JETIR.ORG ISSN: 2349-5162 | ESTD Year : 2014 | Monthly Issue
JOURNAL OF EMERGING TECHNOLOGIES AND INNOVATIVE RESEARCH (JETIR)
An International Scholarly Open Access, Peer-reviewed, Refereed Journal

Utilization of Biomass Ash and Tile Waste Material as Replacement of Fine Aggregate in Hot Mix Asphalt

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Abstract

This study explored the use of Tile Waste Material Biomass Ash as fine aggregates, along with Polymer Modified Bitumen (PMB 40) as a bitumen modifier in hot mix asphalt (HMA). Three different combinations were tested. The integration of PMB-40 binders with DBM-II graded aggregates showed potential to enhance the pavement's design life. For the analysis, three specimens were prepared and tested to evaluate key parameters such as stability, flow value, unit weight, air void percentage, voids filled with bitumen (VFB), and voids in mineralaggregates (VMA) at binder contents of 4.0%, 4.5%, 5%, and 5.5%. The optimal bitumen concentration and highest Marshall Stability were identified. Incorporating tile waste and biomass ash as fine aggregates in hot mix asphalt provides significant environmental advantages. It improves trash disposal, conserves natural resources, lowers greenhouse gas emissions, and reduces environmental pollution. By using these materials, the road building industry may help to create a more sustainable future while boosting asphalt performance andlowering dependency on virgin resources.

Keywords

Hot Mix Asphalt, Dense Bitumen Macadam-2, Tile Waste, Biomass Ash, Polymer Modified Bitumen

1.Introduction

Worldwide road networks are developing as the number of cars on the road increases year after year, resulting in greater demand for roads. This tendency is seen in the ongoing road expansion across countries **[1]**.The International Organization of Motor Vehicle Manufacturers has reported steady growth in the number of vehicles over the past several years **[2]**. Asphalt concrete is a mix of aggregate, bitumen (binder), and filler (often limestone), commonly used for constructing and maintaining roads, parking lots, outdoor spaces, and sports grounds **[3]**. Fillers play a crucial role in asphalt pavement design by preventing incomplete constructions and enhancing stability **[4]**. These inert mineral additives are finely ground and incorporated into Hot Mix Asphalt (HMA) to improve its density and strength. To ensure durability and longevity under various conditions, fillers are selected for their ability to stiffen the binder matrix and strengthen the adhesion between the binder and aggregate **[5]**.

Clay-built structures date back to the earliest civilizations, and it has remained a popular building material due to its versatility and durability. Its continued use is attributed to its availability, ease of application, and natural insulation properties **[6]**. While clay's role inconstruction has evolved over time, it remains an essential element in modern architecture, highlighting its enduring significance in human development and settlement **[7]**. Rice mills, sugar mills, and coffee roasting facilities produce locally available materials such as sawdust ash, rice husk ash, sugarcane bagasse ash, and coffee husk ash **[8]**. In Uganda, coffee husk is being explored as a potential energy source for the cement industry **[9]**. concrete aggregatecan be use in normal construction work or sustainable pavement for rural or urban areas that might be control the depletion of the natural recourses or mining work .It is possible to usethe RCA up 30% with natural aggregate or virgin aggregate. **[10].**

Modupe et al. [11] proposed replacing quarry dust with Cow Bone Ash (CBA) as mineral filler. CBA was used to substitute the conventional filler in varying proportions of 2.5%, 5%, 7.5%, 10%, 20%, 30%, 40%, and 50%. Marshall stability tests and Artificial Neural Networks (ANN) analyses were conducted. The results showed improvements in the stability, flow, and physical and volumetric properties of the asphalt mix. Abdul Rasool et al.

[12] reported the use of cow dung ash as filler in asphalt mixtures. The results showed the highest Marshall Stability at 11.11 kN with 50% filler substitution, a 33.5% improvement over the reference mix. Additionally, the lowest flow value of 3 was recorded, representing a 17.83% decrease. The study concluded that cow dung ash can be effectively used as a filler to improve the mechanical properties of asphalt mixtures. Hassan [13] suggested that incinerator ash from municipal solid waste (MSW) can be used as a filler substitute in asphalt mixtures. The results indicated that MSW ash can be used effectively as filler, with up to 15 % suitable for bituminous surface courses and up to 20% for base courses. Sargın et al. [14] investigated the use of Rice Husk Ash (RHA) as a filler in hot-mix asphalt. The best results were achieved with 4.73% OBC using 5% filler ratio (FR). The MS test results indicated that a mixture of 50% RHA and 50% limestone produced the highest Marshall Stability.

Zainudin et al. [15] proposed using Sugarcane Bagasse Ash (SCBA) as an alternative filler in hot mix asphalt. Replacing standard fillers with SCBA improved Marshall Stability], flow, and Resilient Modulus. The study concluded that SCBA can be effectively used as a partial replacement filler in HMA. Choi et al. [16] investigated the use of waste tire-derived fuel fly ash as a filler in hot mix asphalt (HMA). The increase in tire-derived fuel fly ash is likely due to the rapid growth of the vehicle industry. TDF fly ash exhibited higher Marshall Stability compared to the other fillers. Stripping resistance tests also indicated that a higher proportion of TDF fly ash improved the degree of coating by up to 30 %.

The present suggests the use of tile waste and biomass ash as fine aggregate replacements in Hot Mix Asphalt (HMA) has a variety of consequences on the asphalt's material qualities, performance, and sustainability. Mechanical characteristics, durability, workability, and environmental advantages are some of the impacts. The use of tile waste and biomass ash as substitutes for fine aggregate in Hot Mix Asphalt can increase mechanical performance, notably strength, durability, and thermal stability. These materials also have considerable environmental benefits, including waste reduction and resource conservation. However, careful mix design and material preparation are necessary to guarantee that the asphalt retains its desirable qualities and performs effectively over time. When utilized in the proper amounts, tile waste and biomass ash can improve the sustainability and performanceof asphalt pavements.

2.Experimental Methods

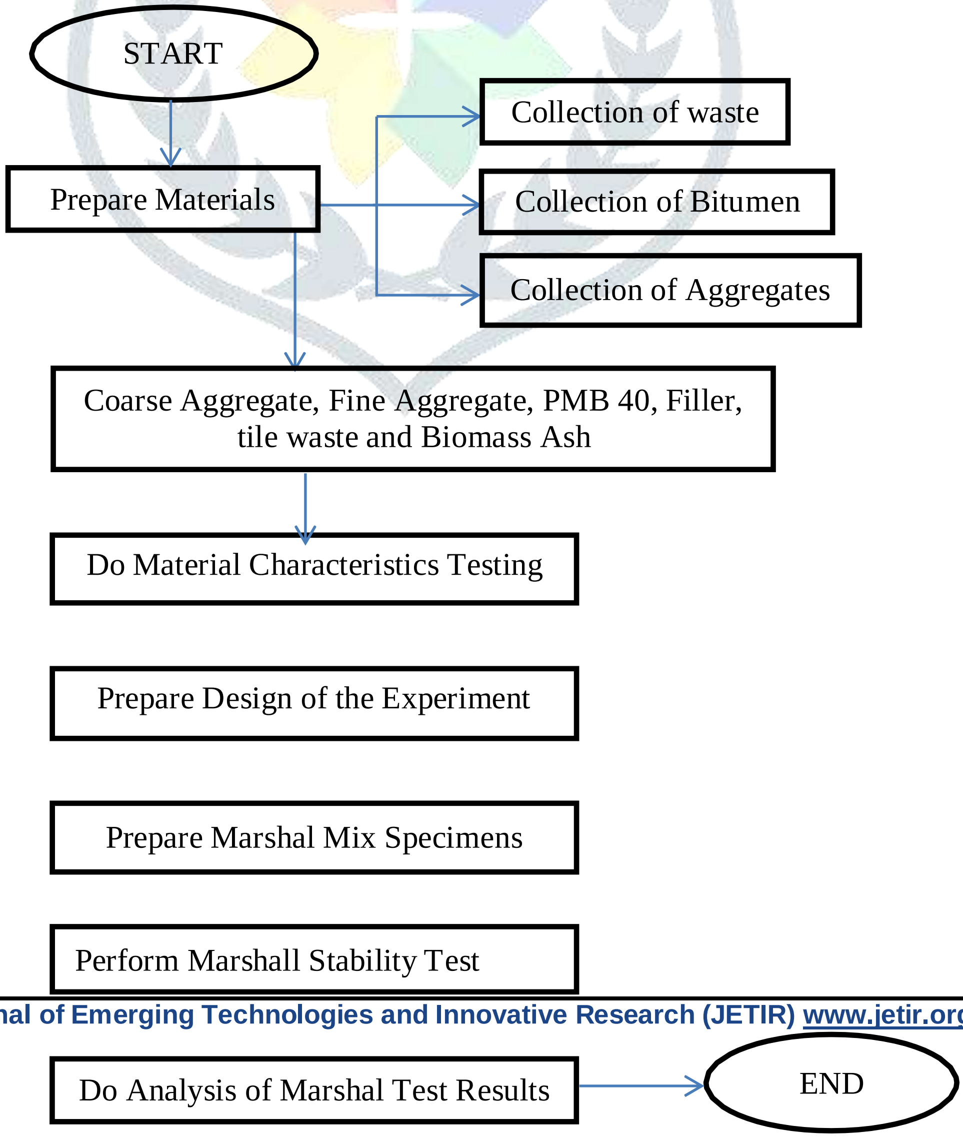

Fig. 1 Flow chart of methodology used in Experimental work

2.1 Materials

2.1.1 Asphalt Binder

Polymer Modified Binder 40 (PMB 40) is an asphalt binder enhanced by the addition of polymers. These modifications improve the binder's properties, making it more suitable for challenging paving applications, including heavy traffic and harsh weather conditions. **Table 1** shows the types of various modifiers.

Table 1 Types of Various Modifiers

Modifier type	Examples
Chemical modifiers	Lignin, Sulphur ,Organo-metallic compounds
Adhesion improvers	Amides
ThermoplasticElastomers	Styrene-butadiene-rubber (SBR), Natural rubber, Polybutadiene (PBD), Styrene-butadiene-styrene (SBS), Crumb tyre rubber etc.
Thermoplastic Polymers	Polyethylene (PE),Polyvinyl chloride (PVC), Polypropylene (PP), Ethylene vinyl acetate (EVA) etc.
Thermosetting polymers	Acrylic resin, Epoxy resin, Phenolic resin etc.
Natural Asphalts	Rock asphalt, Trinidad Lake Asphalt (TLA)
Antioxidants	Phenols, Amines
Fibres	Glass fibre, Asbestos ,Cellulose, Polyester, Polypropylene
Fillers	Lime, Fly ash, Carbon black, Hydrated lime

PMB 40 enhances aggregate adhesion, reducing the risk of stripping and extending pavement durability. Ongoing research focuses on further improving polymer-modified binders like PMB 40, developing new polymer blends, and better understanding their long- term performance under various conditions. The purpose of the improvements is to improve PMB 40's efficiency and application range, making it a more appealing option for infrastructure projects all around the world. Asphalt binder properties may be determined using a number of standard techniques. This examination involved several standard tests, including the penetration test, softening point test, and specific gravity test. The test results and apparatus for determining the physical parameters of bitumen are shown in **Table 2** and **Fig. 2**. The ductility testing machine is shown in **Fig. 3**.

Fig. 2 (a) Softening point Test (b) Ductility setup for Polymer Modified Bitumen (c) Ovenused Drying for Aggregates

Fig. 3 Ductility Testing Machine

Table 2 Test Results for physical properties of bitumen.

S. No.	Properties (Bitumen)	Test specifications	Test Result
1	Specific gravity	1-1.02	1.05
2	Penetration (25 °C, 0.1 mm, 5 sec	30-50	32.2 dmm
3	Softening point	60 °C	67.5 °C
4	Viscosity (150 °C, Centi Poise)	3-9	6.5
5	Flash point, °C	220 °C	227 °C

2.1.2 Aggregates and Waste Materials

Physical properties of the natural aggregate were evaluated, including specific gravity, water absorption, hardness, toughness, cleanliness, and crushing value. **Table 3** shows the findings.

Table 3 Test results for determination of physical properties of Aggregates.

S. No.	Property	Test Performed	Specificationsas per MoRTH	Test result
1	Specific Gravity	Specific Gravity test	-	2.42 (20 mm) 2.48(10mm) 2.18 (dust)
2	Particle shape	Flakiness and Elongation Test	Max 35%	25 %
3	Cleanliness	Grain Size analysis	Max. 5% passing 0.0750mm sieve	3.12 %
4	Strength	Aggregate ImpactTest	Max. 24 %	22 %
5	Stripping Value	Coating and Stripping bitumen Aggregate Mix	Min. Retained Coating 95%	97 %

Fig. 4 depicts the device used to grade the aggregates. The Marshal Parameters for Dense Bituminous Macadam-II are presented in **Table 4**. The mechanical properties of the mix are critical for ensuring the pavement's lifespan and functioning under traffic loads, and the machine's output helps determine these characteristics. **Fig. 5** Flexible Pavement Layer Distribution.

Fig. 4 Sieve Analysis for Aggregates

Table 4 Marshall Parameters for Dense bituminous Macadam-II

Binder Content (%)	Theoretical Specific gravity (G_t)	Bulk Specific gravity of Mix (G_m)	Voids in Aggregate (*VMA*) %)	Air Voids (V_v),%	Marshall stability (kN)	Flow Value (mm)
4.00	2.16	2.27	15.4	5.88	18	2.2
4.50	2.35	2.25	15.8	5.95	20.25	2.9
5.00	2.31	2.50	15.95	3.98	21.65	3.5
5.50	2.15	2.21	16.2	3.5	20.8	4.2

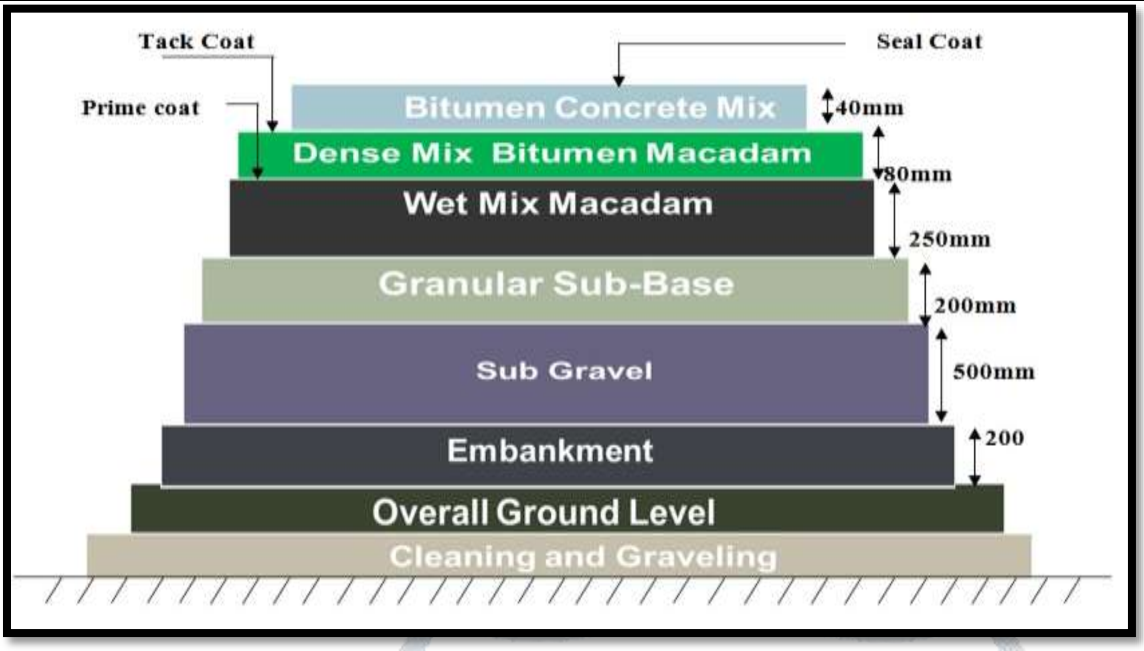

Fig. 5 Flexible Pavement Layer Distribution

3.Results and Discussion

For DBM-II, the Marshall Mix design technique was used to determine the optimal binder content (OBC). Three specimens with binder contents of 4 %, 4.5 %, 5 %, and 5.5 % were created and tested to assess stability, unit weight, flow value, percentage of air voids, voids filled with bitumen (VFB), and voids in mineral aggregates (VMA). Table 3 shows the average values for all of them. The accompanying plots, shown in **Fig. 6 - 9**, plot many parameters versus binder content to show how they alter with binder content. The average binder percentage which equates to maximum stability, maximum unit weight, and 4% air voids is known as the optimal binder content of DBM-II, and it was estimated to be 5% of the aggregate weight, as shown in **Table 5**. The goal of each mix was to see how adding more trash would impact the Marshall Mix's overall performance and stability. The inability of two samples to form emphasizes the need of understanding material compatibility and the constraints of waste material assimilation. **Table 6** shows the comparison between All Aggregates used.

Table 5 Determination of optimum binder content

OBC of DBM II using PMB 40,%	5.1
Binder content corresponding to highest bulk density ,%	5.1
Binder content corresponding to maximum stability ,%	5.3
Binder content corresponding to 4% air voids	4.7

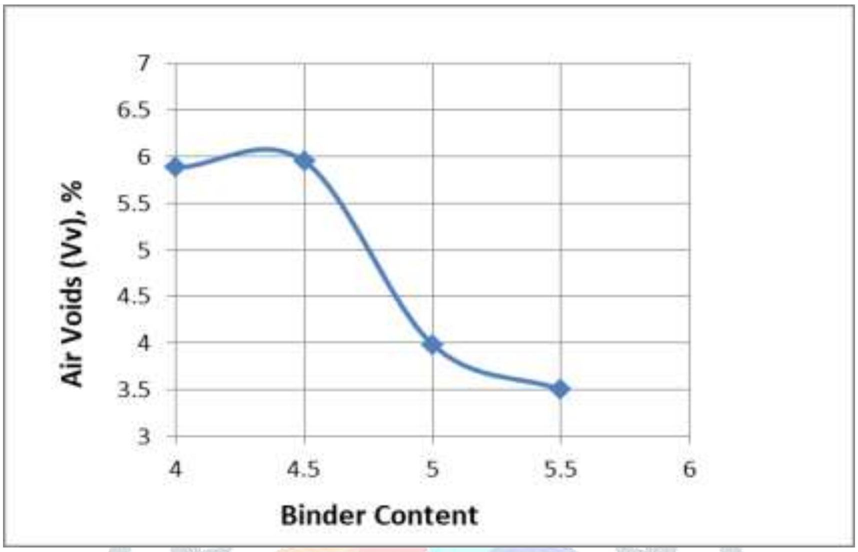

Fig. 6 Percentage Air Voids vs Binder Content

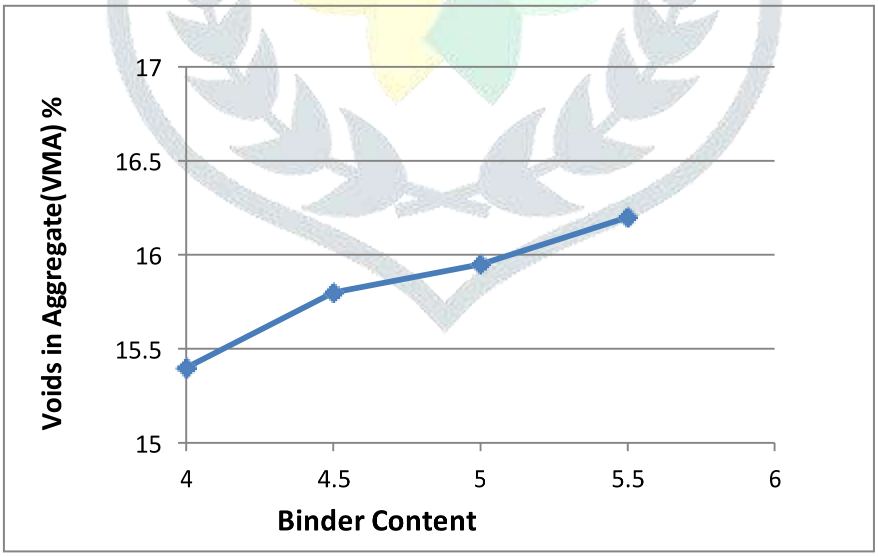

Fig. 7 Voids in Aggregate (VMA) vs Binder Content

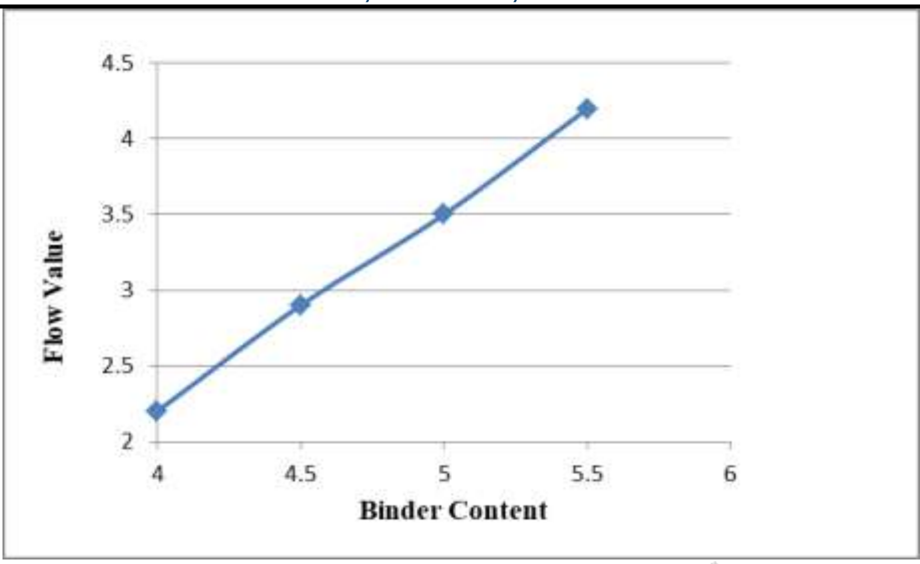

Fig. 8 Flow Value vs Binder Content

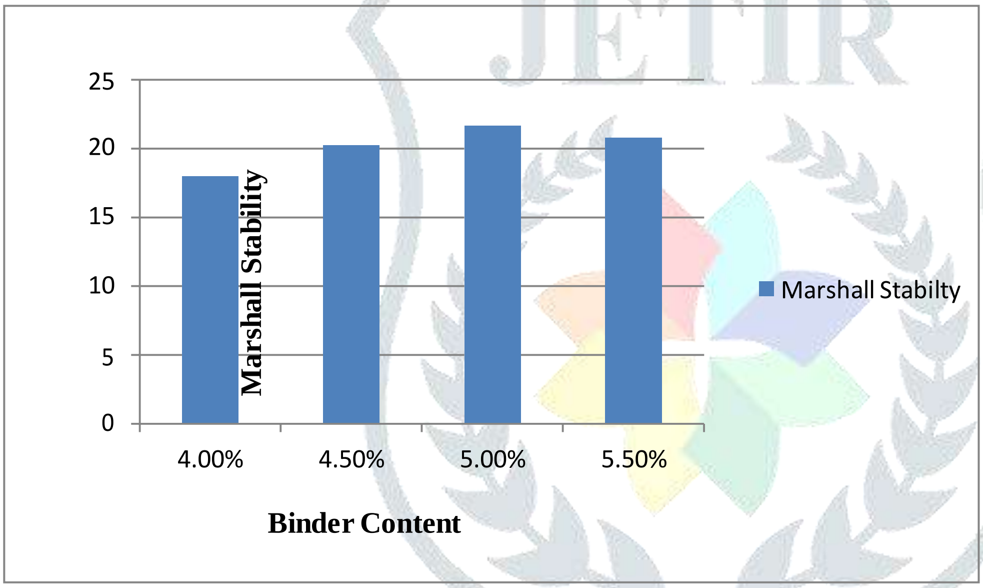

Fig. 9 Marshall Stability vs Binder Content

Table 6 Comparison between All Aggregates used

Parameter	**Conventional Fine AggregateSand**	**Terracotta Tile Waste**	**Biomass Ash**
Material Cost	High	Low (low costs for acquiring the waste product)	Low (Waste product, low procurement cost)
Availability	Easily accessible	Depends on construction and demolition waste	Limited availability (depends on industry)
Transportation Cost	Moderate to High (depending	Low to Moderate (close proximity preferred)	Low to Moderate (close proximity preferred)

	on source)		
ProcessingCost	None or minimal	Requires crushing and sieving	Requires drying and grinding
Environmental Impact	High (Depletion of natural resources)	Low (Utilizes waste, reduces landfill burden)	Low (Utilizes waste, reduces landfill burden)
Strength Properties	Standard (meets all construction standards)	Comparable with additional treatment	May require blending with other materials
Durability	High	High (if processed correctly)	Medium to High (depends on proportion)
Regulatory Approval	Standard	May require additional testing and approval	May require additional testing and approval
Market Acceptance	High (Industry standard)	Low to Moderate (depends on awareness)	Low (still under research and testing)
Overall Cost Efficiency	Standard	Potentially High (depends on scale ofuse)	Potentially High (depends on scale ofuse)

4.Conclusion

It should be noted that the major purpose of this research is to investigate whether using Terracotta tile waste and Eucalyptus Tree Ash in hot asphalt mixes for Dense Bitumen Macadam layer II (DBM-II) is technologically viable. To do this, the TTW and ETA asphalt mixes must fulfill the MoRTH regulations for the DBM -II layer, with regard to minimum standards. The laboratory testing of the glass-contained asphalt and control mixes yields the following conclusions:

• High stability is achieved at the expense of lesser flexibility and greater VMA,resulting in a brittle mix that may shatter.

• Optimal Binder Content strikes a balance between strength and flexibility, providing the greatest performance through maximum stability, balanced VMA, and suitable flow.

• High binder content produces a softer, more flexible mix with reduced stability and excessive flow, which may cause rutting or deformation under high traffic. Achieving the proper binder content is crucial for maximizing performance in terms of strength, durability, and deformability.

• Combining terracotta tile waste with biomass ash offers the added benefit of recycling both construction and agricultural/industrial wastes.

• The blend may benefit from terracotta's hardness and the fine filler properties of biomass ash, resulting in improved load-bearing and stability.

• Reducing environmental pollution, conserving natural resources, and perhaps saving money on road development.

• Terracotta tile, a ceramic material, may give greater resilience to wear and tear when used as aggregate in HMA, adding to better durability.

- The usage of terracotta tile waste decreases the quantity of building trash that ends up in landfills while also helping to conserve natural aggregate resources.
- Using biomass ash, a byproduct of agriculture and energy production, lowers waste disposal costs while also reducing the need to mine virgin resources.
- The kind of biomass and ash treatment may have an impact on the HMA's workability and compaction. The high carbon content of the ash may hinder bonding with the bitumen.

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