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An Evaluation Of Potential Of Using Bitumen Modified With Glass Dust And Crumb Rubber As Binder In Asphalt Concrete

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Abstract: *Two bitumen modifications were separately produced, tested, and then optimally combined to produce one binder mixture. The mixture was tested to ensure its physical and mechanical properties sufficiently met standard requirements for use as an asphalt binder. The first modification was with waste glass. Bitumen was replaced by weight in percentages of 0, 5, 10 and 15% with glass dust and tested. This mix was referred to as Glass Dust Modified Bitumen (GDMB). 10% replacement was found to be the optimum mix. The second modification was done using crumb rubber produced from old discarded tyres. This mix was termed Crumb Rubber Modified Bitumen (CRMB). The percentage replacement was 0, 5, 10, 15 and 20%. The 15% crumb rubber modification was found to produce the most encouraging results as per standard specifications. The optimum samples from both modifications were then combined in ratios of 7:3, 3:2 and 1:1 as CRMB:GDMB. Tests and analyses were done to determine which ratio was most suitable for use as sustainable alternative to ordinary bitumen for asphalt concrete production. The optimum was found to be 1:1. Results were then documented and discussed.*

Keywords: *glass dust, crumb rubber, modification, bitumen, asphalt*

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1. INTRODUCTION

Hot Mix Asphalt (HMA) is the most widely used material for pavement construction on road networks. In the United States, approximately 96 percent of all paved roads were done using hot mix asphalt (Copeland, 2007). The reliance on natural resources raises concerns about resource depletion and environmental sustainability. The extraction and processing of resources entail significant energy consumption, habitat disruption, and landscape alteration (Brasileiro et al., 2019). To address these challenges, researchers and industry professionals are exploring alternative materials and technologies to modify asphalt mixtures. By repurposing existing materials, this reduces the demand for virgin resources and minimizes waste generation (L-Badawy et al., 2019). While asphalt remains indispensable for road pavements for now, the depletion of natural resources necessitates a shift towards more sustainable practices.

Glass is non-biodegradable and is generally not considered incinerable in the same way that organic matter and some plastics are. When incinerated, glass does not undergo combustion due to it high melting point and inert nature (Rinkesh, 2024). Recycling of waste glass is a tedious and slow process. Only about 21% of glass produced worldwide ends up recycled, the remaining millions of tonnes produced annually ends up as waste. Hamid et al. (2023) observed that the use of 10% Borosilicate glass (BSG) produced significant enhancements in the Marshall properties of asphalt. Rutting resistance was also enhanced with up to 10% addition of BSG, providing a 26.6% decrease in the measured rut depth. Further increment of BSG however affected the rut resistance negatively. Due to the high angularity of the BSG aggregates, the modified asphalt provided better results than that of traditional quarried aggregates. The research work also observed that for Moisture Damage, a dosage of 10% produced reasonable results and higher dosage resulted in significant loss of bitumen coating. Wu et al. (2013) submitted that the use of waste glass in asphalt concrete is feasible and can be used with a maximum particle size of 4.75mm. To get optimal results, the percentage replacement is 10% and the performance such as strength index, high temperature stability and water stability would still be maintained within the acceptable standards. Shafabakhsh et al. (2014) proposed that dynamic properties of glassphalt such as fatigue life, stiffness modulus and creep compliance are improved when compared with those of traditional asphalt concrete. Issa (2016) carried out a test on 70/100 penetration grade bitumen and laminated glass. In the research work he observed the change in stability and flow values of the asphalt mix after the addition of laminated glass. It was discovered that the average stability improved by 10%, with laminated glass addition until the optimum level (approximately 10% of glass) was reached. Further increase of the laminated glass in the samples caused the stability readings to decrease. Hence he noted that 10% glass produced the best result for stability as the result was higher than that of the traditional asphalt (asphalt with 0% glass. Viswanathan (1996) studied the characterization of waste recycled glass as highway material. He concluded that waste glass cullet has characteristics similar to quarried aggregates and can be used for road pavement as aggregate.

Salem et Al. (2017) studied the effect of waste glass on properties of asphalt concrete mixtures. He determined that with the increase in glass percentage by weight of fine aggregate a more economical mix was prepared which was significantly more durable. The optimum glass content was determined to be 10% by weight of fine aggregates. He determined that optimum binder content for the mix with 10% glass decreased by 0.4% compared to a normal asphalt concrete mix. Similarly, an increase of approximately 10% in Marshall Stability values was determined. Airey et al. (2004) observed that if waste glass with a dosage of 10 to 15% by weight of mixture is added to asphalt, then satisfactory performance of asphalt pavement layer can be achieved. Simone et al. (2019) demonstrated a significant enhancement in the bearing capacity and rutting resistance of flexible pavements by introducing glass powder as filler. Jony et al. (2011) conducted a study using glass powder as filler material in the asphalt concrete mix. An average improvement of 13% was observed in stability. The Marshall Flow values however suffered an average decrease of 39%. Huang et al. (2007) reported that roads paved with asphalt modified with 10% to 15% glass cullet showed satisfactory performance. It was revealed that the maximum permissible size of crushed glass is 4.75mm due to safety considerations. A higher dosage of crushed glass resulted in inadequate friction and less bonding strength. The study also encourages the use of 2% hydrated lime as an anti-stripping agent. Disfani et al. (2014) observed that waste glass cullet with maximum particle size of 4.75 mm have high angularity and, in many engineering aspects, are similar to traditional quarried aggregates. Thus, this cullet can partially replace quarried aggregate particles. It was however noted that due to their high angularity, they may cause skin cutting and puncturing if waste glass cullet larger than 4.75 mm was used in the asphalt mixture.

Tyres are highly durable and can persist in the environment for decades, contributing to long-term pollution. When burned, whether intentionally or accidentally, they release harmful chemicals and particulate matter into the air, posing health risks to humans and wildlife alike. Unlike other thermoplastic polymers, the rubber from old tyres cannot be remolded or softened by melting or heating, thus the stripping of the rubber from the old tyres and the creation of crumb is seen as a major way to reuse the rubber (Adhilkarri et al., 2000).

Huang et al. (2007) observed that the modification of asphalt with crumb rubber could be done using two different methods; the wet process and the dry process. The wet process involves directly introducing the crumb rubber into the bitumen as a binder modifier, and then adding the aggregates to create the modified asphalt. The Dry process on the other hand, is executed by substituting a percentage of the fines in the aggregates with ground rubber particles. Hicks et al. (1985) observed that in the wet process method, the crumb rubber is mixed directly with bitumen at a consistent temperature of ranging from 191°C - 218°C for duration of 60 - 120 minutes. Xiao et al. (2008) studied the influences of crumb rubber size and type on reclaimed asphalt pavement (RAP) mixtures and concluded that modifying bitumen with ground crumb rubber enhanced its elastic behaviour and also improved rutting resistance at intermediate temperature, also reducing reflective cracking, which caused increment in ductility. Heitzman (1992) observed that the interaction between crumb rubber and bitumen is nonchemical. He concluded that the crumb rubber does not melt in the bitumen, rather at high temperatures during the wet process rubber particles swell in the oily phase of the asphalt binder, forming a gel-like material. This interaction reduces the free space in the modified bitumen, thus increasing the overall viscosity of the crumb rubber modified bitumen. Yildirim (2005) observed that despite the advantages that crumb rubber modification of asphalt presented, there were also some negative aspects. He highlighted the need for a prolonged application of high temperatures as a negative factor, as the digestion time for the wet process can take up to 2 hours and sometimes require temperatures above 200 degrees Celsius. He noted the sensitivity to decomposition and oxygen absorption of crumb rubber modified bitumen as a problem requiring further research. Hassan (2012) reported that when crumb rubber particles are mixed with bitumen at high temperatures, they absorb the light components of bitumen and swell 2 to 3 times the former size, resulting in dramatically increased viscosity of the modified mix. However, if the temperature is too high or the process is prolonged the crumb rubber tends to disperse in the modified mix as it degrades. Venudharan et al. (2018) observed the rheological and thermo-chemical behaviour of crumb rubber modified bitumen. It was noted that as the percentage of crumb rubber increased in the modified mix, the bitumen complex modulus increased, while the phase angle decreased. This resulted in overall improved elasticity and strength of the binder. Emphasis was also laid on the importance of closely monitoring and controlling both the interaction temperature and time in order to produce the optimum results and avoid the degradation of the crumb rubber in the mix.

The integration of waste glass and crumb rubber in asphalt concrete presents a promising avenue for sustainable road construction. However, several unresolved challenges related to performance, compatibility and environmental impact hinder its widespread adoption. Addressing these issues through comprehensive research is crucial to realizing the full potential of this innovative approach and advancing towards a more sustainable infrastructure system. This study is aimed at evaluating the potential of using Rubberized-Glassphalt for sustainable road construction. The objectives were to evaluate the physical and rheological properties of rubberized-glassphalt binder blends and to compare the performance of rubberized-glassphalt concrete with that of conventional hot mix asphalt (HMA).

II. MATERIALS AND METHODS

The materials used in this project work include: bitumen, waste glass and crumb rubber.

2.1 MATERIALS.

2.1.1 Crumb Rubber

The crumb rubber used as a bitumen modifier in this research work was sourced from Fursa Technology Nig. Ltd, Building Materials Market, Dei-Dei, F.C.T Abuja in Nigeria. It was produced by mechanical shredding and sieving of old discarded tyres. It was thoroughly cleaned and free of any metal reinforcement particles from the waste tyres. The maximum particle size of the crumb rubber was 2mm. ASTM D5603 and ASTM D6270 specifications were followed in determining the physical characteristics and gradation of the processed crumb rubber used in this research. The gradation results are presented in Table 1 and Fig 1.

2.1.2 Glass Powder

Broken waste glass was procured from Jabi Upstairs Glass Depot, Jabi, F.C.T Abuja in Nigeria. It was clear sheet glass commonly used for making sliding windows for buildings in Nigeria. The waste glass was thoroughly washed and cleaned. It was then hand-crushed and pulverized into dust-sized particles. Crushing and screening is necessary to eliminate harmful sharp edges and also elongated or flat particles which are susceptible to stripping. It was important to use properly shaped and sized particles for this study to encourage cohesion in the mix. The glass dust was sieved using a set of ASTM sieves and the particles passing Sieve No. 200 (0.075mm) were used for this study. Clear sheet glass typically has a specific gravity slightly varying between 2.5 and 2.6.

2.1.3 Bitumen

For this research work, penetration grade bitumen 60/70 procured from Ringardas Nigeria Limited (ASCA) was used. It is commonly used for highway pavement works in Nigeria. It falls under the penetration grade category, indicating its viscosity and hardness characteristics. The number '60/70' denotes its penetration value (in units of 0.1dmm) at 25°C: 60 to 70. This range signifies its medium hardness and moderate resistance to temperature variations, making it suitable for various road construction applications in moderate climes. The physical properties of the bitumen 60/70 used in this study were determined using Penetration Test, Softening Point Test and the Flash point and Fire point Tests. The results are presented in Table 2.

Table 1: Crumb rubber gradation result

SIEVE SIZE (mm)	PERCENTAGE PASSING (%)	
	SPECIFICATION	RESULTS
2.000	100	100
1.180	65 – 100	98.92
0.600	20 – 100	43.52
0.300	0 – 45	5.51
0.063	0 – 5	0.12

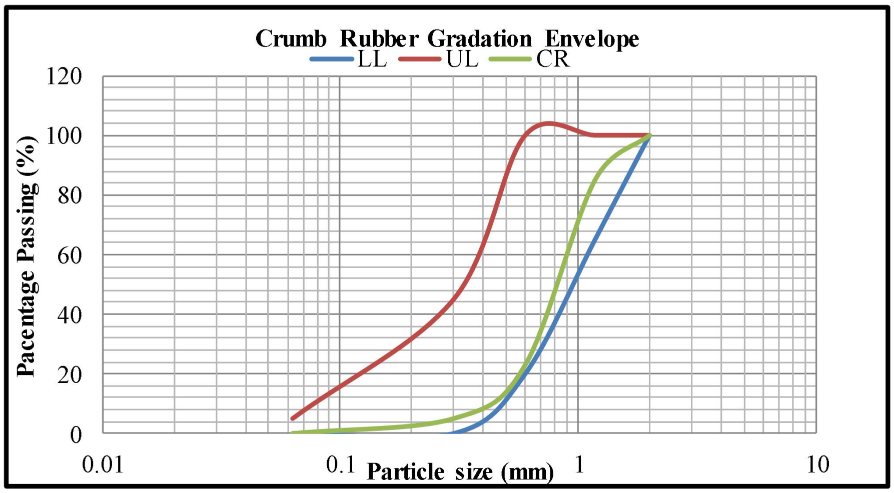

Fig. 1: Crumb Rubber Gradation Envelope

Table 2: Test results for unmodified bitumen

TEST DESCRIPTION	SPECIFICATION	RESULT	ASTM SPECIFICATION LIMITS
Softening Point	ASTM D36-2002	47.8ºC	48 – 56ºC
Penetration	ASTM D5/D5M-13	66.3d-mm	60 – 70d-mm
Flash Point of Unmodified Bitumen	ASTM D96-12b	252ºC	Min. 230ºC
Fire Point of Unmodified Bitumen	ASTM D96-12b	270ºC	--------
Specific Gravity	ASTM D3289-03	1.03	0.97 – 1.08

2.2 Sample preparation and testing methods

Marshall Mix design was used in this design for the determination of the optimum binder content (OBC). Wet Process was used for the modification of asphalt concrete. Both glass dust modified bitumen (GDMB) and Crumb rubber modified bitumen (CRMB) were produced by the same process. In separated experiments, they were introduced in varying percentages to unmodified bitumen samples at a temperature of 160°C - 170°C. Each sample was thoroughly mixed using a propeller blade mixer at a blending speed of 500 rpm. While maintaining the temperature, the mixture was then kept to digest for 45 minutes.

2.2.1 Preparation of Glass Dust-Modified Bitumen (GDMB) samples

From literature, 10% replacement is recommended as the optimum quantity of waste glass. In this study 4 sets of samples were produced by partial replacement by weight of bitumen with glass dust. The samples had 0%, 5%, 10%, and 15% replacement respectively. Each sample produced 3 specimens. This made a total of 12 specimens. Tests were carried out on each sample. Since each sample has 3 specimens, the average of the results from the 3 specimens was calculated and recorded as the final result for each sample.

The Penetration Test results are presented in Table 3 and Fig. 2. It was observed that as the percentage of glass dust increased in the mixture, penetration depth decreased. Penetration depth reduced by 6.033%, 8.446% and 15.083% in the specimens with the introduction of 5%, 10% and 15% of glass dust by weight to bitumen respectively. However, increase of glass dust above 10% reduced the penetration depth beyond penetration grade bitumen 60/70 limits.

The Softening Point Test results are presented in Table 3 and Fig. 3. It was observed that with the percentage increase of glass dust, the softening point temperature of the mixture increased as well. It increased by 2.092%, 3.556% and 6.903% when 5%, 10% and 15% of glass dust by weight was mixed with bitumen respectively. These results indicate that bitumen modified with glass dust has a lower susceptibility to temperature changes. A higher softening point means that the asphalt pavement can better withstand higher temperatures without becoming excessively soft or deforming. This is particularly advantageous in hot climes or under heavy traffic conditions where high temperatures can affect road performance.

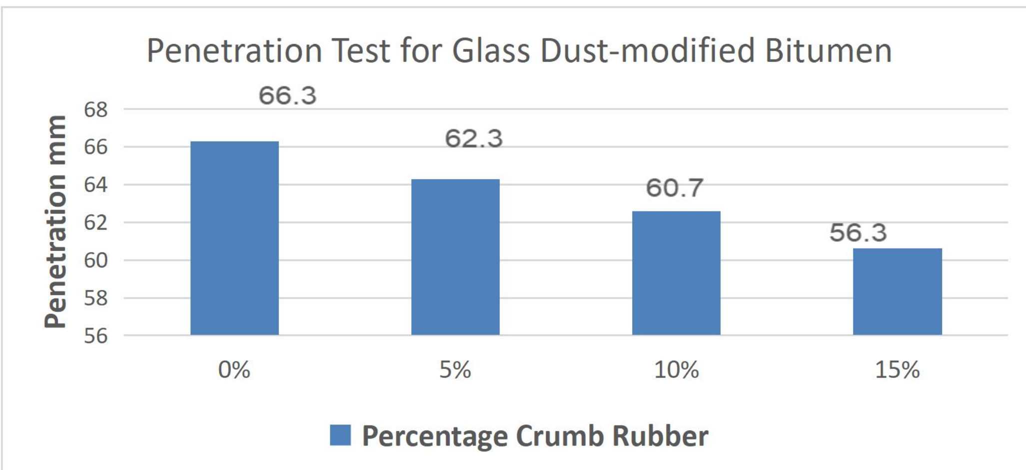

Fig. 2: Graphical representation of Penetration Test for GDMB

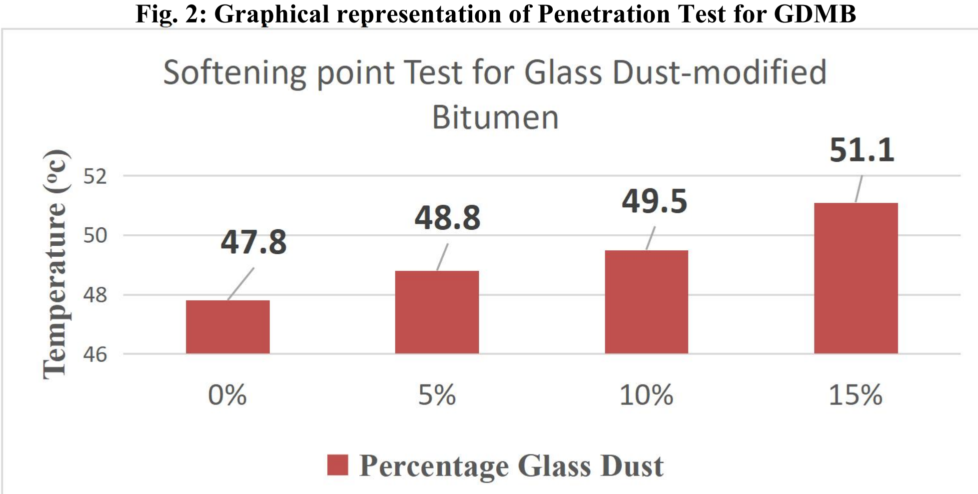

Fig.3: Graphical representation of Softening Point Test for GDMB

2.2.2 Preparation of Crumb Rubber-Modified Bitumen (CRMB) samples

4 sets of modified samples were produced by partially replacing bitumen by weight with crumb rubber. The samples had 0%, 5%, 10%, 15% and 20% replacement respectively. From each sample 3 specimens were produced for testing. The CRMB had a total of 12 specimens in addition to the 3 specimens of the control, which brought the total number of specimens to 15. Tests were also carried out on each specimen. Since each sample had 3 specimens, the average of the results from the 3 specimens was calculated and recorded as the final result for each sample.

III. RESULTS AND DISCUSSION

The Penetration Test results are presented in Table 3 and Fig. 4. It was observed that increase of crumb rubber by weight in the mixture resulted in decrease of penetration depth as compared to the control. Penetration depth decreased by 3.016%, 5.581%, 8.597% and 12.066% with the replacement of 5%, 10%, 15% and 20% of bitumen by weight with crumb rubber respectively. Crumb rubber as a bitumen modifier therefore results in higher viscosity, provides better rutting resistance, enhanced durability and better ageing resistance. Results showed that glass dust had higher percentage decrease in depth with the increase of percentage replacement of bitumen with modifier. Glass dust therefore performs better as a modifier than crumb rubber in terms of stiffness and penetration.

The Softening Point Test results are presented in Table 3 and Fig. 5. The results showed that softening point temperature increased as the crumb rubber percentage increased. However, beyond 15% replacement of bitumen by weight with crumb rubber the softening point improved above PG 60/70 limits. It increased by 5.230%, 8.787%, 17.155% and 24.059% when 5%, 10%, 15% and 20% of bitumen by weight was replaced with crumb rubber respectively. This study submitted that crumb rubber performed better as a modifier than glass dust in terms of temperature susceptibility.

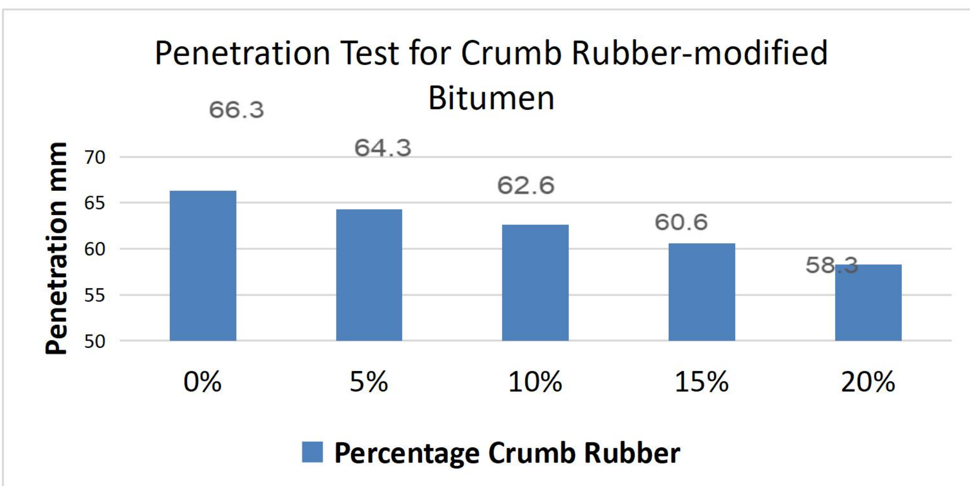

Fig. 4: Graphical representation of Penetration Test for crumb rubber-modified bitumen

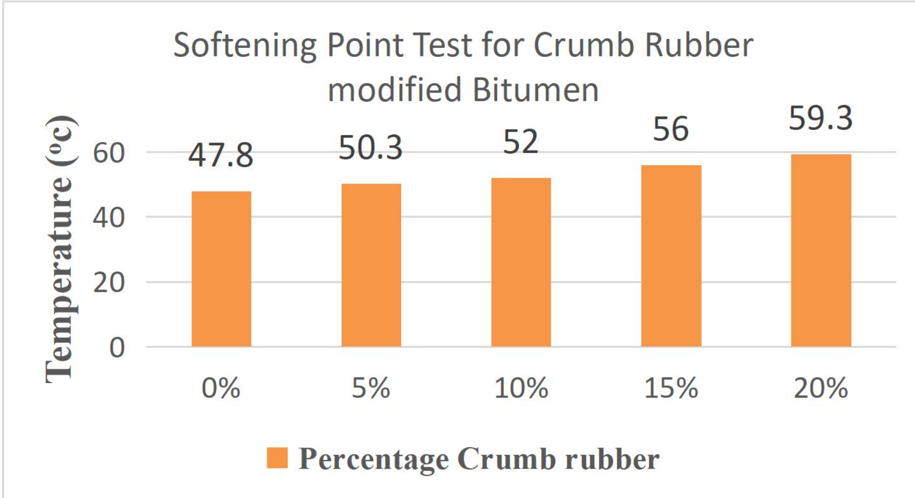

Fig. 5: Graphical representation of Softening Point Test for crumb rubber-modified bitumen.

Table 3: Penetration and Softening Point Test Results

	PENETRATION TEST RESULTS					SOFTENING POINT TEST RESULTS				
	0%	5%	10%	15%	20%	0%	5%	10%	15%	20%
GDMB	66.3	62.3	60.7	56.3	--	47.8	48.8	49.5	51.1	--
CRMB	66.3	64.3	62.6	60.6	58.3	47.8	50.3	52.0	56.0	59.3

2.2.3 Selection of optimum percentage modifications of GDMB and CRMB for the production of RGMB

For GDMB, it was observed that both the 5% and the 10% sample results satisfied ASTM specifications for PG 60/70. The 10% modification was stiffer, more durable and had better resistance to rutting than the 5% modification. Its softening point value was 1.434% higher than that of the 5% modification. Thus the 10% GDMB was selected. It also encourages more utilization of waste glass, hence diverting more quantities from landfills and promoting sustainability. For CRMB, the 5%, 10%, and 15% samples all satisfied ASTM specifications for PG 60/70. The 15% modification mix produced results that indicate a more durable and long lasting option to the other percentages. Its penetration depth was 5.754% and 3.195% less than 5% and 10% modifications respectively, while it's softening point was 11.332% and 7.692% higher than those of 5% and 10% respectively. The 15% modification was selected because it utilises higher quantities of crumb rubber than the other percentages. It is therefore a more sustainable option and repurposes more waste material.

2.2.4 Optimum Combination of CRMB and GDMB for use as sustainable alternative to ordinary bitumen

The test results show that crumb rubber primarily improves temperature susceptibility by increasing softening point temperature, while glass dust primarily improves hardness and rutting resistance by reducing penetration depth. Thus a combination of both modifications will overall improve the performance beyond that of ordinary bitumen. The selected modified specimens (i.e. 15% CRMB and 10% GDBM) were mixed in varying ratios of 7:3, 3:2 and 1:1 with the first Fig. being CRMB and the second one GDMB. The decision to have CRMB in higher quantity than GDMB was taken because the former has had more extensive research conducted on it and has yielded better results. Research has shown that crumb rubber reduces the OBC required in an asphalt mixture. Also, since glass is hydrophilic in nature there were concerns about adequate adhesion within the mixture, to prevent ravelling and stripping. This combined mixture of 15% CRMB and 10% GDMB was then referred to as Rubberized-Glass-Modified Bitumen (RGMB). The

Penetration and Softening point test results for the varying ratios are presented in Table 4 and Table 5.

Table 4: Penetration Test results for varying ratios of CRMB:GDMB mixtures

Ratio of CRMB to GDMB	TEST DESCRIPTION	Penetration (d-mm)	ASTM SPECIFICATION LIMITS (60 – 70d-mm)
70% CRMB : 30% GDMB	ASTM D5/D5M-13	57.6	Fail
60% CRMB : 40% GDMB	ASTM D5/D5M-13	62.3	Pass
50% CRMB : 50% GDMB	ASTM D5/D5M-13	64.3	Pass

Table 5: Softening Point Test results for varying ratios of CRMB:GDMB mixtures

Ratio of CRMB to GDMB	TEST DESCRIPTION	Softening Point (^{0}C)	ASTM SPECIFICATION LIMITS (48 – 56^{0}C)
70% CRMB : 30% GDMB	ASTM D36-2002	57.9	Fail
60% CRMB : 40% GDMB	ASTM D36-2002	55.1	Pass
50% CRMB : 50% GDMB	ASTM D36-2002	54.4	Pass

2.2.5 DSR analysis results for RGMB specimens

Complex shear modulus and phase angle test result values were gotten for three of the modified samples for the varying ratios of CRMB: GDMB mixtures. The rutting parameter was then determined for each mixture under consideration, with respect to the temperature schedule. For fresh, un-aged asphalt binder, specifications recommend that the rutting parameter (G*/Sinδ) be greater than 1000Pa (1.0kPa). This is because rutting is of greater concern during the early to midlife of hot mix asphalt (Almohanna, 2019). Tables 6 through to 8 present the DSR analysis results for the RGMB samples.

Table 6: Performance Grade (PG) Assessment of 70% CRMB: 30% GDMB mixture (Single Frequency Strain-Control Temperature).

Temperature (°C)	G*	δ	Sinδ	G*/Sinδ (Pa)	Criteria (G*/Sinδ> 1000Pa)
46	1.01E+04	78.56	0.980133	10314.93	**Pass**
52	3.87E+03	81.08	0.987906	3914.34	**Pass**
58	1.61E+03	82.76	0.992027	1617.90	**Pass**
64	719.5	71.93	0.950678	756.83	**Fail**
70	353.2	83.59	0.993748	355.42	**Fail**
76	191.3	81.78	0.989726	193.29	**Fail**

Table 7: Performance Grade (PG) Assessment of 60% CRMB: 40% GDMB mixture (Single Frequency Strain-Control Temperature).

Temperature (°C)	G*	δ	Sinδ	G*/sinδ (Pa)	Criteria (G*/sinδ> 1000Pa)
46	1.38E+04	69.50	0.936916	14718.49	**Pass**
52	5.95E+03	71.76	0.949754	6259.52	**Pass**
58	2.70E+03	73.29	0.957772	2821.13	**Pass**
64	1.31E+03	73.73	0.959952	1359.44	**Pass**
70	680.4	72.24	0.952343	714.45	**Fail**
76	389.4	68.28	0.929003	419.16	**Fail**

Table 8: Performance Grade (PG) Assessment of 50% CRMB: 50% GDMB mixture (Single Frequency Strain-Control Temperature).

Temperature (°C)	G*	δ	Sinδ	G*/sinδ (Pa)	Criteria (G*/sinδ> 1000Pa)
46	4.11E+04	72.37	0.953032	43083.54	**Pass**
52	1.73E+04	74.40	0.963163	17940.90	**Pass**
58	7.43E+03	74.56	0.96391	7710.27	**Pass**
64	3.53E+03	71.98	0.950949	3713.13	**Pass**
70	1.88E+03	66.74	0.918722	2047.41	**Pass**
76	1.14E+03	58.73	0.854731	1332.58	**Pass**

2.3 Discussion of results

From the results of the tests conducted on the RGMB specimens it was observed that the 70% CRMB: 30% GDMB mixture did not meet ASTM specifications for PG 60/70. It failed both the penetration and softening point tests. For the DSR analysis it was observed that though it performed satisfactorily at lower temperatures of 46°Cto 58°C in terms of rutting parameter, it however failed at higher temperatures. The study revealed that 60% CRMB: 40% GDMB mixture met ASTM specifications for PG Bitumen 60/70 as per the penetration test and also softening point test results. However, the rutting parameter (G*/Sinδ) parameter failed at 70°C. In-service temperatures for wearing courses on Nigerian highways can sometimes reach 70°C, negatively impacting pavement performance and causing issues such as softening of asphalt, rutting and accelerated ageing. Thus this modified mix specimen also failed to meet the requirements as asphalt concrete pavement is designed to withstand the maximum anticipated temperature in service. 50% CRMB: 50% GDMB mixture passed both the penetration test and the softening point test as per ASTM specifications. As for the DSR-conducted analysis, the mixture also got acceptable values for all the temperatures anticipated for in-service pavement (G*/Sinδ> 1000Pa). Thus the 50% CRMB: 50% GDMB mixture qualified to be used as an asphalt binder in the production of asphalt concrete for wearing course. It was observed that as compared to unmodified bitumen, RGMB mixture has better penetration test results (3.017% less than the control). This indicates that it is harder and will withstand traffic loads better. RGMB also has a higher Softening point than unmodified bitumen (13.81% higher).This indicates that it will retain its shape under high temperatures and has better rutting resistance than ordinary bitumen 60/70.

IV. CONCLUSION

This research work attempted to answer the question: Can waste glass and crumb rubber from old discarded tyres be utilized together for bitumen modification as an alternative to ordinary bitumen? This study submitted that RGMB as an asphalt binder is stable and has adequate consistency. RGMB also has adequate hardness, rutting resistance at high temperature, fatigue cracking resistance, and can resist damage from climatic conditions. The results produced by this experimental study represent an encouraging starting point for more studies to be carried out to shed light on important questions like the durability of RGMB while in service and its skid and raveling resistance.

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