The Potential Waste Glass as Replacement Of Aggregate in Pavement

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ABSTRACT

Due to the rapid development of our country, there has been a significant increase in highway construction aimed at improving travel efficiency. Consequently, the demand for coarse aggregates has surged alongside the expansion of highways and roads, resulting in a sharp rise in aggregate mining activities. However, this increase in mining operations can have detrimental environmental impacts, including landscape destruction, loss of agricultural and grazing lands, riverbank erosion, deforestation, habitat destruction, and pollution of air and noise. Glass is a unique material which is hardness, durability and ability to be completely recycled, but glass recycling in Malaysia is in its early stages. Less than 30% of new bottles are produced from recycled glass. In pavement applications, the replacement of aggregates with 10% and 30% waste glass has been investigated as part of controlled experiments. The study aims to assess the effectiveness of waste glass in achieving optimal pavement stability and flow characteristics. Adjustments in bitumen content have been made based on Marshall Testing to determine the optimal point for stability and flow.

KEYWORDS

Waste Glass, Aggregate, Pavement

1. INTRODUCTION

Roads are essential infrastructure, providing critical connections between communities and enabling economic development [S. Salehi et. al., 2021]. The effectiveness of road networks is heavily influenced by pavement design, which impacts factors such as load-bearing capacity, durability, and environmental sustainability (Jaime Styler et. al., 2023). However, the traditional reliance on natural aggregates for pavement construction presents significant environmental challenges, including resource depletion, habitat destruction, and increased carbon emissions. At the same time, waste glass, which is non-biodegradable and often disposed of in landfills, exacerbates environmental problems. Despite being 100% recyclable, only 21% of glass is recycled globally, leading to the inefficient use of resources and contributing to landfill overflow (Jaime Styler et. al., 2023). This study seeks to address both these issues by exploring the use of waste glass as a partial replacement for natural aggregates in asphalt pavements, offering a more sustainable solution that reduces waste and conserves natural resources.

Pavements are primarily categorized into two types based on design consideration. flexible pavement and rigid pavement. The difference between flexible and rigid pavements lies in how they distribute loads to the subgrade. Aggregates serve critical functions in both flexible and rigid pavements by providing structural support and stability. In flexible pavements, aggregates are used in the base and sub-base layers, where they distribute the load from the surface asphalt layer, providing a stable foundation that helps prevent deformation and rutting. In rigid pavements, aggregates are an essential component of the concrete mix, where they enhance the strength and durability of the concrete slab. The aggregates help distribute loads over a larger area, reducing stress on the underlying soil and contributing to the pavement's overall longevity. In developing countries, asphalt pavement typically consists predominantly of natural aggregates, making up to 95% of the aggregate content. The quantity required for a project is determined by factors such as the road's subgrade, anticipated traffic loads, and the overall scale of the project (A.Busari et. al., 2019).

The primary objective of this study is to assess the feasibility and performance of waste glass as a partial substitute for natural aggregates in asphalt mixtures. Specifically, the study will investigate how varying proportions of waste glass (10%, 20%, and 30%) affect key mechanical properties of the asphalt, such as stability, flow, and durability. Additionally, the research will determine the optimal bitumen content for glass-modified asphalt through Marshall testing, with the aim of achieving the best balance of performance and sustainability. This research is novel, as it focuses on incorporating waste glass into asphalt, an area that has received limited attention in comparison to its use in concrete. Moreover, the study adopts an innovative approach by adjusting the bitumen content to optimise the performance of glass-modified asphalt, ensuring that it meets the required industry standards for durability and stability.

This study contributes significantly to the field of sustainable infrastructure by demonstrating the potential for using recycled glass in asphalt pavements. By replacing natural aggregates with waste glass, this research provides a practical solution to both the depletion of natural resources and the accumulation of glass waste. The findings will offer valuable guidance for the construction industry, enabling the adoption of more sustainable practices that incorporate recycled materials. Furthermore, this study supports the circular economy by promoting the recycling of waste glass, thus reducing the environmental footprint of road construction. Ultimately, this research aims to improve the mechanical performance of pavements, reduce the carbon footprint of infrastructure projects, and contribute to more sustainable practices in the construction industry.

2. METHODOLOGY

The research methodology employed in this study focuses on utilising waste glass as a partial replacement for aggregates in pavement construction. The experimental procedures and testing protocols adhere to the Manual on Standard Specifications for Road Works, Section 4: Flexible Pavements, as outlined by the Jabatan Kerja Raya (JKR) Malaysia. Aggregates and equipments for creating samples also for tests (stability and flow) were provided by Institusi Kerja Raya Malaysia (IKRAM). The flow chart methodology for this research is shown as follow:

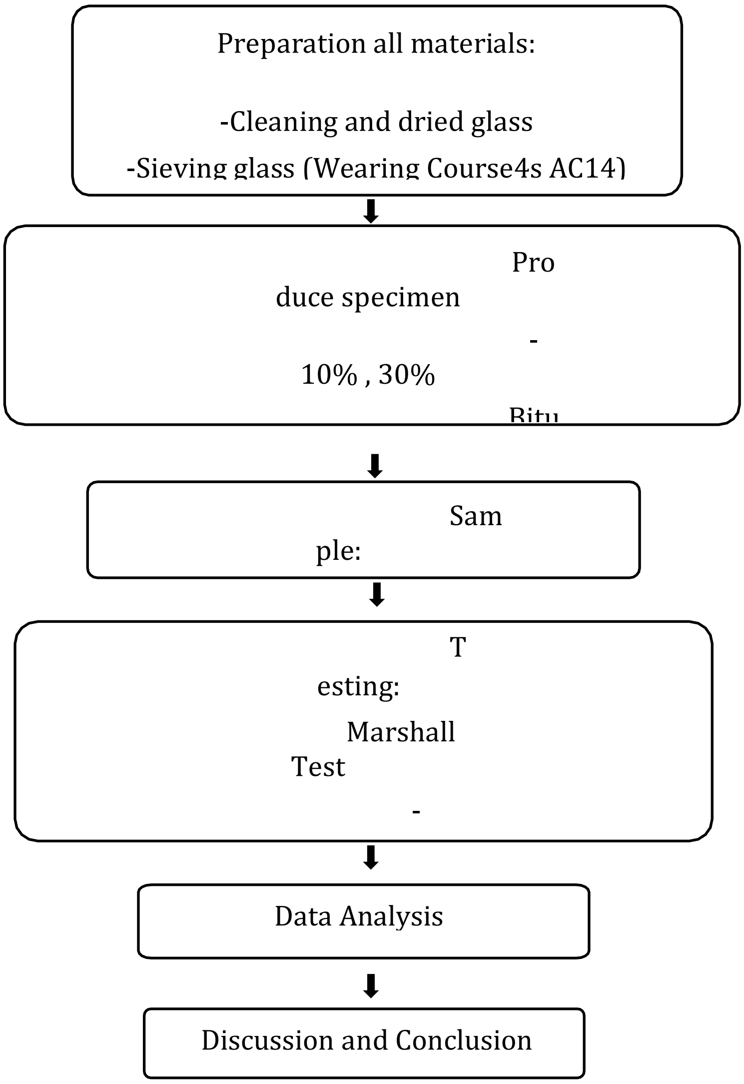

Figure 1. Flow Chart Methodology

2. 1 Material

The wasted glasses bottle was collected from household and landfill in Sabak Bernam dumpsite. The waste glass was brushed and washed to remove all the logo sticker and dirt. The glass was crushed and sieve following JKR roadwork specification for flexible pavement for wearing course (AC-14) standard for aggregate. Table 1 shows wearing course AC-14 gradation limit.

Table 1. Wearing course AC-14 gradation limit

Mix Design B.S Sieve	AC 14 % Passing By Weight
28.0 mm	-
20.0 mm	100
14.0 mm	90 – 100
10.0 mm	76 – 86
5.0 mm	50 – 62
3.35 mm	40 – 54
1.18 mm	18 – 34
425 µm	12 – 24
150 µm	6 – 14
75 µm	4 – 8

2. 2 Produce Sampel

Two levels of waste glass content, specifically 10% and 30%, were utilized to create 20 samples varying in bitumen percentages (4.0%, 4.5%, 5.0%, 5.5%, 6.0%). The waste glass and aggregate were mix together and pre heated at 120˚C for 30 minutes before mixing with the bitumen. Bitumen was heated in the oven at 135˚C . The mixture temperature should be between 140˚C to 160˚C before compaction. The sample place on compacting machine for 75 blows for the upwards and bottoms of the mold. After 24 hours sample will be tested.

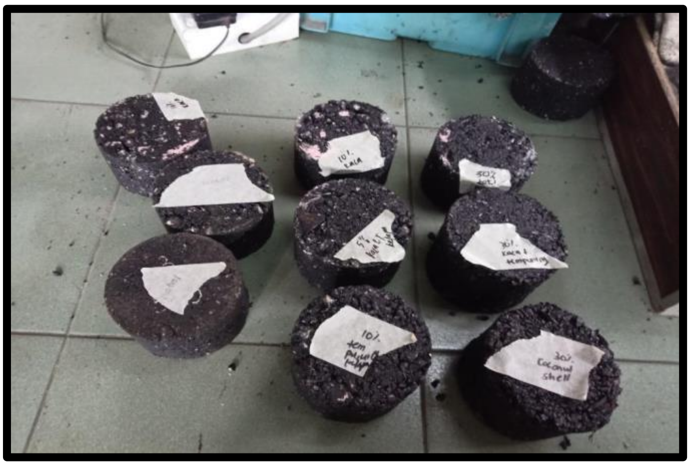

Figure 2. Sample of the asphalt concrete

2. 3 Testing

The pavement needs to offer a smooth riding experience with sufficient skid resistance, and its thickness should be designed to ensure the uniform distribution of traffic loads. This distribution helps keep stresses and strains within the capacity limits of the materials at each layer of the pavement and subgrade (V. Gunalaan & Hi-dayu, 2014) . To assess the effectiveness of waste glass in achieving optimal pavement stability and flow characteristics, adjustments in bitumen content have been made based on Marshall Testing (ASTM D 1559) to determine the optimal point for stability and flow. Table 2 presents the design bitumen content and corresponding test values. The mean optimum bitumen content is then determined from the plotted smooth curves, which must comply with the design parameters specified in Table 3, as outlined in the Manual on Standard Specifications for Road Works, Section 4: Flexible Pavements, Jabatan Kerja Raya (JKR) Malaysia.

Table 2. Design Bitumen Content

AC 10 - Wearing Course	5.0 - 7.0%
AC 14 - Wearing Course	4.0 - 6.0 %
AC 28 - Binder Course	3.5 - 5.5%

Table 3. Test and Analysis Parameter

Parameter	Wearing Course	Binder Course
Stability, S	> 8000 N	> 8000 N
Flow, F	2.0 - 4.0 mm	2.0 - 4.0 mm
Stiffness, S/F	> 2000 N/mm	> 2000 N/mm
Air voids in mix (VIM)	3.0 - 5.0%	3.0 - 7.0%
Voids in aggregate filled with bitumen (VFB)	70 - 80%	65 - 75%

3. RESULTS AND DISCUSSION

A total 20 sample specifically 10% and 30%, waste aggregate tested at Institusi Kerja Raya Malaysia (IKRAM). Table 4 the data of Marshall test consist Stability, flow, stiffness, air void in mix (VTM) and void in aggregate with bitumen (VFB) for 10% waste glass in pavement.

Table 4. The data of Marshall Test sample 10% waste glass

AC%	Density	Stability N	Flow mm	Stifffnes N/mm	VTM %	VFB %
4.0	2.208	8670.5	3.11	5149.7	9.55	47.93
4.5	2.240	9052.5	4.01	17121.7	7.55	56.81
5.0	2.275	11708.5	3.94	44099.1	5.45	67.24
5.5	2.275	8850	3.54	2432.5	4.73	72.18
6.0	2.339	11209	4.01	44817.8	2.52	84.38

Based on the data and analysis, an Optimum Binder Content (OBC) of 5.25% bitumen (AC)has been determined. Table 5 presents a comparison between the data at 5.25% bitumen(OBC) and the standard requirements specified in the Manual on Standard SpecificationFor Road Work Section 4: Flexible Pavement, issued by Jabatan Kerja Raya(JKR) Malaysia.

Table 5 . The data of Marshall Test sample 10% waste glass & comparison against standard requirements.

Parameter	Results	Specification (Wearing Course, JKR 2008)	Remarks
Stability , S	11000	>8000 N	✓
Flow, F	3.25	2.0 - 4.0	✓
Stiffness, S/F	4500	>2000 N/mm	✓
Air voids In Mix (VTM)	3	3.0 -5.0 %	✓
Voids In Aggregates filled with bitumen(VFB)	78	70 -80 %	✓

Additionally, Table 6 presents the Marshall test data, including Stability, flow, stiffness, air voids in mix (VTM), and voids in aggregate with bitumen (VFB), specifically for pavement containing 30% waste glass.

Table 6. The data of Marshall Test sample 10% waste glass

AC%	Density	Stability N	Flow mm	Stifffnes N/mm	VTM %	VFB %
4.0	2.194	6654	3.45	2043.94	9.51	49.70
4.5	2.207	5971	2.83	208086.8 4	8.27	54.04
5.0	2.240	6786	3.11	22304.91	6.26	63.65
5.5	2.220	7178	3.06	2268.73	6.43	65.40
6.0	2.313	8568	4.25	2130.55	1.83	88.16

Based on the data and analysis, an Optimum Binder Content (OBC) of 5.0% bitumen (AC) has been determined. Table 7 presents a comparison between the data at 5.0% bitumen (OBC) and the standard requirements specified in the Manual on Standard Specification For Road Work Section 4: Flexible Pavement, issued by Jabatan Kerja Raya(JKR) Malaysia.

Table 7. The data of Marshall Test sample 10% waste glass & comparison against standard requirements

Parameter	Results	Specification (Wearing Course, JKR 2008)	Remarks
Stability , S	6800	>8000 N	
Flow, F	3.00	2.0 - 4.0	✓
Stiffness, S/F	30000	>2000 N/mm	✓
Air voids In Mix (VTM)	30000	3.0 -5.0 %	
Voids In Aggregates filled with bitumen(VFB)	68	70 -80 %	

4. CONCLUSION

In conclusion, the sample containing 10% waste glass and 5.25% bitumen represents the optimal combination for aggregate replacement, with comply the standard requirements outlined in the Manual on Standard Specification For Road Work Section 4: Flexible Pavement Jabatan Kerja Raya (JKR) Malaysia. Conversely, the sample containing 30% glass exhibits lower strength compared to the standard. These results indicate that glass can be effectively used as a replacement for pavement aggregate.

5. REFERENCES

S. Salehi, M. Arashpour, J. Kodikara, R. Guppy, Sustainable pavement construction: a systematic literature review of environmental and economic analysis of recycled materials, J. Clean. Prod. 313 (Sep. 2021) 127936, https://doi.org/10.1016/j.jclepro.2021.127936

Jaime Styler, Lori Tunstall, Amy Landis, James Grenfell (2023) Innovations in pavement design and engineering: A 2023 sustainability review. Journal of Heliyon

Wahid Ferdous, Allan Manalo, Rafat Siddique, Priyan Mendis, Yan Zhuge5, Hong S. Wong, Weena Lokuge, Thiru Aravinthan and Peter Schubel (2021) Recycling of landfill wastes (tyres, plastics and glass) in construction – Areview on global waste generation, performance, application and futureopportunities. Journal of American Science

Lyle, D. P. (2008). Howdunit Forensics. Writer's Digest Books. ISBN 978-1-58297-474-3. Khatib, Jamal (2016-08-12). Sustainability of Construction Materials. Woodhead Publishing. ISBN 978-0-08-100391-6.

A. BUSARI, E. Adeyanju, T. Loto, and D. Ademola (2019) Recycled Aggregate in Pavement Construction: Review of Literatures. Journal of International Conference on Engineering for Sustainable World
Standard Specification For Road Works: Section 4 : Flexible Pavement. Jabatan Kerja Raya Malaysia (JKR) JKR/SPJ/2008-S4

V. Gunalaan and Hidayu (2014). Study on Comparative Flexible Pavement Thickness Analysis Using Various Design Method. IJRET: International Journal of Research In Engineering and Technology.