



The use of Crushed Waste Glass as a Partial Replacement of Fine Aggregates in Asphalt Concrete Mixtures (Glassphalt)

**Gbadamosi Aderemi Tobi ^{a*}, Ogunsuyi Raphael Abidemi ^a
and Ojo Meshach Felix ^a**

^a *Department of Civil Engineering, Ekiti State University, Ado-Ekiti, Nigeria.*

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

With the rapid economic growth and continuously increased consumption, a large amount of glass waste materials is generated; this study investigated the effect of crushed waste glass as filler and also as an aggregate in the asphalt binder course. It compares the glassphalt mix with the specification range at different percentages to meet specifications limit according to Nigeria roads and bridges reverse book of 1997 Waste glass are cleaned and crushed from the glass bottles and added to the asphalt as a filler and as a replacement for coarse aggregates, the marshal method is used to determine the optimum bitumen content and evaluate the properties of the asphalt mix. However, 24 samples were prepared in total, 12 samples each for the asphalt mix used to determine the optimum bitumen content and the other 12 samples for the glassphalt mix used to find out the effect of adding the different percentages of crushed waste glass to the asphalt mixture. The Marshall test carried out on the asphalt mixtures showed that the optimum bitumen content of bitumen was found out to be 6.2% of the asphalt mix by weight. Also, Marshall Test carried out on the glassphalt mix showed the optimum percentage of glass used in the binder course of the weights of aggregates in the asphalt mix. The result of this experiment is been checked to be consistent with the Nigeria road and bridges reverse book of 1997, i.e. Marshall Stability, flow, bulk density, and air voids.

*Corresponding author: Email: tobiaderemigbadamosi@gmail.com;

Keywords: Glassphlat; asphalt concrete; glass waste; optimum bitumen content; marshall test.

1. INTRODUCTION

1.1 Background of the Study

The use of sustainable and cost-effective alternative materials for asphalt mixes in road and airfield pavements has been recently emphasized due to the potential depletion of natural aggregate sources and the increasing awareness of environmental issues i.e., green gas emissions, disposals, etc., associated with conventional asphalt materials [1,2]. For instance, industrial by-products (e.g. steel slag) are gaining adoption worldwide for road construction. The waste crushed glass that is processed can be used as a portion of fine aggregate in asphalt paving mixes [3-5]. Satisfactory performance has been obtained from hot mix asphalt pavements incorporating 10 to 15 percent crushed glass in wearing surface mixes [6]. The term "glassphlat" has at times been used to describe these pavements [7]. A study by Flynn [8] demonstrated that optimum performance can best be achieved when crushed glass is used as a fine aggregate substitute in asphalt pavements as opposed to larger-sized glass particles which adversely affects pavement performance due to raveling and stripping related problems. Furthermore, it has been demonstrated that when glass is utilized as a substitute fine aggregate in hot mix asphalt, the performance-related properties are comparable to conventional asphalt mixes [9]. When the glass was initially implemented in asphalt pavements in the early 1960s and 1970's, glass particles greater than 12.7 mm and quantities more than 25 percent by weight of mix were utilized [Recycled Materials Resource Centre-RMRC, USA]. Factors such as the lack of absorption of bitumen by the glass and the hydrophilic properties of glass also contribute to the moisture damage (stripping and raveling) experienced by glass asphalt pavements; particularly when high percentages and large particles are introduced into the surface course. Hughes [1990] revealed that the addition of hydrated lime (approximately 1 to 3 percent by weight of aggregate) to mix with glass acts as an antistripping agent and reduces potential stripping problems. The study indicated that although antistripping agents could be beneficial, however, satisfactory performance can be achieved if only fine-grained glass (4.75 mm) is used with substitution rates not surpassing 15 percent. The benefits of utilizing

crushed glass in asphalt pavements include the high angularity of the crushed glass which can enhance the stability of glass asphalt mixes when compared with conventional asphalt mixes with virgin aggregates [10-12,6]. Other favorable characteristics include low absorption, specific gravity and thermal conductivity, which enhances heat retention in mixes with glass.

Up till now, in Nigeria, there are few investigations on the application of waste glass in the field of pavement, not to mention field applications.

The main objectives of the research are as follows

- To determine the optimum glass content of a selected mix for the Asphalt wearing course.
- To determine the optimum bitumen content for the selected mix of asphalt
- Find out the effect of adding different percentages of crushed waste glass on the mechanical properties of asphalt mix.
- Determine the optimum percent of crushed waste glass to be added to the hot mix asphalt.

2. MATERIALS AND METHODS

The materials used in the research are:

2.1 Aggregate

The aggregates commonly used for asphalt mixes are fine and coarse aggregates, the aggregates used in the course of the research were brought in from Itami-Ekiti Quarry in Ekiti state, sieve analysis test was carried out on all the aggregates which follow the BS 1377,1990. Table (1) shows the gradation of aggregate and Table (2) summarizes the properties of aggregate used in the research.

2.2 Asphalt

In this research, a kind of asphalt binder with a 70/80 penetration grade was used for producing all test specimens. Physical properties tests for this asphalt cement were conducted in the Materials and Soil Laboratory of Federal Polytechnic Ado-Ekiti. The table below shows the physical properties of used bitumen.

Table 1. Gradation of Aggregate

Sieve Size	Specification Limits % passing	Percentage Passing	Percentage Retained	Cumulative % passing
¾" (19.5mm)	100	100	0	0
½" (12.5mm)	80-100	90	10	10
3/8" (9.5mm)	56-80	68	22	32
#4 (4.76mm)	35-56	45	23	55
#8 (2.36mm)	23-38	30	15	70
0.85mm	13-27	20	10	80
0.425mm	8-12	10	10	90
0.0075mm	2-8	5	5	95
pan				100

Table 2. Used Aggregates in this Research

Material	Type of Aggregates	Size of Aggregate	Percentage in the Mix
Coarse	Granite	19.5mm	17%
	Stone Dust	9.5mm	15%
Fine	Quarry Dust	4.75mm	30%
	River Sand	0.6mm	28%
Filler			10%

Table 3. Properties of the Asphalt Used in this Research

Test	Specification	Test result
Penetration @ 25	ASTM D5	70.45
Flash Point	ASTM D92	273
Softening Point	ASTM D36	47.2
Fire Point	ASTM D92	284
Ductility	ASTM D113	140.3
Specific Gravity	ASTM D70	1.02

Table 4. Sieve Analysis gradations of the crushed waste glass

Sievesize (mm)	Sieve #	Percentage of Sample Passing
4.75	#4	97.67
2.36	#8	69.33
1.18	#16	51.00
0.6	#30	36.00
0.425	#40	30.00
0.3	#50	26.00
0.15	#100	20.13
0.075	#200	16.67
Pan	pan	0.00

2.3 Crushed Waste Glass

Fine passing sieve # 4-4.75mm with the graduation of waste glass was used. Table (4) presents the sieve analysis gradations of the crushed waste glass.

3. RESULTS AND DISCUSSION

Data analysis and results of laboratory investigations that were conducted to study the effect of using crushed waste glass in asphalt binder course specifically, the influence of glass content on the flow, and air voids content of asphalt concrete will be presented in this chapter. Marshall Method for designing hot asphalt mixtures was used to determine the optimum bitumen content to be added to a specific aggregate blend. Also, Marshall Method for designing hot asphalt mixtures was used to evaluate the specimens of glassphalt to determine the best content of glassphalt. The results of this study only apply to the specific gradation of glass and the type of mixes that were used. Other gradations of glass or source may produce different results.

3.1 Determination of Optimum Bitumen Content

To determine the optimum asphalt content for the mixture, the procedure indicated by the standard American Institute MS-2 Manual (2008) and ASTM D1559 (2008) was followed as part of this study. Three specimens at each asphalt content (5.0, 5.4, 5.8, 6.2, 6.6, and 7%) were tested for stability, flow, and air voids in mineral aggregate. The optimum bitumen content of bituminous mixtures is determined based on the average values that satisfy the sets of requirements for Marshall Stability, Marshall Flow, air voids, VMA and VFB.

3.1.1 Marshall stability

Stability against varying bitumen contents.

The stability of the specimen is the maximum load required to produce a failure of the specimen when the load is applied at a constant rate of 50 mm/min [13]. From the Fig. below it is noticed that the maximum stability of asphalt mix is 940 kg at 6.2 % bitumen content.

Table 5. Summary of the Marshall Test result

Bitumen (%) by total weight)	Sample No.	Corr. Stability	Flow (mm)	Bulk Density	Void in total mix	Volume of bitumen	SGM	Void filled with bitumen (VFB)	Voids in mineral aggregate (VMA)
5.0	1	625.0	2.5	2.269	8.8	11.18	2.495	55.8	20
	2	650.0	2.9	2.289	8.8	11.16	2.495	55.7	20
	Avg.	637.5	2.7	2.279	8.8	11.17	2.495	55.9	20
5.4	1	762.0	2.8	2.33	6.7	12.30	2.479	64.7	19.4
	2	763.0	2.8	2.32	6.75	12.30	2.479	64.7	19.4
	Avg.	762.5	2.8	2.325	6.7	12.30	2.479	64.7	19.4
5.8	1	862.5	3.5	2.34	5.3	13.29	2.465	71.3	18.6
	2	886.6	3.5	2.32	5.3	13.29	2.465	71.3	18.6
	Avg.	874.5	3.5	2.40	5.3	13.29	2.465	71.3	18.6
6.2	1	910.0	4.2	2.36	3.76	14.34	2.44	79.2	18.1
	2	964.0	4.2	2.36	3.76	14.34	2.44	79.2	18.1
	Avg.	937.0	4.2	2.36	3.76	14.34	2.44	79.2	18.1
6.6	1	834.6	4.5	2.36	3.3	15.50	2.435	82.4	17.4
	2	834.6	4.5	2.34	3.3	15.50	2.435	82.4	17.6
	Avg.	834.6	4.5	2.35	3.3	15.50	2.435	82.4	17.5
7.0	1	834.4	5.0	2.28	5.9	15.6	2.42	72.5	17.0
	2	743.7	5.0	2.28	5.9	15.6	2.42	72.5	17.0
	Avg.	743.8	5.0	2.28	5.9	15.6	2.42	72.5	17.0

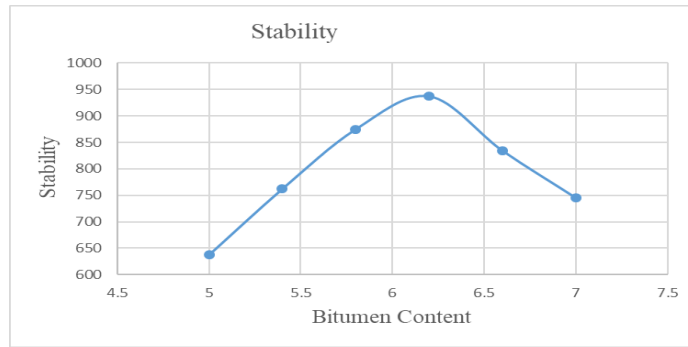


Fig. 1. A graph of Stability against volume of bitumen and stability

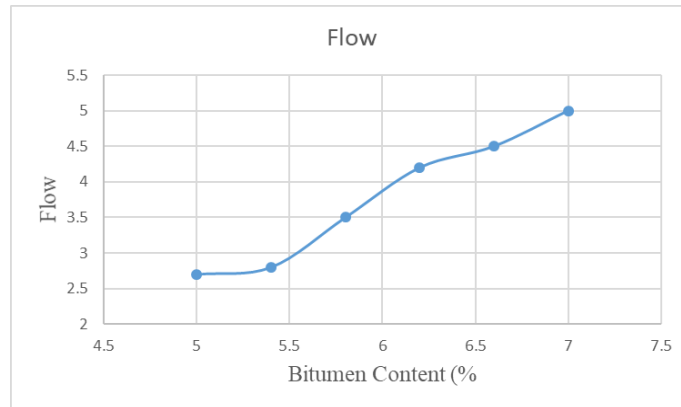


Fig. 2. A graph of flow against volume of bitumen

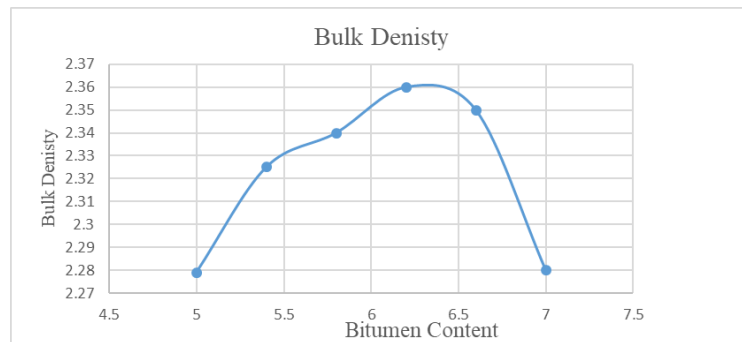


Fig. 3. A graph of bulk density against volume of bitumen

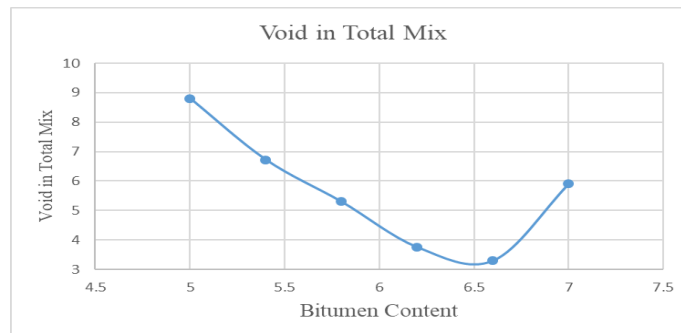


Fig. 4. A graph of Void in total mix against volume of bitumen

3.1.2 Flow

Flow is the total amount of deformation which occurs at maximum load [13]. From the figure below it is noticed that the maximum flow is recorded at 7% bitumen content. This indicates that greater deformation is recorded as bitumen content increases.

3.1.3 Bulk density

Bulk density is the actual density of the compacted mix. Fig. (3) represents the bulk density results for varying bitumen contents. The bulk density of the HMA increases as the bitumen content increase till it reaches its peak at the optimum bitumen content and then starts to decline gradually at higher bitumen content. From the figure below its noticed that the maximum bulk density is 2.36 g/cm³ at 6.2 % bitumen content.

3.1.4 Voids In total mix

The air voids, V_a , is the total volume of the small pockets of air between the coated aggregate particles throughout a compacted paving mixture, expressed as a percent of the bulk volume of the

compacted paving mixture [1]. From Figure below it is noticed that the air voids content gradually decreases with increasing the bitumen content this is because of the increase in voids filled with bitumen in the asphalt mix.

3.1.5 Voids in mineral aggregates

The voids in the mineral aggregate, VMA, are defined as the intergranular void space between the aggregate particles in a compacted paving mixture that includes the air voids and the effective bitumen content, expressed as a percent of the total volume [2]. From Figure (5) it's noticed that the VMA decreases gradually as bitumen content increase but rises gradually at bitumen content beyond 6.2%.

3.1.6 Voids filled with bitumen

The voids filled with bitumen, VFB, is the percentage of the intergranular void space between the aggregate particles (VMA) that are filled with bitumen [1]. From Figure (6) it's noticed that the VFB% increases gradually as bitumen content increases. This occurs because as bitumen content increases more void spaces between mineral aggregates.

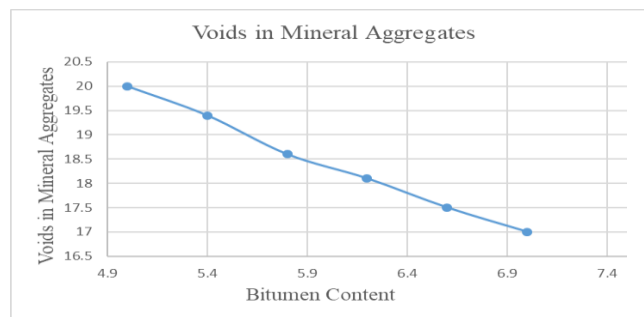


Fig. 5. A graph of VMA against volume of bitumen

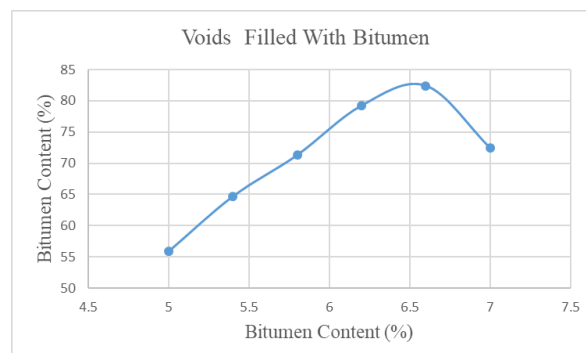


Fig. 6. Voids filled with bitumen against varying bitumen contents

3.1.7 Optimum bitumen content (OBC)

The optimum bitumen content was found equal to 6.2% by weight of the total mix which is calculated as the average of bitumen content values that correspond to the maximum stability, maximum density and median of the air voids

1. Bitumen content at the maximum stability = 6.2 %
2. Bitumen content at the maximum value of bulk density = 6.2%
3. Bitumen content at the median percent of air voids = 6.15%

Optimum Bitumen Content (OBC) = $(6.2 + 6.2 + 6.15) / 3 = 6.18\%$ approx. 6.2%.

3.2 Glassphalts Results

18 samples of glasphalt each weigh 1200gm were prepared using six different crushed glass content (5.0,7.5,10.0,12.5,15 and 17.5 %) by the weight of total mix using the optimum bitumen content (6.2% by the weight of total mix). Crushed waste glass replaced river sand using the aforementioned percentages and mixed with other aggregates. Marshall Stability tests were performed on the samples with different

percentages of crushed waste glass and the results are presented below.

3.3 Marshall Stability

From the figure below, a steady rise in stability is recorded as crushed waste glass content is increased. However, at higher glass content Marshall stability decreases. A minimum value of 3.5kn is given as the required standard for the stability of wearing course from the Nigeria standard for roads and bridges revised edition,1997. Percentages from 7.5% –17.5 % meets this local requirement.

3.3.1 Flow

The flow gives a slightly higher range value when compared to conventional Hot Mix asphalts. The flow percentage values of 5.0% - 10% oscillate around the value of conventional mix which is 2mm – 4mm according to local specifications [2].

3.3.2 Bulk density

The bulk density data gotten achieves the local and international specification which is 2.3 g/cm³ at a glass percentage value of 10% through to 17.5%. The general trend shows that the bulk density increases as the glass content increases.

Table 6. Summary of properties of Asphalt mix with Crushed waste Glass

Glass content (%)	Sample No.	Corr. Stability	Flow (mm)	Bulk Density	Void in total mix	Volume of bitumen	SGM	Void filled with bitumen (VFB)	Voids in mineral aggregate (VMA)
5.0	1	2.79	3.8	2.33	6.7	11.43	2.494	63.3	17.9
	2	2.79	3.8	2.33	6.5	11.41	2.494	63.5	18.0
	Avg.	2.79	3.8	2.33	6.6	11.42	2.494	63.4	18.0
7.5	1	3.534	4.0	2.343	5.4	12.43	2.48	70.3	17.7
	2	3.534	4.0	2.353	5.2	12.43	2.478	70.1	17.7
	Avg.	3.534	4.0	2.348	5.3	12.43	2.479	70.2	17.7
10	1	4.743	4.0	2.35	4.4	13.43	2.465	75.3	17.7
	2	4.743	4.0	2.35	4.2	13.41	2.465	75.3	17.7
	Avg.	4.743	4.0	2.35	4.3	13.42	2.465	75.3	17.7
12.5	1	4.836	5.8	2.373	3.2	14.41	2.45	82.0	17.61
	2	4.836	5.8	2.373	3.2	14.43	2.45	82.0	17.61
	Avg.	4.836	5.8	2.373	3.2	14.42	2.45	82.0	17.61
15	1	5.4	6.0	2.39	1.8	15.	2.418	89.7	17.4
	2	5.4	6.0	2.39	1.8	15.450	2.416	89.5	17.5
	Avg.	5.4	6.0	2.39	1.8	15.550	2.417	89.6	17.3
17.5	1	6.032	6.4	2.410	0.46	16.55	2.421	97.3	17.0
	2	6.032	6.4	2.410	0.46	16.53	2.421	97.3	17.0
	Avg.	6.032	6.4	2.410	0.46	16.54	2.421	97.3	17.0

3.3.3 Voids in total mix

The air voids of Glasphalt mix decreases gradually as the glass content increase. This decline in air voids in Glasphalt mixes return to the reduction in internal pores of glass than river sand It's noticed that glass percentages 7.5% - 10.0% fall in the range of local specification 3% - 5% and are very close to the median value of international specification of 4.0%.

3.3.4 Voids in mineral aggregates

From the results gotten, it can be seen that the voids in mineral aggregates decrease slightly as the glass content increase. This is a result of better intergranular bonding as the glass content is added.

3.4 Analysis of Result

Glassphalt surfaces appear to dry faster than traditional paving after rain, because the glass particles do not absorb water. Glassphalt surfaces are more reflective than conventional asphalt and may improve night-time road visibility.

From the figure below, it is noticed that all values of Marshall Stability for different glass content satisfy the local and international specifications which are (3.5KN) apart from the 5% of crushed glass. It should also be observed from the table that all our needed parameters are within the range of the local specifications according to Nigeria Roads and Bridges design specifications [2].

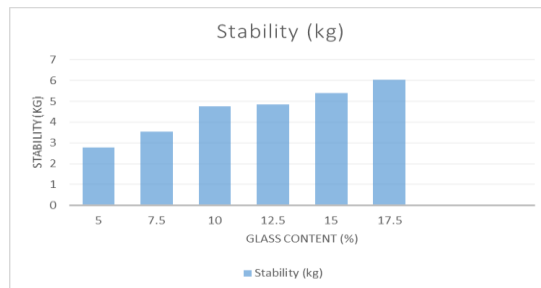


Fig. 7. A graph of stability against varying glass content

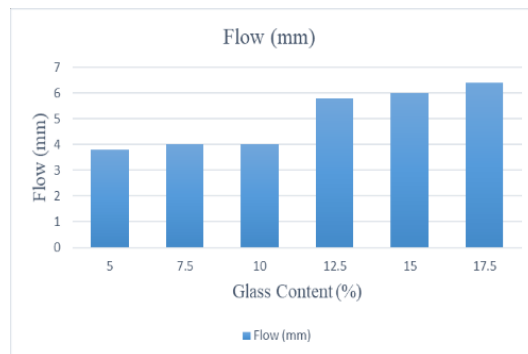


Fig. 8. Flow against varying glass contents

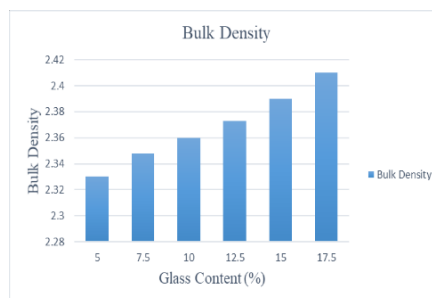


Fig. 9. Bulk Density against varying glass contents

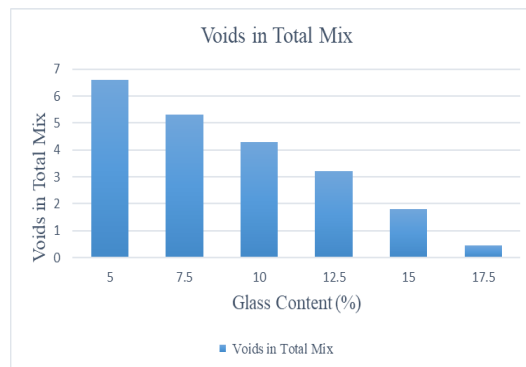


Fig. 10. Voids in total mix against varying glass contents

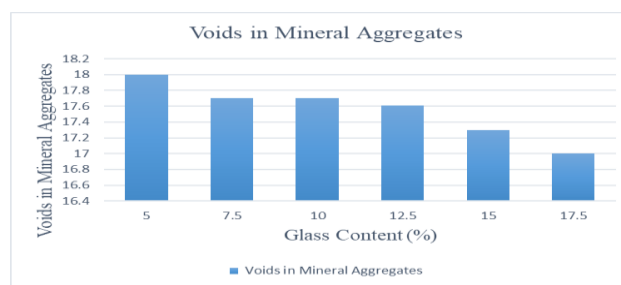


Fig. 11. Voids in mineral aggregates against varying glass contents

Table 7. Summary of the Glassphalt Properties

Glass Content %	Stability	Flow	Bulk Density	Voids in total mix	VFB
5.0	2.79	3.8	2.33	6.6	63.4
7.5	3.534	4.0	2.348	5.3	70.2
10.0	4.73	4.0	2.35	4.3	75.3
12.5	4.836	5.8	2.373	3.2	82.0
15.0	5.4	6.0	2.39	1.8	89.6
17.5	6.032	6.4	2.410	0.46	97.3

Table 8. Nigeria Roads and Bridges Specifications [2]

Property	Specifications	
	Min	Max
Stability	3.5KN	-
Flow	2mm	4mm
Void in total mix	3%	5%
Volume Filled with Bitumen	75%	82%
Bulk density	2.35	2.35

By using different percentages of glass waste, 10% glassphalt which satisfied all the requirements as per the specification limit was found to be Optimum Glass Content.

4. CONCLUSION

The objective of this study is to investigate the effect of using crushed waste glass as a filler and as coarse aggregates in the Asphalt wearing

Course, where the results can be concluded as the following:

- The existence of crushed glass in the asphalt binder course mixture is considered an eco-friendly material and it can be utilized as sustainable management of waste glass.
- Crushed waste glass can be used in asphalt binder course with the maximal

size of 4.75mm and the optimum replacement of 10% of river sand (0/4.75) aggregate.

- The results of Marshall Stability, flow, bulk density and air voids of glasphalt are consistent with the specifications range at the different percentages of glass contents (5.0% - 17.5%).
- Marshall Stability and the bulk density achieve the requirements of the local and international specifications with 10% glass content.
- At 10% glass content the value of flow consistent with the local specification and slightly higher than the maximum limit of the international specification.
- The results of this study apply only to the specific gradation and the type of glass that was used. Other gradations of glass or resources may produce different results.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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