NILE UNIVERSITY OF NIGERIA
HONORIS UNITED UNIVERSITIES

Received: August 19, 2025

Revised: September 18, 2025

Accepted: September 18, 2025

PERFORMANCE EVALUATION OF ASPHALTIC CONCRETE PRODUCED USING GLASS WASTE AND EGGSHELL AS ALTERNATIVE FILLERS.

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ABSTRACT

Reliance on non-renewable natural resources in pavement construction poses environmental and sustainability challenges, hence possible incorporation of wastes becomes novel. This study investigates the performance of asphalt modified with glass waste and eggshell powder as alternative fillers. The materials were selected due to their distinct compositions: glass, predominantly silica-based, enhances stiffness which prevent cracks and reduces premature pavement distress, while eggshell, rich in calcium carbonate, improves adhesion and moisture resistance of pavement. Glass waste was collected, grounded and sieved through 0.075mm, also eggshell was collected, washed, dried, pulverized and sieved through the 0.075mm as required. XRD/SEM analysis was performed on the wastes to confirmed their silicate and calcium carbonate content. Marshall asphaltic concrete samples were prepared using the conventional fillers and tested for the optimum bitumen content determined as 6.53%. The optimum bitumen content was used to produce the modified asphalt with combined glass waste and eggshell as fillers at (0, 6, 12 and 18%) proportions. The modified samples were tested for stability, flow, indirect tensile strength (ITS), and moisture susceptibility. All proportion's result met the AASHTO and Nig. Min. of works specifications, with TSR values exceeding the AASHTO minimum of 80%, indicating excellent resistance to moisture-induced damage. Notably, the inclusion of eggshell powder improved the mixtures' anti-stripping properties compared to glass dust alone. Therefore, glass waste and eggshell can be combined and incorporated into asphalt mix as fillers up to 18% and will reduce the environmental challenges of wastes, cost-effective asphalt, promoting resource conservation and sustainability. Further studies are recommended to evaluate other engineering performance parameters.

KEYWORDS: Asphaltic Concrete, Glass waste, Eggshell, Mineral Fillers, Waste Management, stability, Flow, Indirect Tensile Strength (ITS), Moisture Susceptibility.

DOI: *https://doi.org/10.5455/NJEAS.277542*

NJEAS
NILE JOURNAL OF ENGINEERING & APPLIED SCIENCE

1 | INTRODUCTION

One of the seventeen objectives of the 2030 (SDG 9) Agenda for Sustainable Development Goal refers to grow quality, reliable, sustainable and resilient infrastructure, strengthening economic development and social well-being [1]. Transportation is one of the primary needs of human beings and developing a sustainable transportation facility is of main concern [2]. The productivity and efficiency of transportation infrastructures including highways, airports, railways and ports significantly depends on its structural and functional performances [3]. New pavement construction generally involves the use of high-quality materials and advanced technologies. However, this process heavily relies on non-renewable natural resources, such as quarried aggregates and carbon-based energy sources like industrial fuel and bituminous binders, [3] which places a significant strain on these finite resources. The performance evaluation of asphaltic concrete is a critical aspect of civil engineering, particularly in the context of sustainable infrastructure development. The extraction and processing of these raw materials used in the production of the conventional asphaltic concrete lead to the depletion of natural resources, environmental degradation and increased carbon emissions which posed sustainability concerns. Consequently, there is a pressing need to identify alternative materials that are sustainable, environmentally friendly, and capable of enhancing yet not compromising the engineering performance of asphaltic concrete. Replacement of waste materials in in civil engineering constructions have garnered more attention in recent time. Waste materials such as glass and eggshells, which are abundant and often considered as environmental burdens, have earned interest from researchers as potential asphaltic filler alternatives. The utilization of these waste materials not only addresses the issue of waste management but also contributes to the circular economy by reducing the reliance on virgin materials [4].

Glass waste, primarily composed of silica, is a non-biodegradable material that can also not be incinerated, thus poses significant disposal challenges. Recycling glass waste as a filler in asphaltic concrete has been explored in recent studies due to its potential to enhance the mechanical properties and durability of the concrete [5], [6], [7] . Waste glass, commonly disposed of in landfills, constitutes a significant portion of urban waste. When processed and utilized as a filler in asphaltic concrete, it not only enhances the mechanical properties but also contributes to waste reduction and environmental sustainability [8], [9].

Recent studies have observed that glass powder modified mixes displayed superior resistance against rutting and cracking, however, glass powder displayed poor moisture resistance [4]. Poor moisture sensitivity and adhesion of the glass modified asphalt mixes have been attributed to poor bonding of bitumen asphalts because of the dominance of silica in glass's composition. Eggshells, which are rich in calcium carbonate, represent another sustainable alternative to conventional mineral fillers in asphaltic concrete. The disposal of eggshell waste, particularly from the food industry, poses environmental challenges, making its reuse in construction materials an attractive mitigation [10], [11], [12], [13]. The fine particles of eggshell powder can fill the voids within the asphalt matrix, thereby increasing its density and reducing its susceptibility to water infiltration and related damages [10], [14], [15], [16].

This research attempts to evaluate the feasibility of a lternative fillers in asphaltic concrete and performance for sustainable construction practices. Filler can be considered as the finest portion of aggregate which passes through a sieve number 0.075mm [17], and occupies up to 12% by weight in asphalt mixes [18], [19]. Despite being used in limited concentration, inclusion of filler in asphalt mix has significant influences over properties of mixes such as:

(i) filler satisfies the aggregate gradation specification and influences the strength and volumetric requirements of the mix [20], [21].
(ii) filler extend the bitumen to increase the bitumen volume in the mixture and reduce optimum bitumen content and material cost of mix [22].
(iii) influence ‘‘bond” in the aggregate-bitumen system which further effects moisture sensitivity of mix [23], [24].
(iv) fillers also influence aging process of asphalt mixes by either catalyzing oxidation or by hindering the diffusion of oxygen in mastic [25], [26].
(v) influence constructability of mix by influencing its mixing and compaction temperature [27].

All these effects are ultimately linked to physical and chemical characteristics of the chosen filler, its interaction with bitumen and its volumetric concentration in the mix. Hence the choice of suitable materials as asphaltic fillers is of primary concern amongst field engineers. The use of waste materials as fillers in asphaltic concrete has been explored to reduce the environmental impact of construction activities and as waste management tactics. At present, there is a serious global issue caused by environmental pollution from waste products, and it has become a threat to sustainable development policy. It is well known that wastes pose environmental and human health challenges, and combined with an intensive exploitation of natural resources, they can determine permanent alterations in the natural environment, such as disturbances in the existing ecosystem, groundwater level, and vegetation degradation [28].

Several research have reported the potentials of waste materials as replacement for the traditional filler in asphaltic concrete, including fly ash, steel slag, recycled concrete powder, cement kiln dust, waste glass, rice husk ash, paper industry wastes, municipal solid waste incineration ash, waste marble materials, waste tires etc. it had been reported also that the chemical composition of the filler significantly influences the behaviors of asphalt mixtures over their service period as well [29].

Glass is an inorganic solid material that is usually hard, brittle in nature having low absorption, and impervious to the natural elements [30]. Its rich silica, a property that enhance the mechanical strength and durability of construction materials like concrete and asphalt. Though silica rich materials improve durability of asphalt, there are deficient in adhesion [31] Nearly 10 million tons of glass waste is generated in metro cities annually, which is about 3–5% of the total domestic waste [4]. Recycling glass waste into construction materials, including asphaltic concrete, offers a sustainable solution. Several studies have investigated the use of glass waste as a filler in asphalt mixtures as presented below:

In the study by [7], the usability of cullet glass and domestic glass waste dust in HMA as mineral filler material was investigated and concluded that, cullet glass and domestic glass waste dusts can be used in asphalt concrete mixtures as mineral filler materials, and that using glass waste in hot mix asphalt pavements would be very useful in view of waste management.

The utilization of some specific types of waste glass in surface asphalt mixtures generally led to a reduction in their overall Mashall properties as opined by [9]. Nevertheless, it is possible to apply these glassphalts containing 10% waste glass in surface layers for pavements with lower traffic compared to those designed with conventional mixture for higher traffic. They suggested that when using the Glassphalts with up to 15% content for surface layers in low-volume roads, it is imperative to employ an appropriate antistripping agent.

The addition of waste glass increases the compressive strength of asphalt concrete mixtures as well as increases the strength to rutting as concluded by [8]. He averred that the glass modified asphalt concrete mixtures has less workability and tensile strength compared to conventional asphalt concrete mixtures. Addition of 12% of crushed Waste glass improves the mechanical properties of asphalt concrete in the terms of Marshall Stiffness and compressive strength.

In the evaluation of the impact of recycled glass on asphalt mixture performances by [32], reported that the addition of crushed glass to asphalt mixture reduces the volume of binder absorbed, increases the mixture workability, and decreases the rutting resistance.

In the Investigation of using crushed glass waste as filler replacement in hot asphalt mixtures by [33], it was reported that the utilization of waste glass powder to replace 25% and 50% of minerals filler reduces the stiffness of the conventional HMA by 21%, reduction of the optimum binder content, rutting resistance, improved the fatigue and thermal cracking. [34] in their study that evaluated the mechanical performance of asphalt mixes incorporating waste glass as a substitute for the fine fraction of natural aggregate reported that the higher the percentage of the waste glass, the higher will be the bitumen content for the mix, also higher waste glass reduces the density of the sample depicting more air void. They opined that higher waste glass content in the mix reduces the tensile strength, adhesion, but increases the sample stiffness. They also reported that calcium carbonate filler increases the adhesion of the asphalt mastic. Studies have observed that though, waste glass is a good potential for asphalt filler, it lacks adhesion with bitumen as well as poor moisture resistance [35]. Poor moisture sensitivity and adhesion of glass-modified asphalt mixes are attributed to poor bitumen-asphalt bonding, due to the predominance of silica in the composition of glass.

However, a recent study has observed that utilization of glass powder with the addiction of anti – stripping materials that is rich in calcium like hydrated lime can significantly improve the moisture resistance as well as adhesion of asphalt mix [36]. They recommended studies on glass as asphalt fillers with addiction of anti-stripping agents. Also, according to [37], anti-stripping agent, can be used to enhance the mechanical characteristics and moisture sensitivity of a mixture including asphalt and glass.

Eggshells, an agricultural and food waste product, are primarily composed of calcium carbonate [38]. The fine particles of eggshell powder have shown potential as an alternative filler in asphaltic concrete. The similarity of eggshell powder in its chemical composition to lime and cement made it a good replacement to them [39]. Several studies have reported that the incorporation of eggshell powder in asphaltic concrete can improve its mechanical properties, such as stability, adhesion, stiffness, and tensile strength. [40] found that eggshell powder increased the mixture's density and reduced its susceptibility to deformation under traffic loads. [11] have used egg shells in their study to evaluate the effect of eggshell as filler in hot mix asphalt. Their results showed the effective eggshell content was in the range of 3% to 5% and using eggshell as a filler will reduce the specific gravity. At last, they gave a summary that the eggshell is one of the substances that can be used as filler in the asphalt mixture. [41] investigated the ability of using eggshell powder as a filler in hot mix asphalt mixture and concluded that adding 6% ESP to asphalt mixture gives a higher density, higher stability, lower flow and higher tensile ratio value. [42] in their evaluation of natural asphalt properties treated with egg shell waste and low-density polyethylene reported that ESP and LPD improved the physical, thermal and water absorption ability of the natural asphalt. They concluded that the correct distribution of the powder eggshells has led to the formation of asphalt that can withstand mechanical forces, weather conditions, increases resistance against thermal breakage and premature aging.

In studies on concrete using fly ash, rice husk ash and egg shell by [43], it was reported that egg shell performed equally with RHA and fly ash in concrete as replacement for cement portraying its pozzolanic properties. [44] studied the sustainability of HMA by using egg shell powder and concluded that asphalt with egg shell as filler increases in viscosity, improved resistance to deformation (rutting), reduced temperature susceptibility and enhanced the asphalt binder. [45] evaluated the effect of egg shell powder as a modifier material on asphalt binder to investigate the effectiveness of the material on the improvement of the properties of the asphalt binder and reported an improvement in hardness, resistance to temperature, rutting resistance, increased stiffness and improved the behaviors of asphalt binder but decreased the ductility value.

From the literature, the potential benefits of using waste glass and eggshell as fillers in asphalt concrete have been well-documented. Waste glass is effective in improving resistance to rutting, cracking, and stiffness. However, it has notable shortcomings in moisture resistance, adhesion, and flow properties. On the other hand, eggshell exhibits pozzolanic properties, enhancing the bonding of materials (adhesion) and providing proven resistance to moisture. Therefore, this study aims to evaluate the complementary effects of these two materials (waste glass and eggshell) as alternative fillers on the Marshall properties of asphalt, focusing on how their combined use can address each material's deficiencies and improve overall asphalt performance. Their combination presents a promising solution for reducing pavement costs, improving functional performance, and enhancing sustainability by utilizing waste materials. Asphaltic concrete modified with glass waste and eggshell were produced and their engineering properties were determined.

2 | MATERIAL AND METHODS

This research is made to examine the combine effect of glass waste and eggshells powder used as alternative fillers in Marshall Specimens. The combined percentages of this powder used were 0, 6, 12, and 18%. Materials characterization used, specimen preparation and testing procedure are presented below.

2.1 Materials

This study utilized bitumen, aggregates, and various mineral fillers, including conventional fillers, glass waste, and eggshell powder, to evaluate their impact on material performance and sustainability in construction applications. The glass waste powder used as a filler was sourced from glass factory at the Suleja Aluminum market. The eggshell was sourced from a food processing outlet (Shoprite Lugbe).

2.1.1 Asphalt Binder (ASTM D946)

The asphalt binder used in this study is a conventional bitumen with penetration grade 60/70, commonly used in asphalt pavement construction in Nigeria. The bitumen was sourced from a local supplier and was tested for, penetration, softening point, specific gravity and flash point properties in accordance with **ASTM D946** to ensure it meets the required specifications.

Plate 1: Showing penetration test

Plate 2: Showing softening point

Table 1. Showing the properties of bitumen used

S/N	Test/method	Result	Specification
1	Penetration/AASHTO T49, ASTM D5	65.2d-mm	60 – 70d-mm
2	Softening Point/ASTM D36 – 95	49.7°C	48 – 56°C
3	Specific gravity/ASTM D70	1.027/25°C	1.01 – 1.06/25°C
4	Flash point/AASHTO T48 and ASTM D92	259°C	Min. 230°C

Therefore, the bitumen met the ASTM specification and is classified as 60 – 70mm penetration grade.

2.1.2 Asphalt Aggregates (ASTM C127 and ASTM C131)

The 12.5mm and 9.5mm were used as coarse aggregates, while river sand and quarry dust that passed through sieve 4.75mm but retained on 0.075mm were used as fine aggregates. The aggregates were obtained from a local quarry market (Arab contractor quarry) at Mpape here in Abuja. The following properties were ascertained for requirement compliance.

Table 2. Showing the properties of aggregates used

S/N	Test/method	Result		Specification
		Coarse	Fine	
1	Los Angeles Abrasion/ASTM C131	23%		20 – 30%
2	Water Absorption/ASTM C128	0.5%	0.47%	2% max.
3	Specific gravity/ASTM C127	2.63	2..6	2.5 -2.9

The aggregates met all the ASTM requirement hence are suitable for asphaltic usage.

2.1.3 Mineral filler (AASHTO M17 and ASTM D 546)

Mineral filler is that portion of the aggregate passing the 0.075-mm sieve usually use to fill the aggregate voids. Their specification as asphalt constituents is in AASHTO M17. In this study granite dust was used as the control filler. The glass waste powder used as a filler was sourced from glass factory at the Suleja Aluminum market, the particle of glass generated during the glass processing was gathered, further crushed into fine powder and sieved through the 0.075mm sieve. The eggshell was sourced from a food processing outlet (Shoprite Lugbe). The eggshells were collected, washed to remove organic matter, and dried at **105°C** for 24 hours, the dried eggshells were pulverized into a fine powder and sieved through the 0.075mm sieve.

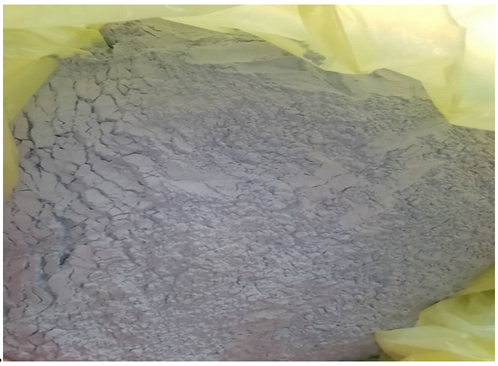

Plate 3. Sieved granite dust

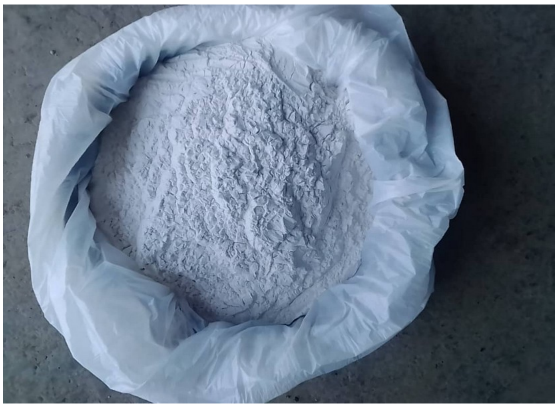

Plate 4. Sieved glass waste dust

Plate 5. Eggshell and the sieved pulverized eggshell.

2.2 Chemical Composition

The X-Ray Diffraction (XRD) (ASTM D934) and Scanning Electron Microscopy (SEM) (ASTM E1508) techniques was used to identifies the crystalline structures and chemical compositions of the glass waste and the eggshell used in this research. The tests were conducted at the Nigeria Building and Road Research Institute (NBRRI), Jabi Abuja. The results are as shown below:

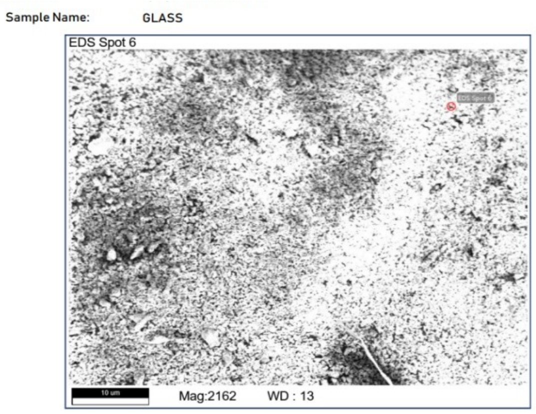

Fig.1. Sem of glass waste

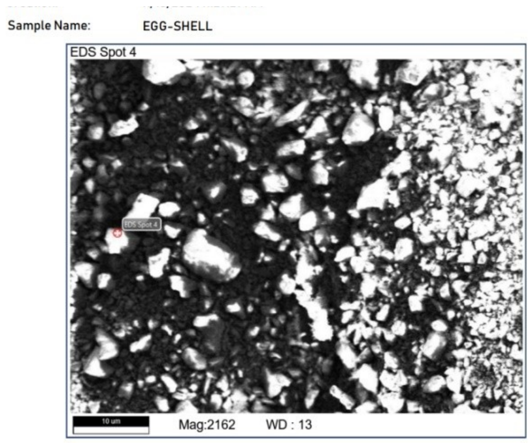

Fig. 2. Sem of eggshell

Table 3. Element composition of the glass waste

ELEMENT COMPOSITION OF GLASS WASTE		
ELEMENT	WEIGHT (%)	ATOMIC (%)
Oxygen (O)	56.96	69.39
Sodium (Na)	10.72	9.09
Magnesium (Mg)	2.06	1.65
Aluminum (Al)	0.69	0.5
Silicon (Si)	24.03	16.68
Calcium (Ca)	5.54	2.69

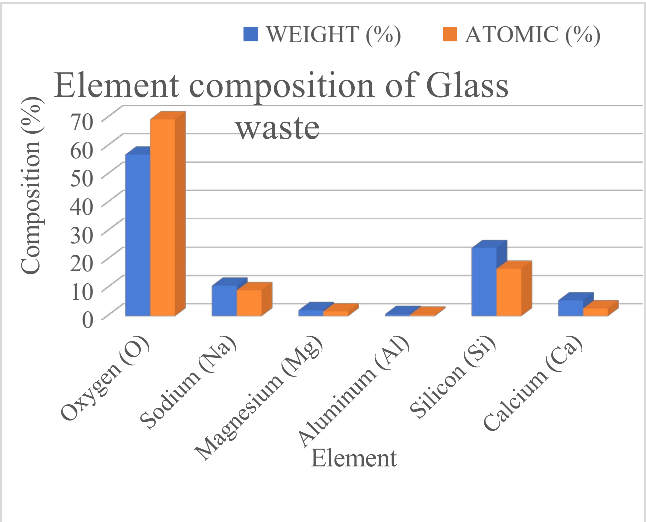

Fig.3. Element composition of glass

Table 4. Element Composition (XRD) of Eggshell

ELEMENT COMPOSITION OF EGGSHELL		
ELEMENT	WEIGHT (%)	ATOMIC (%)
Carbon (C)	15.16	25.07
Oxygen (O)	44.13	54.76
Calcium (Ca)	40.71	20.17

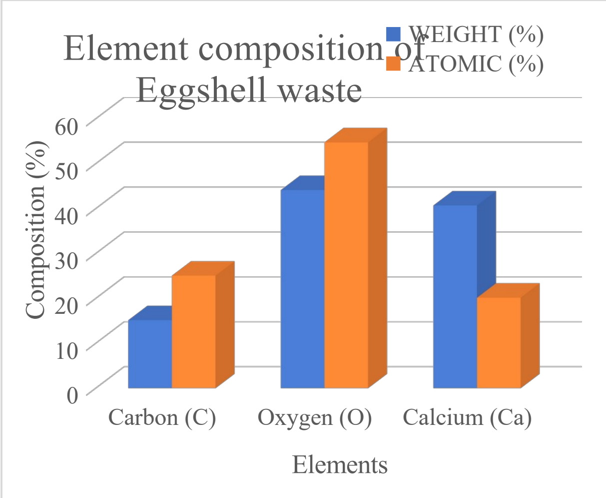

Fig.4. Element Composition of Eggshell.

Based on the SEM/XRD analysis, the results indicate that the glass sample is predominantly composed of oxygen, silicon, and sodium. This composition is a characteristic of silicate or quartz-based materials, which are commonly found in natural rocks. Such properties suggest that the material possesses the structural integrity, durability, and stability typically associated with silicate minerals, making it highly suitable for use in construction applications. Also, the SEM/XRD analysis of the eggshell revealed that the eggshell sample is predominantly composed of oxygen and calcium, with a significant presence of carbon. This elemental composition strongly indicates that the eggshell is primarily composed of calcium carbonate ($CaCO_3$), a compound that is extensively found in natural materials such as limestone and chalk, a material commonly used as fillers in asphaltic mixture and raw material for cement production. The high calcium carbonate presence in the eggshell revealed its potential as alternative or supplementary material in construction applications.

2.3 Aggregate Gradation (JOB Method)

The Job method was adopted for the combined gradation of the aggregates using the AASHTO and the Nigerian Ministry of Works Specifications for the Asphalt wearing course. The gradation was selected from the sieved analysis of the materials, such that it felled in between the specification curve as presented below:

Table 5. Aggregates sieve analysis

Sieve Analysis					
Sieve Size (mm)	Fine aggregate		Coarse Aggregate		Filler
	Quarry dust	River sand	12.5mm	9.5mm	
	% passing	% passing	% passing	% passing	% passing

12.5	100	100	40.8	100	100
9.5	100	100	37	44	100
4.75	99.5	97.7	14	18	100
2.38	96.9	94.4	2.6	3.6	100
1.18	72.1	72.3	2	3.6	100
0.6	60.4	54.8	1.4	3.6	100
0.3	37.5	22.3	1.2	3.6	100
0.075	6.1	1.8	1	3.6	100

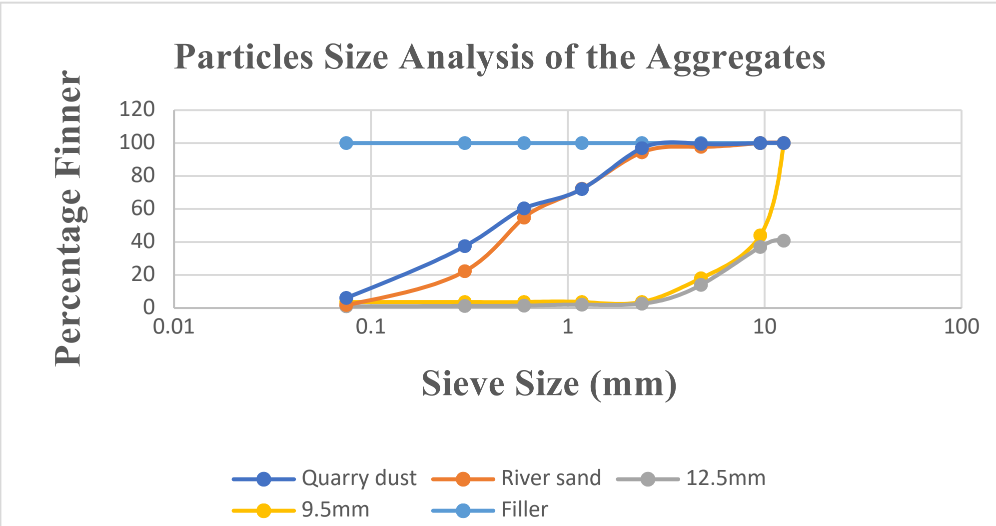

Fig.5. Particles Analysis of the Aggregates

Table 6. Aggregate Gradation

Aggregate gradation blend (Job method)									
Sieve Size (mm)	Fine Aggregate		Coarse Aggregate		Fillers	My total blend	Nig. Min. of work Specification		
	Quarry dust	River Sand	12.5mm	9.5mm					
	Percentage blend								
	35%	20%	15%	24%	6%	Total	Averag	lower	upper

							e	limit	limit
12.5	35	20	6.12	24	6	91.12	92.5	85	100
9.5	35	20	5.55	10.56	6	77.11	83.5	75	92
4.75	34.825	19.54	2.1	4.3 2	6	66.785	73.5	65	82
2.38	33.915	18.88	0.39	0.864	6	60.049	57.5	50	65
1.18	25.235	14.46	0.3	0.864	6	46.859	43.5	36	51
0.6	21.14	10.96	0.21	0.864	6	39.174	33	26	40
0.3	13.125	4.46	0.18	0.864	6	24.629	24	18	30
0.075	2.135	0.36	0.15	0.864	6	9.509	10.5	7	14

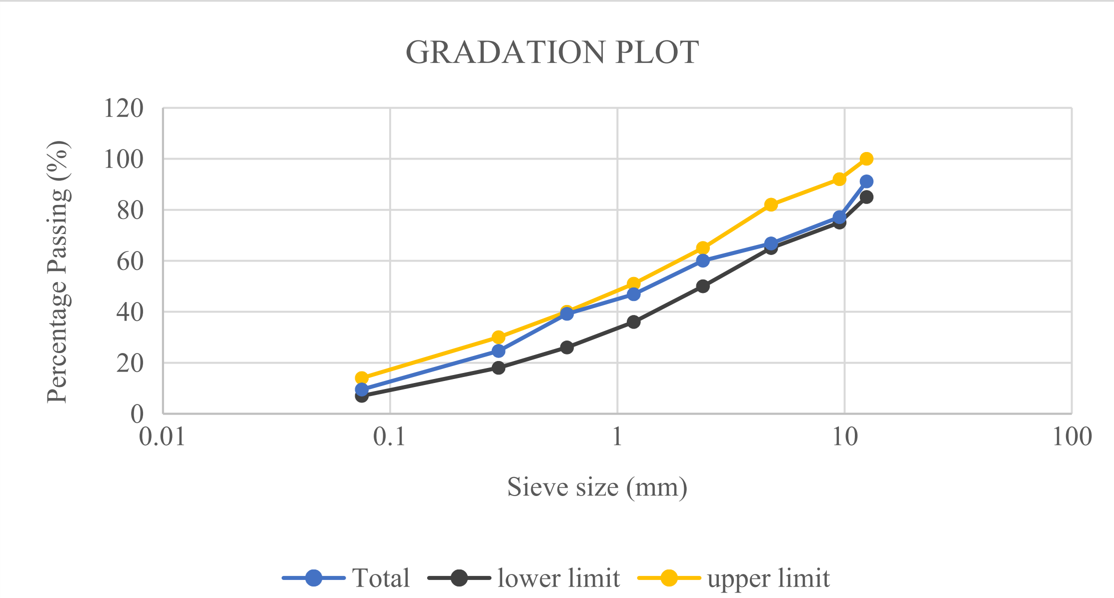

Fig.6. Aggregate Combined Gradation Curves

Once the total gradation blend fit into the specification curve, it means the mix design have been established. This aggregate gradation results correspond to the dense-graded specifications, revealing good interlocking and stability property.

Therefore, the Mix design used is:

Table 7. Mix design

Materials	**Percentage (%)**	**Quantity (1200g)**
12.5	15	180
9.5	24	288
Q/dust	35	420
River sand	20	240
Filler (quarry)	6	72
Total	100	1200

Bitumen = trial of 5 to 8%

Each of the aggregate percentage and the quantities were adjusted to accommodate the various bitumen content.

2.4 Optimum Bitumen Content determination (OBC)

The Marshall samples were used to determine the optimum bitumen content for the study.

2.4.1 Marshall Sample Preparation

The Marshall method was employed to determine the optimum binder content (OBC) for the asphalt mixtures.

Aggregates were selected and measured according to the designed gradation. The specified total materials weight of 1200g for each Marshall sample were weighed according to the determined gradation, Asphalt concrete specimens were then prepared with varying percentages of bitumen content of 5, 5.5, 6, 6.5, 7, 7.5 and 8%, mixed in a heated laboratory mixer at the required temperature (160°C to 170°C). The mixture was then compacted using a Marshall Compactor with 75 blows both top and bottom. the compacted specimens were allowed to cooled for 24 before it was extruded and prepared for Marshall tests.

Plate 7: Prepared Marshall sample

2.4.2 Marshall test

The compacted Marshall samples were soaked in the water bath at 60°C for 30 minutes prior to testing for stability, flow and density, voids also were calculated following ASTM D1559 guidelines to determine the OBC as shown below:

Plate 8: Marshall stability and flow test

2.4.3 Marshall Properties:

The result of the Marshall properties for the various percentages of the bitumen content is summarized in table 6, the various properties were plotted against the bitumen content as shown in the figures below

Table 8. Summary of the Marshall Properties for OBC

% of bitumen	Density (Gmb)	Stability (KN)	Flow (mm)	Void in mineral agg.	Void in total mix
5.0	1.96	8.67	2.84	29.5	4.66
5.5	1.99	8.75	3.01	28.2	4.48
6.0	2.10	890	3.40	25.23	4.36
6.5	2.17	11.00	3.65	23.1	4.1
7.0	2.15	9.80	4.70	24.3	3.86
7.5	2.12	9.25	4.82	25.72	3.63
8.0	1.85	8.94	5.04	35.5	3.46

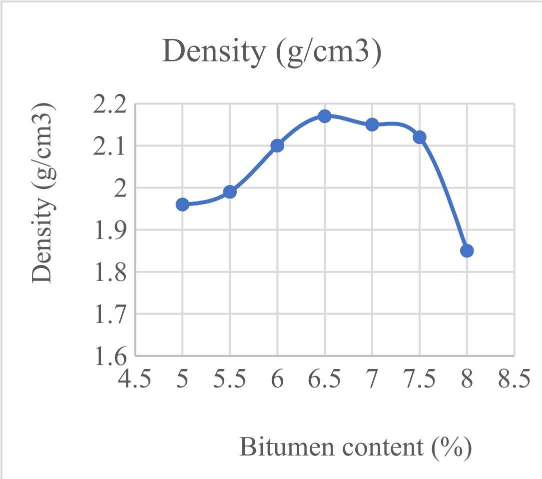

Fig.7. Graph of density

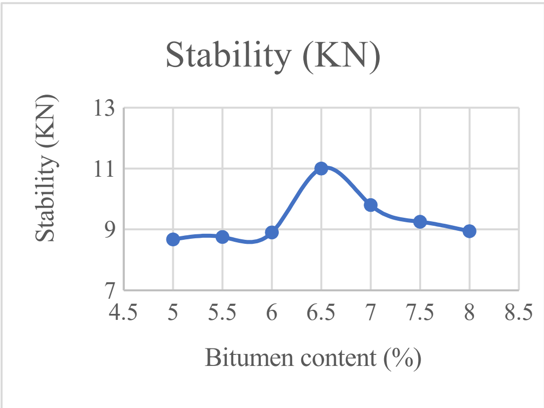

Fig.8. Graph of stability

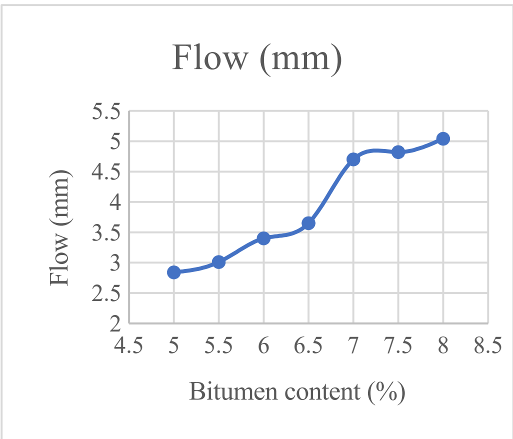

Fig.9. Graph of flow

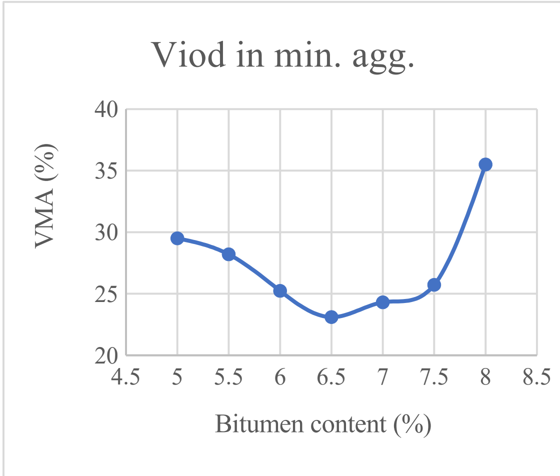

Fig.10. Graph of VMA

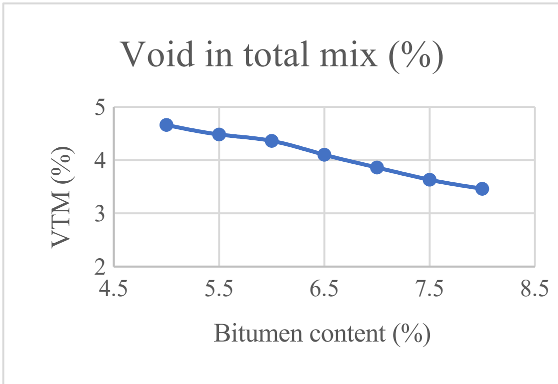

Fig. 11. Graph of VTM

In the determination of the optimum bitumen content, three parameters (density, stability and void in total mix) were used in line with the AASHTO/ Nig. Min. of work requirement. The percent of the bitumen content that produced the highest density and stability were noted, the percent air voids (VTM) is calculated using the mean of the Federal Ministry of Works' specified range of 3% to 5%, resulting in an average value of 4%. At this 4% VTM, the corresponding bitumen content was determined to be 6.6%. Consequently, the optimum bitumen content was computed as the average of the three (Density, Stability & VTM) measured values.

Therefore, the optimum bitumen content

$$OBC = \frac{6.5+6.5+6.6}{3} = 6.53\% \quad (1)$$

This value represents the ideal binder content for achieving the desired balance of durability, stability, and flexibility in the asphalt mix and so was used in this study for the evaluation of the glass waste and egg shell as alternative filler in asphalt mix.

3 |PERFORMANCE RESULTS AND DISCUSSION

3.1 Sample preparation

The determined optimum bitumen content (OBC) of 6.53% was used to prepared the modified Marshall samples for the performance evaluation. The glass waste and eggshell powder were combined in equal proportion and was used at 0%, 6%, 12% and 18% of the total designed filler percent. Fo example, for a 6% replacement, it was 3:3:94% of glass waste, eggshell and granite dust respectively.

3.2 Result of the modified Sample

3.2.1 Marshall Properties (ASTM D6927 ASTM D2726)

The Marshall stability, flow and volumetric analysis were performed on the modified samples to evaluate their ability to withstand traffic loads and resistance to deformation (rutting), comparing their values with the standard specifications.

Table 9. Marshall Properties of the Modified Samples

Combined glass dust & eggshell (%)	Marshall properties				
	OBC (%)	Stability (KN)	Flow (mm)	VMA (%)	VTM (%)
0	6.53	11.1	3.2	23.09	4.14
6	6.53	10.1	2.6	22.87	3.98
12	6.53	9.8	2.54	22.66	3.92
18	6.53	9.8	2.2	22.65	3.89
Spec. (AASHTO & Nig. Min. of work)	**5 – 8**	**Not less than 3.5KN**	**2 – 4mm**	**14% min.**	**3 - 5**
Note: glass dust and eggshell are combined at 50:50%					

The asphalt mix incorporating various percentages of combined glass dust and eggshell meets all the AASHTO and Nigerian Ministry of Works specifications for stability, flow, VMA, and VTM. Although slight decreases in these properties are observed with increasing proportions of the additives, indicating their complementary effects, while the glass waste provided stability, the eggshell enhances bonding. their combined inclusion in the asphalt mix remains within acceptable standards, demonstrating their suitability as sustainable components in asphalt production. This result revealed a significant improvement compared to literatures where each of these materials were separately used.

3.2.2 Indirect Tensile Strength (ITS) (ASTM D6931)

The Indirect Tensile Strength (ITS) test was conducted in accordance with ASTM D6931 to evaluate the stiffness of the asphalt mixtures, providing insights into the cracking resistance of the modified asphalt. It was determined as

$$ITS = \frac{2000\,P}{\pi t d} \quad (2)$$

Where P = maximum load (N)

d = diameter of the sample

t = mean thickness of the sample

Table 10. ITS Results

Combined glass dust & eggshell (%)	ITS (kPa)
0 (100% Conventional Filler)	648.4
6 (3% Glass Dust, 3% Eggshell)	639.6
12 (6% Glass Dust, 6% Eggshell)	618.2
18 (9% Glass Dust, 9% Eggshell)	598.7
Specification	500 to 700

From the results, while there are slight variations compared to the conventional sample, the Indirect Tensile Strength (ITS) values for all the proportions remain generally comparable, indicating minimal deviation in performance. The bonding properties of the eggshell have helped the samples against brittle.

3.2.3 Moisture Susceptibility Test (AASHTO T283 & ASTM D 4867)

A moisture susceptibility test was conducted on the modified asphalt samples following the AASHTO and ASTM procedures to evaluate their resistance to water-induced damage including the loss of bond strength between aggregates and the binder, known as stripping. Some of the samples were conditioned in water for 24hrs and tested against the unconditioned dried samples, and their percent ratio determined as the Tensile strength ratio.

Table 11. Moisture Susceptibility Results

Combined glass dust & eggshell (%)	ITS (kPa) unconditioned	ITS (kPa) conditioned (24hrs)	TSR (%) Condition/unconditioned * 100
0	578.6	538.2	93
6	572.8	518.6	90.5
12	571.7	501.5	87.7
18	571. 4	482.4	84.4
AASHTO Specification = 80% min.			

The moisture susceptibility results indicate that the TSR values for all proportions satisfy the AASHTO minimum requirement of 80%. The inclusion of eggshell acting as an anti-stripping agent has enhanced the performance by filling more voids and helped in adhesion compared to using glass alone, thereby improving moisture resistance in the asphalt mixtures.

4 | CONCLUSIONS

This study evaluated the performance of asphaltic concrete modified with glass waste and eggshell as alternative fillers. The following conclusions were drawn:

1. The SEM/XRD analysis confirmed the composition of glass dust and eggshell, revealing their silicate and calcium carbonate properties, respectively. These compositions makethem suitable for use in construction especially as fillers in asphaltic mix.
2. Although there were slight variations in the stability, flow, indirect tensile strength (ITS), and moisture susceptibility of the modified asphaltic concrete, all values remained within standard specifications.

3. The moisture susceptibility test indicated that all samples met the AASHTO minimum TSR requirement of 80%, demonstrating satisfactory resistance to moisture-induced damage.
4. The combined inclusion of glass waste and eggshell complement each other. While the glass waste provided stiffness, strength and stability, the eggshell act as an anti-stripping agent in the mixtures thereby improving the overall performance compared to using glass dust alone.
5. Glass waste and eggshell can therefore be used at a combined proportion of about 18% of the fillers.

5 | RECOMMENDATION

Based on the findings of this study, the following recommendations are made:

1. The use of glass waste and eggshell as fillers in asphaltic concrete should be considered for practical applications, especially where these wastes are allowed as pollutions and into landfills.
2. Further studies should explore the long-term performance of asphaltic concrete containing glass dust and eggshell under varying climatic and traffic conditions.
3. Further optimization of the proportions of glass dust and eggshell should be conducted to maximize the engineering performance of the modified asphaltic concrete.
4. Additional research should investigate the use of other waste materials in combination with glass dust and eggshell to further enhance the sustainability and performance of asphalt mixtures.

Acknowledgement

The authors wish to thank Engr. Oluwatosin Daniel Akinmade of the Nigeria Building and Road Research Institute for providing guidance during the Laboratory works, Engr. Benjamin Osita Okoh for his moral support and encouragement. The authors declare that the contents of this article have not been published previously. All the authors who have contributed to the work described, read and approved the contents for publication in this journal.

Funding Statement

The authors received no specific funding for this study.

Author Contributions

The author (s) and their specific contributions to this paper are as follow**:**

Study conception and design: Otronyi Stephen Okojo Dr. Abubakar Dayyabu., Supervision: Dr. Abubakar Dayyabu., Data Collection: Yakubu Muktar Sakadadi., Methodology: Dr. Akeem Gbenga Amuda., Validation: Dr. Anthony Muoka., Review: Prof. Mambo Danjuma Abdulhameed. All authors reviewed the results and approved the final version of this manuscript.

Availability of Data and Materials

Not applicable, however, further clarification for the materials used will be provided by the corresponding author on request.

Conflicts of Interest

The authors declare no conflicts of interest related to this manuscript. There was no influence (financial, personal, or whatsoever) on the output of this work.

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