy traffic loads can damage bituminous blends, especially in situations with extreme weather and climate conditions. HMA failure is a frequent issue that primarily arises in both hot and cold environments. Nonetheless, certain failure modes, like permanent deformation (rutting), are thought to be more common and severe in higher temperatures where high traffic loads and reduced HMA stiffness are present (Piromanski et al. 2020; Arabani & Mirabdolazimi 2011).

There are various types of cracks in bituminous pavement, such as slipping, longitudinal, edge, block, and alligator cracks. The most frequent cracking happened on the roads is called as alligator crack. As shown in Figure 2(a), it is named as alligator cracking due to the physical appearance that look alike the skin of crocodile which form on the HMA surfaces due to the cracks that interconnect with each other. Both Ratnasamy and Bujang (2006) and Hamed (2010) agreed that inadequate pavement thickness, high loading and sub-grade or base coarse weakness is the prime factor of fatigue cracking shown in Figure 2. The pavement structure is extremely affected when imposed to high temperature as the bitumen tends to soften. According to Yi Qiu et al. (2012), it additionally reduces the asphalt mix's flexibility at low temperatures, which may result in cracking. This type of cracking is called alligator cracking because it seems to resemble the cracks on an alligator's skin. Alligator cracks are often caused by heavy loads and constant traffic on the tire pressure area of asphalt surface.

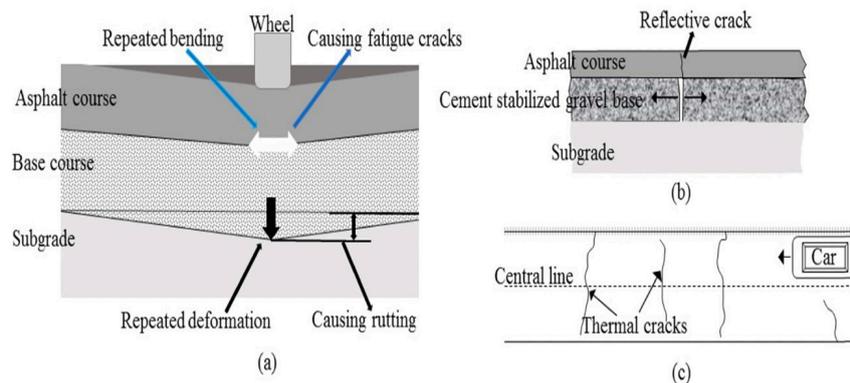


FIGURE 2. Types of cracks (cited from Wang et al. 2021)

Another common issue faced by pavement is rutting or known as pavement distortion. The term “rutting” describes the permanent deformation along the wheel path created by high traffic loads (Tayfur et al. 2007). Similarly, Irianto et al. (2024) suggested that repetitive traffic loads from high traffic density lead to the buildup of permanent deformation in asphalt concrete mixtures, ultimately reducing road performance. Constant compaction and material movement within the pavement layer due to the repeated loading from the vehicle axial load led this deformation to happen. Not only that, factors like weak mixture and weak subgrade were also the contributor that caused rutting. The solution to address this issue is by incorporate modifier into the mixture.

## MODIFICATION OF BITUMEN USING AGRICULTURAL WASTE

Bitumen has been modified in a variety of studies using various modifiers to improve its rheological and physical qualities. (Shaffie, 2018). Bitumen modifiers often reduce asphalt mixture moisture susceptibility, bitumen oxidative hardening, and temperature dependence (Vichitcholchai, 2006). As stated by Beligni et al. (2000), incorporating natural fibres into asphalt mixture can significantly enhance both asphalt mixture's overall performance and mechanical properties. Natural fibres functioned to reinforce the mixture similar as how rebar reinforce the concrete where it will connect the materials inside the HMA and create

stronger bond. Thus, numerous attempts to alter bitumen using agricultural waste have been made in recent years. Harvesting grains produces a significant amount of waste that is produced by agricultural operations (Hainin et al. 2018). Prior research has focused on bitumen's qualities and how agricultural waste affects them. The bitumen's physical properties without creating chemical bonds, it has also been utilized as a filler material. These wastes unique chemical constitution makes it a very stable and robust material that can be employed in structural applications, such composite material reinforcement (Loaiza et al. 2018). Numerous prior research has demonstrated that the binder and asphalt combination's characteristics can be improved by using agricultural waste.

Rice is a staple food that is consumed by people all over the world. Nanjgowda et al. (2023) mentioned that most Asian consumed rice as their major food and this is shown by 90% of rice is produced in Asian country. Both Rawasliney & Suhadah, (2012) and Saeed et al. (2020) stated that Malaysia produced 408,000 metric tonnes of ricehusk which is the byproduct from paddy mills process. According to Zhang et al. (2017), process of paddy mills has produced 72% grain and 5% bran. Meanwhile, a total of 20-22% rice husk wastages were generated during this process which were not fully utilized. Saeed et al. (2021) defined rice husk as the residue of the rice grain outer layer produced during the paddy milling process. According to Saeed et al. (2019), rice husk normally comprises 40% lignocellulose and cellulose, 5% hemicellulose and trace elements and minerals like silica make up the remaining fraction. The frequent disposal of rice husk in landfills presents issues with operation and storage. Additionally, because rice husk is usually burned outdoors, improper management of it results in major environmental issues (Moayedi et al. 2019).

Not only that, the byproduct of sugarcane processing that is naturally produced is sugarcane bagasse. Juice is produced from sugar cane's leftover fibre during the extraction process. Bagasse ash is discarded from industry and dumped on property close to mills, posing numerous environmental problems. (Cokca et al. 2009). Steam and electricity are produced in the sugar industry using bagasse as a fuel. Bagasse ash has binder and pozzolanic qualities that make it suitable for improving the soil's engineering qualities. (Janjaturaphan & Wansom, 2010). Both He et al. (2020) and Li et al. (2022) discovered that chemically modifying the natural bagasse fibre under specific conditions can enhanced it properties such as heat resistance and high-temperature oil absorption. This chemical modification succeeds in removing the glue and hemicellulose that naturally exists on any fibre's surface. Therefore, uniform mixing and bonding were achievable between the modified bagasse fibre and asphalt mixture as

it promoted the compatibility between these two materials. Not only that, at the same time it also boosted the water stability in the mixture, enhance the ability of the asphalt mixture to resist cracking at low and high temperature. All of these enhancements add up to a more resilient and long-lasting asphalt mixture that is better able to withstand the strain of high traffic and adverse conditions.

According to Ghulam (2022), among countries that produce palm oil, Malaysia can be said as one of the top countries that both produce and export it palm oil to other countries around the world. However, despite being the leading producers and exporters it came with adverse effect where it produced tonnes of waste from the process of extracting palm oil. Whenever products made from oil palm are produced in large quantities, nearly equivalent amounts of byproducts are frequently produced as well, which must be properly controlled. Piromanski et al. (2020) listed out the by-products produced from oil palm production such as palm oil clinker (POC), palm oil fuel ash (POFA), palm oil boiler ash (POBA), palm oil fibre, and palm oil shell. Thus, studies done by Zarina et al. (2013), Ahmad et al. (2012) and Safiuddin et al. (2010) have worked on utilizing the potential of this wastes to be used as an alternative to be used in construction in hope to minimize the wastes from accumulated.

Palm oil clinker (POC) is the product from energy generation by process of burning palm fibres and shells at high temperature in the palm oil mill. This waste is produced on a massive scale and disposed in its solid state close to the mill (Vijaya et al. 2008). These wastes products from biomass are just thrown away without being used to their fullest extent. Another palm oil byproducts are palm oil fuel ash (POFA) where Safiuddin (2011) defined palm oil fuel ash (POFA) as the ash produced by oil palm burned in palm oil mills at temperature ranging from 700 °C to 10,000 °C in the process of generating electricity. According to Thangchirapat et al. (2007) and Khankaje et al. (2016), the primary material produced by the mill as an ash by-product is called POFA. Yusoff (2006) mentioned that this residue is becoming more prevalent in parallel with Malaysia's increasing production of palm oil, where the country produces more than 10 million tonnes of POFA annually (Awal & Hussin, 2011; Safiuddin et al, 2011). POFA is an environmentally friendly geopolymer material due to its potential is construction use and reducing the wastage (Ranjbar et al. 2014). Currently, this residue is typically ignored on landfills, which contaminates the surrounding area (Kanadasan & Razak, 2014) and creating an environmental issue (Arabani & Tahami, 2017). These waste materials are merely dumped in Malaysian landfills, never being used in other sectors of the economy or having their potential used (Yaro et al. 2021).

Palm oil boiler ash (POBA) or occasionally known as empty fruit bunch (EFB) ash is a byproduct after the process of palm oil extraction was done where the palm oil mesocarp, shell and unburned kernel is burned at 500–700°C in a boiler furnace. (Bukit et al. 2018). Residue contained 70-85% carbon, hard and black in color is produced after the burning process completed. Studies done by both Lau et al. (2019) and Zarina et al. (2015) proved that POBA also consist of high number of silica range typically from 40 to 86%. However, the exact element composition of POBA is greatly influenced by several factors such as the burning temperature imposed during the process and the proximity from the combustion source. Despite its advantages, the environment was being negatively impacted by the surplus POBA solid waste being disposed of at the plant's disposal location.

In tropical climates, coconuts are a frequent fruit. Coconut waste has been recycled and used to make a variety of industrial goods. The asphalt paving industry has recently embraced the use of coconut fibres and shells. Abundance of coconut shell (CS) waste is concerning as it starting to become the major pollutants for the environment ecosystem. Gunasekaran et al. (2012) reported that a total of 3.18 million tonnes of CS are being produced and dumped annually. Despite it was an organic waste, it still took time to decay and improper dumping will create pests issue. Yet, comparing CS to other traditional crushed granite aggregate, it is also more resistant to impact, crushing, and abrasion (Arabani and Mirabdolazimi, 2011).

Meanwhile, coconut fibre (CF) is one of the byproducts from coconut and Rocha et al. (2018) reported that usage of CF as binder modifier not only hinder bleeding but also promote asphalt coating. Similarly, both research by Tan et al. (2012) and Neves Filho et al. (2004) proved that usage of CF as bitumen modifier promoted the use of irregular grain size, which can boost binder concentration and produce aggregates coating with a thicker film. This will directly improve the pavement resistance towards various wear and tear conditions, safer and less slippery road. Additionally, the utilization of CF with binder also aid in improving the surface drainage pavement of tires and reforming their mechanical properties (Beligni et al. 2000). Water is drained from the surface and thus lengthen the lifespan of the pavement as CF added will create more porous surfacing layer. According to Neves Filho et al. (2004), this can lessen weathering, moisture infiltration, and asphalt mixture oxidation. In order to help porous asphalt withstand deterioration, CF can extend its temperature range. When standard asphalt pavement is exposed to different climates, this feature can lessen the drying and cracking that happens. This occasionally will improve the lifespan of the asphalt mixture thus reducing the possibility of pavement distress.

## RHEOLOGICAL PERFORMANCE OF MODIFIED BINDER WITH AGRICULTURE MODIFIER

Abo-Shanab et al. (2021) conducted a study using varieties of rice husk weight added into bitumen PEN 60/70 which were 3%, 5%, 7% and 10% to determine the how varying rice husk concentration affected the properties of the bitumen. The goal of the study is to enhance the quality of the bitumen which later will be used as binder in road construction. Various tests were conducted to evaluate the physical properties and viscosity of modified bitumen like penetration test, softening point test and rotating viscometer test. From this research, it was found that at high temperatures, the permanent deformation value reduced, the thermal cracking value decreased, the penetration value decreased to 50 mm, rutting resistance improved and the softening point value increased to 700 °C. The performance values of modified bitumen were found to be superior to those of pure bitumen. The conclusion drawn from the research of Xue et al. (2014) is that the bitumen and ash combined physically rather than chemically. Consequently, the physical properties of bitumen were modified by rice husk ash to more closely resemble expected performance values.

The potential of palm oil clicker finer (POCF) and palm oil fuel ash (POFA) to be used as bitumen modifier were widely explored by researchers aiming to improve the pavement durability. A study conducted by Yaro et al. (2021) concluded that incorporating POCF as bitumen modifier has increased its stiffness. The result showed an increment for its softening point and viscosity while at the same time reducing the penetration values. Increasing of softening point indicated that the POCF helped the asphalt mixture to be more resistant towards temperature induced deformation while increased the viscosity implied that it more resistant from flowing. Meanwhile, study by Rusbintardjo et al. (2013) focused on the appropriate amount of POFA to be added as modifier. The result found that the optimum weight to be added were within range 5% to 7% where it improved the physical and rheological properties of modified bitumen. Further investigation by Hainin et al. (2014) looked into the impact of POFA at various percentages under various ageing scenarios. Ageing of bitumen occur when it been exposed to the outside temperature and oxidized which caused it became brittle. The result from the study showed that adding POFA to both unaged and aged bitumen not only increased the softening point but also reduced the penetration value. Abdulrahman et al. (2019) explored the use of POFA in warm mix asphalt, a type of asphalt that is produced and applied at lower temperatures compared to traditional hot mix asphalt. The

result proved that as compared to the standard bitumen with grade PEN 60/70, addition of 5% POFA and 0.75% Evotherm has improved the viscosity up to 40% and reduced both ductility and penetration value. Conversely, study by Akbar (2012) showed contra result where addition of 5% POFA increased the penetration value but no significant increment on its softening point. This outcome suggests that while the modified binder became softer, it did not gain the desired temperature resistance.

Research by Yousif et al. (2023) demonstrated that adding 7%–8% of coconut shell (CS) powder reduced the penetration of modified bitumen by 11.5%, increased the softening point by 2.3%, improved flow at high temperatures, and enhanced ( $G^*/\sin\delta$ ) values by 20%. Given that the complicated shear modulus elastic part is where HMA rutting and fatigue cracking are predicted,  $\delta$  and  $G^*$  should have substantial values.

### MECHANICAL PERFORMANCE OF HMA MODIFIED WITH AGRICULTURAL MODIFIER

According to Arabani and Tahami's (2017) assessment, RHA addition as modifier can improved the key properties of asphalt mixture like rutting resistance and fatigue life. These outcomes proved that RHA usage helped to improve pavement durability and sustainability. Not only that, RHA is to be said as a potential material to be used as filler that can act as a potential sustainable alternative to the traditional filler (Sargin et al. 2013). The result concluded that combination of 50:50 ratio of both RHA and limestone was found to be the most effective combination for improving Marshall Stability and flow. Similar research conducted by Abbasalizadeh and Hesami (2020) aimed to study the effect of variety combination of RHA and limestone towards asphalt binder's performance. From this study, the optimum ratio of RHA and limestone (0.75:0.25) showed higher resilient modulus (39.7%) and greater Marshall stability (880kN) than the combination including 100% limestone. Thus, it can be said that hot asphalt mixes performed better and were more sustainable when biomass ashes were used in place of filler material.

Meanwhile, Zia and Khan's (2021) research, however, revealed that bitumen containing 5% sugarcane bagasse ash (SCBA) can reduce rutting depth by 33%. Zainudin et al. (2016) found that when modified mixes including SCBA were compared to conventional HMA, the modified mixtures improved Marshall stability, flow, and resilient modulus by 0.6%, 4.9%, and 17.4%, respectively. Pavement durability can be extended by reducing the rate of rut depth in the base layers and surface by increasing resilient modulus.

After short-term ageing, asphalt mixtures containing palm oil clinker-fine (POCF) showed increased stiffness relative to unaged mixtures, although not as much as they did when compared to regular mixtures (Jaya et al. 2014). Additionally, it lowers the mixing temperature, which lowers the risk of thermal cracking, rutting, fatigue, and bitumen. Within the elastic limit, there was more resistance to deformation because of the increased elastic modulus. Similarly, a study by Yaro et al. (2021) examined the impact of short-term ageing on the volumetric and mechanical properties of an asphalt mixture modified with Palm Oil Clinker Finer (POCF). Short term aging indicated the changes occur within the material during mixing, transportation and compaction before been exposed to traffic and sunlight. It is very important to assess short term aging as it showed the initial condition of asphalt mixture which will affect its overall performance when subjected to actual traffic loading. From this study, Marshall stability of POCF modified asphalt mixture is improved by 19% when compared with control sample. A higher Marshall stability value indicated a stronger and more durable mixture, capable of bearing heavy traffic loads without significant structural damage.

Using Palm Oil Fuel Ash (POFA) as a filler, Maleka et al. (2014) assessed the asphaltic concrete 14 (AC 14) Indirect Tensile Strength (ITS). Rahman et al. (2019) investigated the impact of utilising POFA as a partial bitumen substitute in asphalt mixtures. The results showed that a 15% replacement ratio raised the susceptibility to temperature by 67%. The Indirect Tensile Strength (ITS) of hybrid asphalt has a major role in determining its resistance to fatigue and cracking (Jaya et al. 2022).

Aside from that, Al-Mansob et al. (2013) explored into modified asphalt that included additives made of palm oil shells (POS). The resilience modulus of the mixture has improved by 28.57% with the addition of 5% POS. When designing the pavement structure mechanistically, resilient modulus is most important. This demonstrates how POS may enhance the asphalt pavement's resilient modulus.

Zulkafli et al. (2023) assessed the addition of 0.5%, 0.75%, and 1.0% coconut fibre to asphalt binder. With 21982 life cycles, the inclusion of 1% coconut fibre (CF) exhibits the maximum fatigue performance. Pavement lifespan increases as a result of increased CF percentage since it increases fatigue resistance. Thulasirajan and Narasimha (2011) studied the flow, stability, and volumetric properties of the modified fibre with CF by varying the binder content, fibre content, and fibre length. Its volumetric characteristics and stability are good when the bitumen concentration is 5.72% and the fibre content is 0.52% of 15 mm. The study concludes that adding coconut fibre to flexible pavement can increase its structural resistance to traffic stresses.

## MICROSTRUCTURE OBSERVATION

The term “microstructure” refers to a material’s appearance on a nanoscale length scale. Microstructure can be observed using certain microscopy techniques. When a material’s microstructural characteristics are examined at various length scales, they can differ significantly. X-ray diffraction (XRD), transmission electron microscopy (TEM), scanning electron microscopy (SEM), and Fourier transform infrared spectroscopy (FTIR) are some of the microstructure analysis techniques that can be used to analyze a material’s structure at the nanoscale.

SEM is a multi-characterization instrument that enables inorganic or organic material to be observed and examined at the nanoscale. SEM was used to examine each

binder’s micromorphology in detail. The SEM study of rice husk ash (RHA) carried out by Ting et al. (2016) was displayed in Figure 3. According to Madakson et al. (2012), the results show that RHA has an abundance of crystalline grains, which suggests that the material’s structure contains a lot of pores. This is indicated by the formation of white-colored mineral. Similarly, from Figure 3, RHA particles seen to have an uneven form, a highly porous structure, and multiple layer systems (interfacial, interior, and exterior). This result is in line with Xu and Lo’s (2012) earlier investigation which found that the interfacial layer is made up of several pores and a crisscrossed network of chips. Meanwhile, Figure 4 demonstrated that a homogenous mix was formed at 7% RHA addition due to the uniform distribution of RHA inside the asphalt binder.

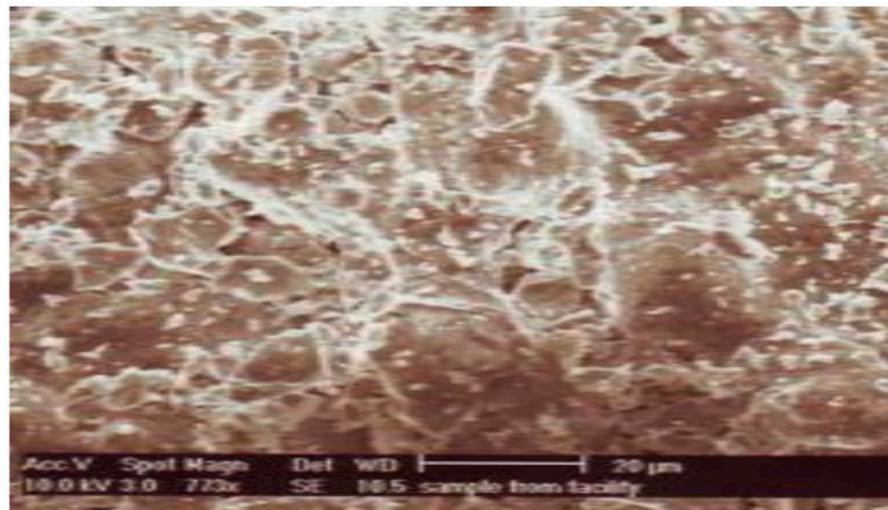
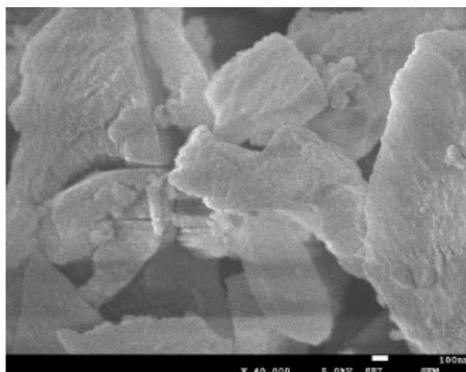
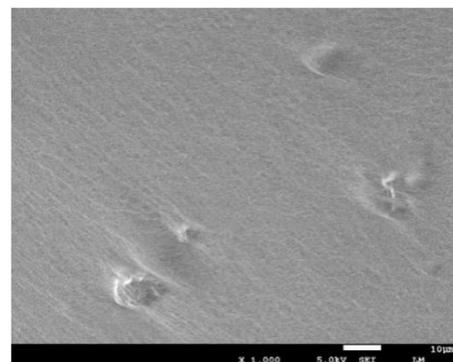


FIGURE 3. SEM images of RHA (cited from Ting et al.2016)



(a)



(b)

FIGURE 4. SEM images of (a) RHA (b) 7% RHA modified asphalt (cited from Li et al. 2022)

In general, every organic substance has its own infrared spectrum. By analysing the functional group, the chemical molecular structure of asphalt can be determined. Li et al. (2022) also performed FTIR analysis for RHA-modified bitumen, as seen in Figure 5, where bitumen is supplemented with 1%, 4%, and 7% of RHA. The presence of a hydroxyl group at peak  $3709\text{ cm}^{-1}$

In contrast to the control sample (PEN 60/80), it suggests that silica and asphalt binder are reacting. Furthermore, strong bonding between SiO and the asphalt binder was demonstrated by the absorption bonds of O-H at peak  $1102\text{ cm}^{-1}$ .

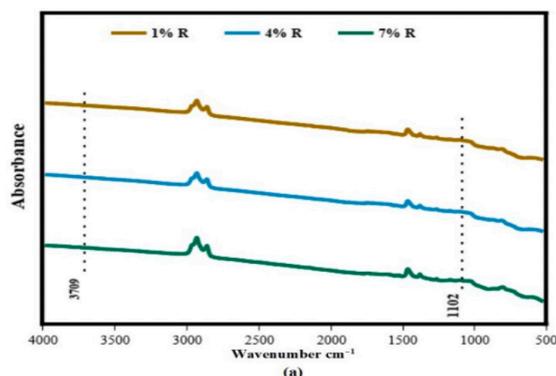


FIGURE 5. FTIR analysis of RHA Modified Bitumen (cited from Li et al. 2022)

In an effort to determine the effect of POBA on the physicochemical characteristics of the binder modification, Akhir et al. (2023) performed a microstructural characterization investigation using FTIR measurements. FTIR analysis measures the sample's infrared light transmittance level at each wavelength to ascertain the material's molecular structure and makeup. Figure 6 illustrates the FTIR transmission spectrum of the POBA sample's primary functional group. There are several prominent bands visible at 2920, 2850, 1450, and 1380

$\text{cm}^{-1}$ , which suggest that C-H stretching is present. Additionally, a modest absorption peak of aromatic C=C stretching vibrations at  $1590\text{ cm}^{-1}$  is visible. However, the presence of C-H bending is indicated by the peaks at 1450 and  $1380\text{ cm}^{-1}$ . Since there was no discernible shift in the peak at the functional groups or chemical interaction, the functional groups of the POBA-modified binders were nearly identical to those of the control sample (PEN 60/70), according to the FTIR graph.

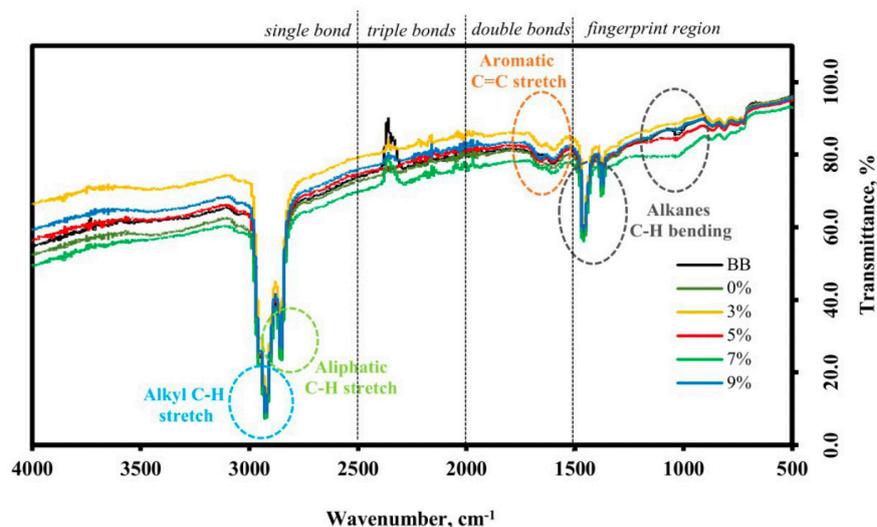


FIGURE 6. FTIR spectrum analysis of POBA Modified Bitumen (cited from Akhir et al. 2023)

According to a study by K. Gunasekaran et al. (2012), scanning electron microscope (SEM) was used to assess discontinuous and continuous CS cells. As illustrated in Figure 7, individual cells in CS range in size from 16.36  $\mu\text{m}$  to 29.33  $\mu\text{m}$  and are rather closely spaced. The size of the micropores varies between 760 nm and 1.64  $\mu\text{m}$ . Furthermore, CS with continuous cells is available in a

range of thicknesses from 852.7 to 1.24  $\mu\text{m}$  and widths from 7.35 to 8.88  $\mu\text{m}$ . The results show that CS specimens can bear higher loads and have good resistance to crushing and abrasion. Meanwhile, as for the coconut shell ash (CSA), SEM study revealed that, as Figure 8 illustrates, its structure is solid by nature but asymmetrical in size.

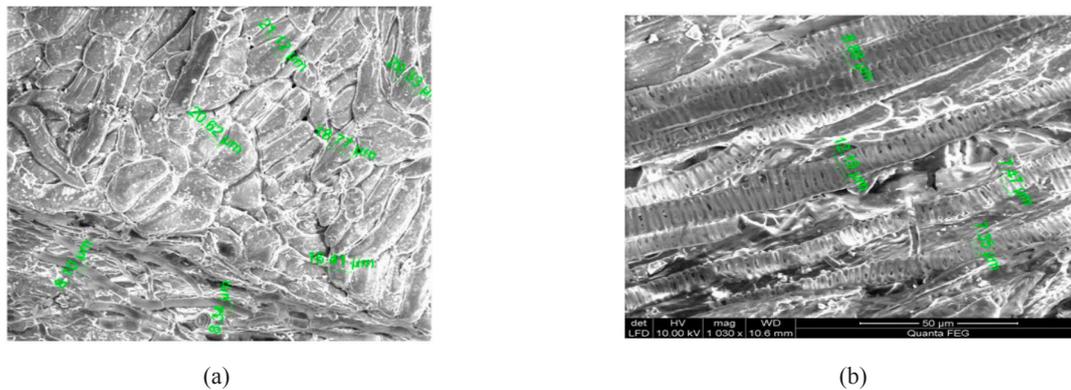


FIGURE 7. SEM images of (a) discrete cell of CS (b) continuous cells of CS (cited from Gunasekaran et al. 2012)

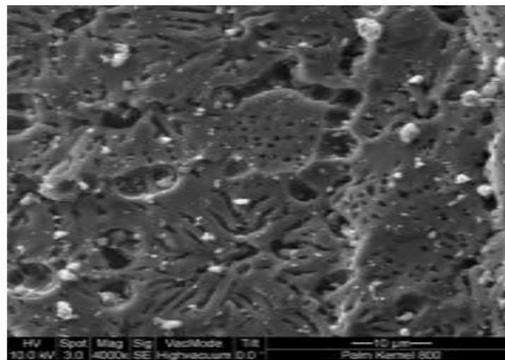


FIGURE 8. SEM images of CSA (cited from Ting et al. 2015)

To determine which phase had developed, XRD analysis was done. Jahan and Feni (2022) measured the XRD pattern for fresh coconut particles at an angle of  $5^{\circ}$  to  $90^{\circ}$  at a step rate of 0.2. The XRD pattern is shown in Figure 9 on line (a). According to Mishra et al. (2003), the most common diffraction maxima for fresh coconut are approximately  $16.6^{\circ}$ ,  $22^{\circ}$ , and  $34.6^{\circ}$ , which correspond to cordierite ( $\text{Mg}_2\text{Al}_4\text{Si}_5\text{O}_{18}$ ), quartz ( $\text{SiO}_2$ ), and moissanite (SiC), respectively. Quartz exhibits the maximum intensity. According to Szlek et al. (2022), the diffraction maxima at 2 theta of  $27^{\circ}$  and  $44^{\circ}$  correspond to sodalities and silicate minerals, respectively.

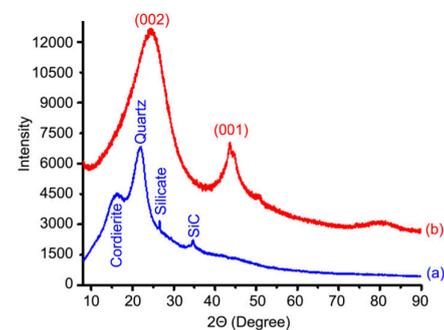


FIGURE 9. XRD diffraction pattern of raw coconut shell (cited from Jahan and Feni, 2022)

## ISSUES RELATED OF AGRICULTURAL WASTE AS BITUMEN MODIFIER CHEMICAL TREATMENT

Inherent qualities and characteristics of agricultural wastes provide particular difficulties when employed as a filler or binder. Agricultural waste cannot mix uniformly with bitumen and asphalt mixtures due to several of problems, including segregation. Segregation happens when the modifier separates during mixing and is unable to form an adhesive bond with the binder and aggregate (Vigneswaran et al. 2023). In addition, proper quantity and dimensions are required to prevent bitumen segregation. Salianni et al. (2021) emphasized on the crucial role of various fibre properties like the length, particle size and amount used in determining the behaviour of HMA when fibre is being used as the modifier. The research highlighted on the interlocking process that occur between the fibre surface with bitumen and aggregate. Similarly, study done by Slebi-Acevedo et al. (2019) claimed that too many fibres could produce blending issues by reducing the contact between the aggregate. In order to prevent the modifier from impairing its capacity to blend with the bitumen and aggregate, the right size and quantity of modifier are required.

Clumping was one of the most frequent issues encountered during combining modifier (Mashaan et al. 2021). The main causes of bitumen clumping are insufficient bitumen matrix dispersion or improper bitumen mixing. Figure 10 illustrates the clumping of fibres both during and after compaction. According to research by Salianni et al. (2021), even with short fibre, clumping may occur in mixtures when fibre is added either during or after compaction. As a result, the performance of fiber-modified mixes is influenced by the physical characteristics of fibres, such as their diameter and strand length, which have a substantial influence on how they interact and interlock with one another and with other HMA components.



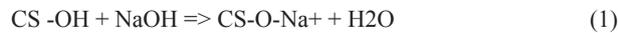
FIGURE 10. Clumping during and after compaction (cited from Salianni et al. 2021)

In order to overcome compatibility issues when adding agricultural waste to bitumen, a cooperative strategy combining chemical and mechanical treatments is needed. Mechanical treatments, such as surface roughening and crystallinity optimisation, are essential for enhancing interfacial bonding and overall compatibility, whereas chemical treatments alter surface chemistry to improve adhesion.

## CHEMICAL TREATMENT

Peschard et al. (2004) suggested that chemical treatment might encourage natural fibres' active hydroxyl groups to react with the matrix. A variety of chemicals, including silane, alkali, isocyanate, and formaldehyde agents, have been employed by numerous researchers to alter the fibre surface in order to reinforce cement and geopolymer matrices (SáRibeiro et al. 2017; Rocha et al. 2018). One of the earliest and most well-known techniques for modifying natural fibres is alkali treatment (Cho et al. 2013). Alkali treatment using sodium hydroxide (NaOH) is commonly used in adjusting the features of natural fibres which made them the best chemical solution that act as reinforcing agents in composites. Compatibility is always an issue for a composite material a incompatibility will leads to improper mixing between two materials. Application of alkali treatment towards fibre which is a cellulose-based material, not only can alter it physical and chemical properties bult also boost their mechanical properties. This improvement occurred when NaOH treatment removed the non-cellulosic component thus help to produce stronger interfacial bonding between fibre and matrix. However, excessive amount and too concentrated solution used can lead to adverse effects that weaken the fibres. Both Sanjay et al. (2018) and SenthamaraiKannan et al. (2018) agreed that balanced approach is needed where too high concentration of alkali been used ruptured the fibres properties which important for interfacial connection. NaOH solution worked by breaking down and removed the naturally exist fibre's components (hemicellulose, lignin, pectin, fat and wax) which hindered the bonding between fibre and matrix which make it less effective. At the same time, hydrogen bonds are being disrupted during this process which make them orderly arranged or crystallined structure. For instance, coconut shell fibre has naturally open structure which contains several hydroxyl and acetyl groups and gives it a high capacity to absorb water. The high-water content in untreated coconut shell fibers can lead to swelling and reduced structural stability, which limits their effectiveness in composite materials Study done by Li et al. (2022) found that the hydrophilic

properties exhibit by the coconut shell can be improved using sodium hydroxide solution. According to Equation 1, NaOH used in treating coconut shell fibre reduced the hydroxide (OH) make it less prone to absorb water.



Not only that, as most acids have the ability to change crystalline cellulose into an amorphous form, acid treatment can also be employed to treat agricultural waste. In addition to stabilizing the cell walls, especially with regard to moisture absorption and the ensuing dimensional change in agricultural waste, the esterification reaction lowers the void content of the fiber's rough surface topography, which enhances the waste's adherence to the matrix (Ukanwa et al. 2019). Throughout the procedure, acid catalysts such acetic and sulphuric acids are often used to maximise the degree of acetylation and speed up the reaction. Mishra et al. (2003) reported improved IFB characteristics of the composites utilising acetic anhydride treatment (with glacial acetic acid and sulphuric acid) on alkali pre-treated (5% and 10% NaOH solution for 1 h at 300 °C) dewaxed sisal fibre.

Meanwhile, the surface of agricultural fibre has been treated with silane treatment as a coupling agent. As useful and efficient agents for modifying lignocellulosic materials, trialkoxysilanes have drawn a lot of attention (Szlek et al. 2022). The hydrolysable alkoxy group is in charge of silanol synthesis when moisture is present. After this interaction occurred, a strong covalent connection is formed between the silanol and the hydroxyl group of the fibre. The bond eventually gets chemisorbed onto the surface of the fibre and sticks to the cell wall.

## MECHANICAL TREATMENT

Many studies have been conducted on the relationship between heat and natural fibres and how they behave in cement composites as a result. These research concentrate on the effects of heat treatment on the mechanical characteristics of fibres, such as elasticity and tensile strength, and how these effects impact the strength and durability of fiber-reinforced cement composites. The treatment of sisal fibres, which has demonstrated remarkable improvements in their mechanical qualities after undergoing particular thermal processing, is one noteworthy example. A study done by Wei et al. (2014) showed the heat treatment used on sisal fibre were done in a vented oven for 8 hours at temperature of 150 °C. From this conditions applied, the sisal fibre had an increment of 45% for it tensile strength which indicated it elasticity and at the same time the Young's modulus which indicated the

stiffness was improved up until 70%. Upon undergoing a total of 30 cycles of soaking and drying, the concrete composites' remarkable durability was associated with the improved mechanical characteristics of sisal fibre. Aside from heat treatment, another mechanical treatment is hornification, which is the process of permanently eliminating water from the cell wall fibre (Diniz et al. 2004). Wetting and drying cycles could be repeated to achieve this decrease in water retention. This phenomenon is commonly explained by submerging the fibres in water until they are fully absorbed, and then drying them for a predetermined amount of time at a temperature between 60 and 80 degrees Celsius (Claramunt et al. 2011; Ballesteros et al. 2005; Ferreira et al. 2017). This proved that hornification process can alter the fibre components and promote better interaction with the matrix. A pullout test conducted by Ferreira et al. (2017) highlighted the advantages of hornification process where the modified cement with sisal fibres underwent repeated 10 cycles of wetting and drying process. Both sisal fibre's adhesion and frictional bond strength is significantly improved compared to untreated fibres. The adhesion bond and frictional bond for treated fibre increased significantly which were 40% and 50%, respectively making them more effective as reinforcing agent for composite materials.

## CONCLUSION

In conclusion, this review aimed to explore the various types of agricultural waste generated by the agricultural industry, as well as the challenges, characteristics, and potential applications of this waste in the asphalt pavement sector. Incorporating agricultural waste into pavement construction can help reduce pollution from waste disposal, decrease reliance on landfills, and lower pavement production costs by diminishing the demand for conventional raw materials and offering sustainable disposal alternatives. Additionally, the study highlights the potential for combining materials with diverse physical properties, which opens up avenues for innovative approaches in construction practices.

By integrating agricultural waste materials like Rice Husk Ash (RHA), Sugar Cane Bagasse Ash (SCBA), Palm Oil Clinker (POCF), Palm Oil Fuel Ash (POFA), Palm Oil Bleaching Earth (POBA) and Coconut Shell (CS) with asphalt, the research promotes sustainable infrastructure development. These materials also contribute to improved mechanical performance in asphalt mixes, particularly in terms of fatigue resistance, permanent deformation, moisture damage resistance, and Marshall properties. This

approach supports the broader goal of fostering environmentally responsible growth. However, there is still a lack of comprehensive data on asphalt mixtures treated with agricultural waste, indicating opportunities for further research and development in this area. The findings from this review could assist in advancing national infrastructure development through the strategic use of agricultural waste materials, thereby encouraging the adoption of environmentally sustainable construction practices.

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### DECLARATION OF COMPETING INTEREST

None.

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