UTILIZATION OF ALTERNATE PAVEMENT MATERIAL IN PAVEMENT CONSTRUCTION: A SYSTEMATIC REVIEW

Abstract

This paper provides a detailed review of different alternate materials being used optimally in asphalt mixes. It demonstrates that various waste materials, including Reclaimed Asphalt Pavement, fly ash, various shells, geopolymer, rubber, scrap tires, plastic waste, bamboo, jute, crushed glass, etc., can be alternatively employed in the production of asphalt mix. In nations such as India, waste generated from different sources is typically subjected to incineration, open burning, disposal into landfills or water bodies, and discharge into sewers. This underscores the potential for utilizing waste as an alternate construction material in pavement development, particularly in developing nations like India, where consumption is high and disposal space is limited. Additionally, the imperative for efficient energy usage and the global concern for climate change make it essential to reduce pollution and enhance recycling and reuse. Therefore, the integration of such practices into civil engineering scenarios is crucial to meet environmental standards. This study assesses the diverse applications of alternate waste in sustainable pavement construction and reviews existing research on the reuse of some waste alternate materials as road construction materials and their sustainability. Further, associated challenges in implementing alternate materials in road construction have been discussed.

Keywords: RAP; RCA; Fly ash; Geopolymer; GGBS; Plastic.

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I. INTRODUCTION

The generation of huge quantities of waste in conjunction with global warming and enhanced emissions has become a significant concern across all genres. Incorporation of alternate materials in asphalt mix has the potential to substitute the conventional natural aggregate and binder material (Choudhary et al., 2012; Al-Hdabi, 2016). The use of alternate waste materials for the construction of asphalt mixtures has become a prominent technique due to its dual benefits of reducing the demand for new or reconstructed pavement materials and addressing the disposal challenges associated with various waste materials. Utilizing materials such as regional, waste and recycled materials can help to reduce gas emissions associated with the development of new road materials (Nandal et al. 2023). By leveraging locally available recycled materials and implementing appropriate guidelines and standards, countries can optimize the use of resources, reduce waste generation, and mitigate the environmental impact of road construction activities (Kumar & Shukla, 2022). According to The energy and resources institute report, India produces more than 62 Million Tons (MT) of waste annually, yet only 43 MT of it is collected. Among the collected waste, 12 MT undergoes treatment before disposal, while the remaining 31 MT is disposed of in waste yards without proper treatment. Certain waste materials, such as RAP, are being utilized as alternative materials (Arshad, 2020), light weight cellular concrete (Ni et al.,2020), recycled concrete aggregate (Akbamezhad et al.,2013), Fly Ash (Singh and Murthy, 1998; Suryanarayana, 2000), Coconut Shells (Nagarajan et al.,2014), palm Shells (Putri et al.,2015), egg Shells (Amu et al.,2005), geopolymer (Milad et al., 2021), ground granulated blast furnace slag (Manohar et al., 2019), rubber (Farina et al., 2007), crushed glass (Gedik et al., 2021), plastic (You et al., 2022), bamboo (Kaur et al., 2022), jute (Kumar et al., 2004), etc.

The pavement is susceptible to different forms of distress such as cracking, rutting, and deformation due to the combination of factors like heavy traffic loads, environmental conditions, and aging, when it reaches towards its design life (Vishnu et al., 2021). Figure 1 describes the typical cross-section of flexible pavement structure showing the different layers of pavement structure. This paper reviews the relevant literature to discuss the alternate pavement materials that could reduce the consumption of natural aggregate and binder in asphalt mixes for the construction of the above-mentioned bituminous layers of pavement structure. The generation and its effect on pavement construction were reviewed. The utilization of waste materials in pavement construction can have significant environmental and economic implications, which contribute to overall sustainability were also discussed.

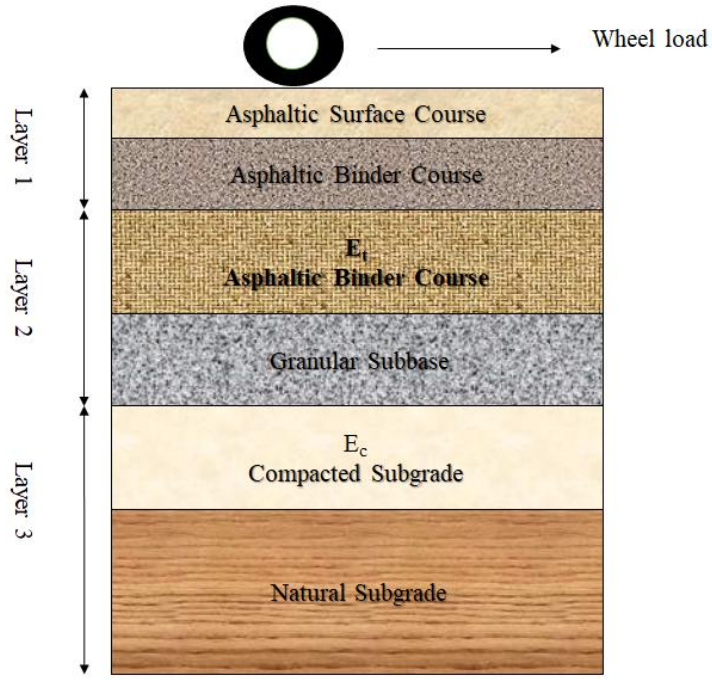

Figure 1: Cross-section of flexible pavement

II. GENERATION OF ALTERNATE MATERIALS

Alternate materials are used as non-traditional or unconventional materials in asphalt mixes. These materials are substitutes for natural aggregate as they reduce the cost of construction and are eco-friendly. Various types of available alternate materials and their generation are described below.

1. **Recycled Asphalt Pavement:** The process of milling and crushing distressed or aged asphalt pavement results in the production of recycled asphalt pavement (RAP). This process involves removing the old asphalt pavement, breaking it down into smaller pieces through milling and crushing, and then combining it with new asphalt binder and aggregates to create recycled asphalt mixtures (Mondal et al. 2022a). RAP typically consists of two primary components: bitumen and aggregates. Bitumen binder is a complex mixture primarily composed of hydrocarbons, which are organic compounds containing hydrogen and carbon atoms. However, bitumen can also contain small amounts of other elements such as oxygen, sulfur, and nitrogen, as well as trace elements and compounds. It has been observed that there is a reduction in global warming (20%), energy consumption (16%), water consumption (11%), life cycle expenses (21%), and hazardous waste creation (11%), when using RAP in the construction of asphalt base and sub-base layers (Lee et al.2023).

2. **Recycled Concrete Aggregate:** Recycled Concrete Aggregate (RCA) is created by crushing and processing waste concrete material from various sources, such as broken concrete, damaged masonry, and distressed rigid pavement slabs (Ding et al., 2016). The direct application of RCA in bituminous mixtures is not recommended for the construction of pavement (Akbarnezhad et al., 2013).

3. **Fly Ash:** Fly ash (FA) is a by-product of coal combustion in thermal power plants. When coal is burned to generate electricity, various by-products are produced, and fly ash is one of them. An estimated 100 million tonnes of fly ash are produced annually by thermal power plants in India. This large volume of fly ash poses challenges for disposal and management, requiring significant land usage and creating environmental and health risks (Singh and Murthy, 1998; Mondal et al., 2022a; Mondal et al., 2023b). One of the most important methods for handling the massive amounts of fly ash produced by power plants is to use it in construction projects like roads and embankments. (Boominathan and Kumar, 1996; Singh et al., 1996; Suryanarayana, 2000).

4. **Coconut Shells:** The coconut is a highly versatile fruit with various parts having multiple uses. The copra, or coconut meat, is the edible part of the coconut fruit and is commonly dried and used to extract coconut oil, which is widely used in cooking, cosmetics, and as a biofuel feedstock. The husk of the coconut is the fibrous outer layer surrounding the nut. It can be used for making ropes, mats, brushes, and handicrafts. The hard shell of the coconut is another part with potential uses. While it is often discarded as waste, coconut shells can be utilized as a source of energy through pyrolysis or carbonization processes. This involves heating the shells in the absence of oxygen to produce charcoal, which can be used as fuel for cooking and heating, as well as for industrial applications like water purification and metallurgy (Nagarajan et al., 2014).

5. **Palm Shell:** Indonesia is one of the world's largest producers of palm oil, with extensive plantation areas dedicated to its cultivation. Indonesia has approximately 21.4 million hectares of plantation areas and about 42.39% of Indonesia's plantation land is planted with oil palm trees. From the total plantation area, approximately 9.07 million hectares are dedicated to producing crude palm oil (CPO). CPO is the primary product derived from palm oil fruit bunches and serves as a key commodity in the global vegetable oil market.

6. **Egg Shells:** Eggshells are remarkable structures with various properties, but it's important to clarify some aspects regarding their strength and durability. Eggshells are formed in layers within the oviduct of birds. The process of eggshell formation, known as calcification, occurs over about 20 hours before the egg is laid. The rate of calcium deposition is 2.2% per hour for the initial four hours. After the first four hours, the rate of calcium deposition increases to 5.6% per hour for the next sixteen hours. But a total of 47% of skeletal calcium is diverted to outer eggshell formation. This means that nearly half of the calcium stored in the bird's skeletal system is utilized for the formation of the eggshell. Table 1 displays the composition of the egg shell powder. It’s common to observe four distinct layers in an eggshell under a microscope, these layers are typically: cuticle layer (outermost layer), foam layer (mammillary layer), spongy or palisade layer and membrane layer (innermost layer). Overall, eggshells serve as a natural and sustainable source of lime in agriculture, contributing to soil health and plant productivity (Amu et al., 2005).

Table 1: Chemical composition of egg shell powder (Razzaq et al., 2018)

Composition	Percentages
CaO	47.49%
SO_3	0.38%
Na_2O	0.14%
SiO_2	0.11%
Al_2O_3	Nill
Fe_2O_3	Traces
MgO	Nill
K_2O	Nill

7. **Geopolymer:** The production of geopolymers at room temperature has the advantage of being environmentally friendly due to its decreased energy consumption, reduced carbon emissions, and use of low-cost waste materials such FA, silica fume, different kinds of clays, and agricultural wastes (Odion et al., 2003). The presence of impurities like iron and calcium might cause variations in the consistency of fly ash characteristics. Geopolymers are synthesized from aluminosilicate materials, and fly ash is a common source of such materials (Kuenzel et al., 2013). Geopolymers typically require a chemical activator to initiate the polymerization reaction between the aluminosilicate precursor and the alkaline solution. Chemical activators that combine metal alkali and silica in an aqueous solution with a molar ratio SiO_2:M_2O greater than 1.65 are commonly used in the production of geopolymers. In this case, M stands for either potassium or sodium, an alkali metal (Hoy et al., 2016).

8. **Granulated Slag:** Ground Granulated Blast Furnace Slag (GGBS) is a by-product of the steel and iron industry, rich in lime content, and it exhibits latent hydraulic properties, making it a valuable material in cementitious applications (Mondal et al., 2023a). When GGBS is used as the sole binder in concrete, it typically requires an activator to enhance its reactivity and promote the formation of cementitious compounds. Sodium hydroxide, potassium hydroxide, or sodium silicate act as activators for GGBS, supplying essential alkalinity. This alkalinity aids in dissolving the glassy phase of GGBS. As a result, it facilitates the formation of crucial cementitious compounds like calcium silicate hydrate (C-S-H) gel. These compounds play a pivotal role in enhancing the strength and durability of the resulting material.

9. **Rubber:** The mixture of natural and synthetic rubber, carbon black, fillers, antioxidants, and oils that dissolve paving grade binder is known as waste tyre rubber, also occasionally called crumb rubber. There are two major ways to include tyre rubber in asphalt binders. In the first, crumb rubber is dissolved into the asphalt and used as a binder modifier. In the second, some of the fine aggregates are swapped out for ground rubber, which doesn't completely react with bitumen (Huang et al., 2008). Alternatively, scrap tyres can be used to make crumb rubber. To do this, they must first be shredded into tiny pieces using specialised machinery like granulators or shredders. This shredding process helps to reduce the size of the tires into more manageable pieces for further processing. After shredding, the tire pieces undergo further processing to remove any

remaining fibres (such as nylon or polyester) and steel wires. There are three main classes of crumb rubber as per their particle size.

10. **Crushed Glass:** Glass waste is not perishable or combustible, managing it at the throwaway level presents a serious environmental problem, especially given the ongoing scarcity of space for dumps (Hayat, 2023; Muthuraman and Ramaswamy, 2019). It is also known as cullet, and its volume has been steadily increasing over the years. This waste was about 5% of the total waste generation in 2016 (Kaza et al., 2018). The global glass bottles and containers market produced 630.52 billion units in 2020 and is projected to touch a production number of 883.52 billion units by 2027 with a compounded annual growth rate of 4.4 % during the years 2022-2027. Glass is generally considered inert and resistant to many chemical substances and could take hundreds of years to biodegrade naturally (Salamatpoor & Salamatpoor, 2017). It is primarily composed of amorphous silica, can react with alkalis, such as potassium and sodium, found in high concentrations in certain materials like high alkali Portland cement.

11. **Plastic:** Polymers, which are large molecules formed of modular components called monomers, are the group of synthetic materials that make up plastics. When these polymers are being manufactured, they can be shaped and moulded into a variety of shapes. It is transparent, poor electrical conductivity, and low density. In general, plastics come in a variety of forms, such as polystyrene, polymethyl methacrylate, polyvinyl chloride (PVC), and polyethylene terephthalate (PET) (Priyanka et al. 2021). A million plastic bottles are produced worldwide every minute, according to reports (Laville et al., 2018), of which less than half are gathered for recycling and fewer than 7% are used again to make plastic bottles. Additionally, by the year 2050, it is expected that the weight of plastic in the oceans would surpass that of fish as per the New Plastics Economy report (2016). The most common type of polyethylene is Low-density polyethylene (LDPE) which is produced from ethylene monomers ($CH_2 = CH_2$). It's characterized by its softness, flexibility, and resistance to moisture, making it suitable for various applications and its versatility has led to its wide use in everyday products like plastic bags, food packaging, and various containers (Wong et al.2017).

12. **Bamboo:** Bamboo is a perennial grass with woody stems (Basoeki & Bagio, 2016; Mudjanarko et al., 2017) and the rate of water absorption is 15-20%. Bamboo biomass is valued for its many beneficial qualities, including affordability, availability, quick growth rate, low weight-to-height ratio, capacity to support loads, and environmental friendliness (Kaur et al., 2022). Bamboo has a long history of traditional uses in a variety of industries, including the manufacturing of paper, pulp, food, building, and construction. Bamboo charcoal coated with nanoparticles ($NiOZnO_5Fe_2O_4$ and silver) has demonstrated shielding properties against microwave and infrared radiation. Charcoal made from bamboo has great therapeutic qualities, is an effective medicine delivery system, and offers a tonne of business opportunities for small and medium-sized businesses. Additionally, bamboo charcoal is being studied for its potential as a blood purifier and toxin adsorber (Kaur et al., 2022).

13. **Jute:** Globally India is the largest jute producer, nearly 60% of the world’s jute production. Annual production is about 1968000 tonnes. The main industrial use of jute fibers in India is for making ropes, carpets, doormats, foam-backed carpets, and other

decorative items (Patel & Patel, 2018). Jute is often referred to as the "golden fiber" due to its shiny golden color and the primary components of plastic comprise 62% of alpha cellulose, 24% of hemicelluloses, 12% of lignin, and 2% of miscellaneous constituents.Two types of jute are available in our country –tossa & white jute. Table 2 shows the properties of jute (Aggarwal & Sharma., 2010). Table 3 presents the properties of the alternative materials under study in a concise manner.

Table 2: Properties of Jute

Specific Gravity	1.12
Diameter Used (mm)	2-8
Colour	Yellowish brown
Hoiocelluiose (%)	83-87
Lignin (%)	12-14
Nitrogen (%)	0.4
Wax (%)	0.4-0.81
Ash (%)	0.5-1.04

Table 3: Properties of the studied alternate materials

Alternate material	References	Specific gravity (gm/cc)	Water absorption (%)	Asphalt content (%)	Density (kg/m^3)	Impact value (%)	SiO_2 content (%)	CaO content (%)
RAP	Rout et al. 2023	2.4-2.49	0.5-1.78	2.16	1395.2-1543.8	10.2-12.56	-	-
RCA	Meena et al. 2021	2.14-2.76	2.05-3.7	5	1784	12.5-26.4	54.67	17.38
Fly ash	Mishra & Gupta 2017	1.9-2.55	1.52	5	1220	9.84	-	-
Coconut shells	Yuliet & Permana 2021	2.591	7.8	-	1515	-	4.64	6.26
Palm shell	Tagbor et al. 2022	2.4-2.9	<2	5	2400-2900	<21	-	-
Egg shell	Razzaq et al. 2018	2.6	1.2	5	2.138-2.25	-	0.11	47.49
Geopolymer	Malid et al. 2021	2.2-2.6	7	5	2130	-	52-95	0.03-10
GGBS	Shalan et al.2019	2.78	<1	-	-	4-6	30.7	42.4
Rubber	Deshmukh et al. 2017	1.015	0.71	6	922-961	-	-	-
Crushed glass	Salem et al. 2017	2.248	-	5	2123-2251	-	60-70	9.1-9.8
Plastic	Nawir et al. 2021	-	-	5.5	940	14.5	-	-
Bamboo	Ahmed et al. 2022	2.325	4.4	5.2	1170	-	-	-
Jute	Zeleke et al. 2023	1.12	11	5-7	1300	-	-	-

III. UTILIZATIONS OF THESE ALTERNATE MATERIALS IN ASPHALT MIXES

1. RAP

Pradyumna et al. (2013), used RAP and virgin mixes in bituminous road construction and finally, the laboratory test result showed that the asphalt mixes containing RAP with rejuvenating agent provide improved performance compared to virgin mixes. It can be inferred that the recycled asphalt mix is less prone to moisture damage because the values obtained for 20% RAP mixtures are greater than those for virgin mixes. At 35°C and 45°C, it was discovered that 20% RAP mixes had less cumulative permanent strain after 10,000 cycles than virgin mixes. This suggests that compared to virgin mixes, RAP mixes have a higher capacity to withstand rutting.

Tarsi et al. (2020) studied the use of high-content RAP aggregates in new asphalt mixtures and also discussed the advantages from an economic and environmental standpoint. This study emphasises the idea that RAP mixes are inferior to virgin mixes due to factors like variability in sources, technological limitations, stiffer material, absence of RAP characterisation techniques, etc. This study further suggested that the life cycle cost analysis is an important tool for designing construction materials for transportation infrastructures, including asphalt mixtures.

Arshad & Ahmed (2017) focused on the characteristics of blended materials containing RAP (50%) and RCA (75%) to know the suitability of uses in granular base and subbase layers of pavements. The result shows that 75% RAP content in the mix increases the Resilient Modulus at higher stress levels compared to the 50% RAP content. Similarly, as RAP percentage rises from 50% to 75%, residual strains may become visible. The outcome also suggests that blends incorporating granular samples are investigated for their stiffness and deformation capabilities using RAP materials containing larger-sized particles (up to 50 mm).

2. Recycled Concrete Aggregate (RCA)

The experiment done by Nwakaire et al. (2020), evaluated mixtures with different percentages of coarse granite and RCA. This study revealed that the mix containing 40% RCA replacement performed similarly to the mix containing 100% coarse granite. In particular, the mix containing forty percent RCA had an indirect tensile strength of 1051 kPa and a resilient modulus of 9340 MPa, which were comparable to the values of 9496 MPa and 1058 kPa found in the mix including 100% coarse granite. It was concluded that a forty percent RCA replacement is suitable for pavement applications.

Arshad & Ahmed (2017) conducted a study to determine if materials comprising RAP with fresh materials and RCA are suitable for granular base and sub-base layers of flexible pavements. The research discovered that the mix with seventy-five percent RAP material and twenty-five percent fresh material showed a significant improvement in their resilient modulus (M_R) values, particularly at greater bulk stress levels. Furthermore, there was a growing trend in the constrained modulus (Mc) test findings as the level of axial stress increased. But when the proportion of RAP content increased, the Mc value dropped.

The behaviour of RCA treated with lime fly ash as a material fpr base course for rural roads is investigated by Kumar & Shankar (2022). In this study, RCA material with ten, fifteen and twenty percent lime-fly ash concentration was stabilized using a 1:2 lime-to-fly ash ratio. The test findings showed that increasing the lime fly ash content by 10-15% is adequate to achieve the 3 MPa strength and durability criteria for stabilizing RCA. This suggests that LFA can successfully improve RCA's mechanical qualities, making it appropriate for use in road construction. Additionally, the design and analysis demonstrated that fatigue and rutting performance are met by a pavement with lime-fly ash RCA at a thickness of 215–250 mm as the base layer for various traffic and subgrade circumstances. The pavement structure was designed for three distinct uses and was based on IRC: SP: 72-2015. The three subgrade situations having CBR of 5%, 7%, and 10%. The traffic categories range (0.6 msa-1.0) msa; (1.0 msa-1.5 msa); and (1.5 msa-2.0 msa).

3. Fly Ash

Woszuk et al. (2019) make use of characteristics of mixtures in which FA was replaced for typical limestone filler in different proportions (25%, 50%, and 75%). For the testing, two varieties of FA—class F and class C—were utilized. The air void content for the samples that had fly ash added varied from 1.2% to 1.6% for class F fly ash and class C fly ash ranging between 1.3% to 2.8%. The samples that had class F and class C fly ash added had water and frost resistance of around hundred percent and around hundred three percent, respectively. The findings show that both fly ash classes (Figure 2) can be used in asphalt mixtures as substitute mineral fillers. The significant chemical composition in class F's and class C's fly ash is observed as a presence of SiO_2, Al_2O_3, Fe_2O_3, CaO, MgO, and K_2O (Milad et al., 2021).

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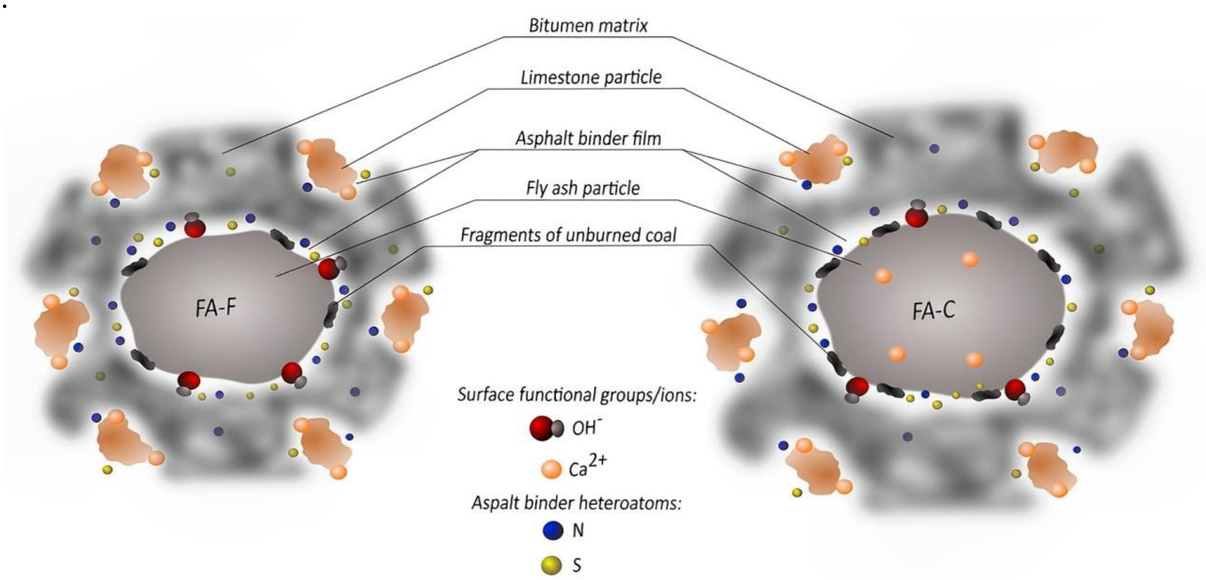

Figure 2: Fly ash, Class F and Class C (Woszuk et al., 2019)

Mistry & Roy (2016) looked at the impact of employing FA as an alternative filler in bituminous mixtures rather than Hydrated Lime (HL) in another study. Using 2% HL in the control mix and variable percentages of FA (from 2% to 8%) in modified mixes, samples were generated with varying bitumen levels (from 3.5% to 6.5% at 0.5% increments). According to the testing findings, the mixture with 4% FA as the ideal filler content outperformed the reference mix regarding stability and had a reduced optimum bitumen content. Whereas, Paul et al. (2021) utilize the FA and glass powder as fillers in steel slag bituminous mixtures for road construction.

4. Coconut Shells

The study by Suchithra et al. (2021) focused on using coconut shell ash as a modifier in bitumen to lower the cost of bituminous roads. The ash was added in varying percentages (0%, 4.5%, 5%, 5.5%, and 6%) to the bitumen. The results show that modified bitumen had better workability compared to 100 percent bitumen. This suggests that the use of coconut shell ash as a modifier not only reduces costs but also improves the workability of binder. Another study done by Girish et al. (2020) focused on using Coconut Shell Charcoal as a partial replacement for stone dust in bituminous concrete (grade 1) for the surface course. According to the findings, a 4.5% binder content and 8% coconut shell charcoal powder produced the highest stability value. Additionally, the percentage of air voids decreased as the bitumen content increased.

Patil et al. (2020) experimented to compare the effectiveness of different fillers, including Stone dust, fly ash, cement, and Coconut Shell Charcoal, in enhancing the properties of Stone Mix Asphalt (SMA) for road pavement improvement. The study will vary the binder content (4%, 5%, 5.5%, 6%, and 7% by weight of aggregates) and use 0.3% by weight of aggregates as the optimum binder content. The Marshall test method is employed to carry out the experiments and obtain accurate results. By comparing the stability and flow parameters of Coconut Shell Charcoal with other fillers, the study aims to establish the ideal combination that can be used as a substitute filler to enhance the durability of road pavements.

The study carried out by Syammaun et al. (2019) concentrated on the replacement of low-density polyethylene (LDPE) plastic waste with coconut-shell ash (CA) as a filler in porous asphalt mixtures. The optimum bitumen content (OAC) of the original bitumen content, without the use of substitutes, was discovered to be 5.76%. The OAC stayed at 5.76% when 50% CA was utilised as filler and LDPE was utilized as a substitute at 3%, 5%, and 7%. The mixture including 3% LDPE substitution satisfied all the requirements at this OAC value. The values were as follows: 560.50 kg, 18.61%, 4.3 mm for Marshall Stability, voids in mineral aggregate, flow.

5. Palm Shell

The possibility of utilising waste plastics (WP) as a binder and palm kernel shells (PKS) as a partial substitute for aggregates in asphaltic mixtures was examined by Tagbor et al. in 2022. The bitumen contents of the mix design samples varied from 4 % to 7.5 % of the aggregates' total weight. According to the Marshall criteria, the flow value ranged from 3.0 mm to 3.7 mm and the maximum Marshall Stability value of the different mix designs increased from 9.8 kN to 12.1 kN at 5.5% bitumen content. The findings of the experiments, which were based on the Marshall method's optimal bitumen content, show that mixtures can be modified by using PaKS and WP.

Samuel (2020) examined the possibility of substituting coarse particles for part of the palm kernel shells in road binder courses, concentrating on the strength of the bituminous mixtures as demonstrated by the Marshal parameters. The purpose of the study was to determine whether palm kernel shells might be used in place of coarse aggregates in pavements. According to the study, palm kernel shells can substitute coarse aggregate up to 20% of the time without significantly lowering strength. It is advised to replace palm kernel shells on heavily used roads with up to 10% of them; on weakly trafficked roads in rural areas, replacements up to 70% can be made. Table 4 displays the palm kernel shells' physical characteristics.

Table 4: Properties of the Palm Shells (Samuel, 2020)

Property	Value
Dry density (Mg/m^3)	0.66
Specific gravity	1.63
Bulk density (Mg/m^3)	0.72
Water content (%)	9
Impact Value (%)	4.48
Water absorption (%)	13
Void ratio	0.41
Porosity (%)	29

6. Egg Shells

Eggshells have been investigated by Erfen & Yunus (2015) as a potential replacement for Portland cement in bituminous mixtures. They assessed the utilisation of eggshell content rates at zero, one, three, and five percent. The outcomes demonstrated that its content in the range of three to five percent was successfully utilised by both the modified and regular samples. Tests for specific gravity were also performed, and the results showed that using this material as a filler lowered the specific gravity.

Razzaq et al. (2017) sought to accomplish the goals of lowering expenses, increasing the economy of hot mix asphalt (HMA), and decreasing weight percentile by introducing eggshell powder as a sustainable modifier. To evaluate the mechanical and physical qualities of HMA and asphalt cement, they added eggshell powder to the asphalt at different weight percentages (3%, 5%, 7%, 10%, and 15%). The study discovered that penetration and rotational viscosity decreased and flash point increased with increasing eggshell powder content.

Using eggshell powder (EP) as an ingredient, Chee et al. (2022) examined the chemical and physical characteristics of Stone Mastic Asphalt (SMA). They tested combinations of 0%, 4%, 8%, and 12% EP to find the ideal percentage of EP as a bitumen modifier. The outcome showed that the ideal bitumen modifier proportion for SMA was 12% EP. The mechanical properties increased in strength from 201 kPa to 230 kPa.

7. Geopolymer

The strength development of the geopolymer-RAP-FA as a material for pavement is examined by Hoy et al. (2015). Solouki et al. (2022) suggested the use of thermally treated waste silt as a double-recycling technology by using it as a grouting material and filler for the bituminous mixtures of a semi-flexible pavement (SFP) based on geopolymers. SFP combines the advantages of cement concrete pavements' rigidity and the flexibility of typical asphalt pavements. To accomplish this, waste silt from a nearby asphalt company is heated to 750°C and utilised as filler to create the porous structure. The grouting material is made of two separate substances: traditional cement-based cement and cement based on geopolymers. Metakaolin (MK), a potassium-based liquid hardener, and calcined silt are combined to create geopolymer grout. Moisture sensitivity, indirect tensile strength (ITS), and indirect tensile strength modulus are used to characterise the porous and grouted samples. The results of using thermally treated waste silt as a filler in mixture are encouraging and are similar to control specimens made with limestone filler.

8. Granulated Slag

According to Du (2018), base course asphalt emulsion mixture (AEM) and limestone filler were replaced with GGBS activated by hydrated lime. In a subsequent study by Mahto & Sinha (2022), bitumen emulsion was utilised to pre-coat the aggregates in order to prepare warm mix asphalt (WMA) mixtures. To further improve the environmental benefits, industrial wastes were employed in place of typical filler in these mixes. The disposal of marble dust (MD) and GGBS, which are produced in large quantities, is a major problem. These were added in different proportions (between 2% and 8% of the mix's weight), and the durability and strength of the WMA were assessed. Comparing the WMA findings to the control mix, it was found that the addition of both MD and GGBS as fillers greatly enhanced the results for stability, ITS, TSR, Cantabro loss and rutting. On the other hand, emulsified warm mixes with GGBS filler also shown improved moisture resistance. When employing slag as opposed to marble dust filler, rut depth was found to be lower. Acikok et al. (2018) looked into the impact of slag and FA on concrete pavement design in another experiment. The water to cement ratio is 0.42 and the cement dose is 350 kg/m3. There are three different concrete mixes made. FA and GGBS (reference concrete) are absent from the first batch of concrete. Fly ash is used in place of 20% of the Portland cement in the second concrete batch. Ultimately, the third concrete has slag that has been 20% displaced with cement.

9. Rubber

Natural Rubber (NR) is a bio-modifier used in pavement construction by Ansari et al. (2020). Warm mix additives can make up for the asphalt mixture's decreased workability caused by NR. For bitumen to function better on pavements, 4-6 weight percent of NR is the ideal composition. In the meantime, 1 kg of NR latex is produced by NR absorbing 24.9 kg of CO_2. By assessing the toughness and absorbed energy of these mixes, Fakhri & Amoosoltani (2017) examine the impact of RCC mixes with RAP or crumb rubber, as a partial aggregate substitute on the mechanical properties of concrete pavements. The findings show that adding 5% rubber component to RCC specimens marginally (around 5%) increases their compressive and flexural strengths. Conversely, a significant drop in the specimens' flexural and compressive strengths was noted as the RAP level increased. According to the regression results, adding up to 10% rubber and 50% RAP could be a good way to extend the life of the pavement by making the mixtures more resilient and energy-absorbing. Mashaan et al. (2013) studied the impact of crumb rubber modifier (CRM) modifiers on the volumetric, mechanical, and stiffness properties of SMA mixes, this study examined the fundamental elements of modified asphalt mixtures. This study used virgin bitumen with a penetration grade of

80/100, modified with CRM at five different weight-based modification levels: 6%, 12%, 16%, and 20%. It was discovered that 12% of the bitumen's weight should be the proper amount of additional CRM. The highest possible level of stability is achieved by this percentage. Modified SMA samples with varying CRM % had a resilience modulus (Mr) that was noticeably greater in comparison with that of unmodified samples.

10. Crushed Glass

The application of glass fibres as a modifier to improve the cracking resistance of asphalt mixtures with different proportions of RAP is examined by Ziari et al. (2019). To assess the cracking behaviour of the mixes, semi-circular bending (SCB) fracture experiments were carried out at temperatures of 15, 0, and -15 degrees Celsius. The findings show that adding up to 0.12% glass fibre considerably increases each mixture's resistance to crack initiation and propagation. Additionally, the study discovers that adding 0.12% glass fibre can significantly mitigate the detrimental effect of RAP material on asphalt mixes' susceptibility to cracking. This suggests that asphalt mixtures containing 100% RAP can be used without a significant reduction in crack resistance when supplemented with glass fibers. Zakaria er al. (2018) investigates the feasibility of using recycled waste plastics and glasses as aggregate replacements in asphalt mixtures for pavement applications. Another experiment done by Tahmoorian et al. (2018) focuses on the use of recycled construction aggregates (RCA) in asphalt mixtures and the problem of high bitumen absorption associated with it. According to the test results, adding recycled glass to asphalt mixtures containing RCA may be a practical way to address the issue of high bitumen absorption. On the other hand Barraj et al. (2023) evaluate performance of glass incorporated asphalt concrete mixtures in comparison to conventional HMA. Three asphalt mixes with varying percentages of filler replacement (0%, 25%, and 50%) were fabricated and tested. In comparison to the other combinations, the mix with 25% broken glass showed superior resistance to fatigue cracking, according to the results. But when compared to traditional HMA, the rutting resistance was decreased by the glass addition in the mixes.

Salem et al. (2017) conducted a study on the performance of asphalt concrete mixtures by substituting a portion of the fractional fine aggregate with different percentages of crushed glass materials (5%, 10%, 15%, and 20%). The study found that the optimum binder content was 5.75% for 0% glassphalt and 5.35% for 10% glassphalt, which satisfied all the specified requirements. The investigation came to the conclusion that crushed glass with a maximum size of 2.36 mm and an ideal replacement ratio of 10% could be utilised in asphalt mixture.

11. Plastic

Naga & Ragab (2019) researched to investigate the effect of using polyethylene terephthalate waste plastic materials (PTP) in asphalt mixes. The modified asphalt binder's softening point was raised and its penetration was decreased by the addition of PTP, according to the test findings for asphalt binder. The outcomes also demonstrated that the asphalt mixtures' strength tended to increase with the addition of PTP. It was discovered that 12% of PTP was the ideal amount for getting the greatest results from the asphalt mixtures. Lastly, the measured benefits showed that adding 12% PTP preserved roughly 20% of the asphalt layer thickness and enhanced pavement service life by 2.81 times. Rahman & Wahab (2013) ascertain the ideal grade and impact of utilising recycled PET in modified asphalt mixtures as a partial replacement for fine aggregate. The findings demonstrated that, in comparison to the unmodified asphalt combination, the stiffness of the PET-modified mixtures tended to decrease.

Ahmadinia et al. (2012) present experimental research on the use of discarded plastic bottles, specifically PET, as an ingredient in stone mastic asphalt. A range of waste PET percentages, from zero to ten percent by weight of binder, were present in the mixtures. The experiment's findings demonstrated that 4-6 percent of the bitumen content's weight was the proper range for the amount of waste PET. To be more precise, it made the combination stiffer, reduced the amount of binder wash down, and strengthened its resistance to rutting, or permanent deformation.

12. Bamboo

Osuolale et al. (2023) investigated the potential of the possibility of employing steel slag powder (SSP) and bamboo leaf ash (BLA) in place of quarry dust (QD), a common mineral filler, in asphalt concrete binder and wearing courses. The findings demonstrated that, when compared to the control (QD), asphalt mixtures including SSP had improvements of 10%, 15%, 20%, and 25%, respectively, in ravelling resistance, rutting resistance, marshal stability, and indirect tensile strength. Nonetheless, the control's (QD) moisture resistance, fatigue, and resilience moduli increased by 15%, 20%, and 25%, respectively, in comparison to the SSP and BLA. Furthermore, the use of BLA and SSP was found to be more cost-effective than conventional fillers, with cost savings of 4.35%, 4.13%, 3.17%, and 3.03% for 1 tonne of asphalt concrete produced. Another study by Shahnewaz et al. (2023) aimed to investigate the potential of bamboo fiber in improving the physical and mechanical properties of porous asphalt addressing the performance properties of mixtures. This suggests that natural fibers like bamboo can be effective additives in alternative pavement materials in road construction. On the other hand, Ahmed et al. (2022) investigated the impact of bamboo fiber (BF) and sugarcane bagasse fiber (SCBF) on the mechanical properties of HMA. This study suggested that using both BF and SCBF fibers in mixtures can improve the performance of asphalt pavements.

13. Jute

Ghosh et al. (2014) focus on the design and engineering of Bituminized Jute Paving Fabric (BJPF) on roads with different traffic loading scenario. The performance of BJPF is assessed based on design considerations, selection criteria, and overall effectiveness in improving pavement performance. Affan & Ali (2022) investigate the effect of freeze-thaw cycles on the dynamic and mechanical behavior of plain concrete (PC) and jute fiber reinforced concrete (JFRC) in the context of pavement construction. The results showed that JFRC exhibited favorable behavior under freeze-thaw conditions compared to PC. The addition of jute fibers enhanced the resistance of mixtures to freeze-thaw cycles, leading to better properties. The study provided insights into the microstructure and potential mechanisms behind the observed behavior.

IV. CHALLENGES IN IMPLEMENTING WASTE MATERIAL

The use of waste materials in pavement construction offers numerous advantages, including environmental benefits, cost savings, and improved pavement performance. However, there are also challenges associated with the use of waste materials, including the need for initial investment in infrastructure and processing technology. One of the main challenges is the need for infrastructure to sort waste materials based on type, source, and risk. Another challenge is the need for advanced technology to process certain types of waste materials. Despite these challenges, the use of waste materials in pavement construction can offer significant long-term benefits.

The key to producing environmentally friendly asphalt and concrete mixes using waste materials lies in determining the optimal combinations of materials through laboratory experimentation. This experimentation should focus on evaluating the compatibility between the waste materials and the binder and aggregate materials, as well as identifying any potential synergistic effects. By conducting thorough testing, it is possible to develop mixes that not only reduce the environmental impact of pavement construction but also offer long-term performance benefits.

Another challenge faced while using waste material is the potential production of leachate. Leachate is a liquid that can be produced when water comes into contact with waste materials, potentially carrying contaminants that can be harmful to ecosystems.

And also, a lack of fixed replacement ratios for integrating waste materials with natural aggregates and other waste materials, which can be influenced by factors such as mechanical properties, location, handling, and parent material composition.

Other problems faced while using waste materials are compatibility, quality control, and mix design-related issues. Waste materials may not be compatible with the binder or other components used in pavement, which can affect the overall performance of the pavement. Developing a mix design that incorporates waste materials can be challenging, as it requires careful consideration of the properties of the waste material and how it will interact with other components of the pavement. Ensuring the quality of the asphalt mix when using waste materials can be difficult, as the properties of the waste material may be variable.

V. CONCLUSION

The utilization of solid waste materials in road construction is a promising area of research and development. By repurposing these materials, we can reduce the consumption of natural resources, decrease the need for landfills, and potentially improve the performance of road infrastructure. However, it's crucial to ensure that these materials are thoroughly tested and free from hazardous substances to avoid any negative environmental impacts in the long term. The study's supporting literature has provided to the beneficial effects of the wastes under investigation on several asphalt mastics and mix characteristics.

This study also emphasizes how crucial waste materials' physical and chemical properties are to their ability to perform as well as standard mixtures when it comes to incorporation for asphalt mixture productions. The advantages of employing waste extend beyond the enhancement of mixes' mechanical and durability performance. They also manifest in a noteworthy decrease in financial and environmental emissions.

ACKNOWLEDGMENT

The authors thankfully acknowledge the Department of Civil Engineering, Aliah University.

DECLARATION

"The facts and views in the manuscript are ours and we are totally responsible for authenticity, validity and originality etc. We undertake and agree that the manuscripts submitted to your journal have not been published elsewhere and have not been simultaneously submitted to other journals. We also declare that manuscripts are our original work and we have not copied from anywhere else. There is no plagiarism in our manuscripts. Our manuscripts whether accepted or rejected will be property of the publisher of the journal and all the copyrights will be with the publisher of the journal".

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