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A Review of Potential on Modified Binder with Glass Cullet as Fine Aggregate Replacement

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Abstract: In Malaysia, the amount of glass waste generated every year continuously increased has led to a major problem in landfill areas due to its classification as non-biodegradable waste which harms the environment. Besides, the usage of raw aggregates resulted in limited supply and getting more costly in the market. Glass cullet is also known as the recycled crushed glass can be substituted for fine aggregates to reduce the consumption of natural aggregates in road paving. Therefore, this study was conducted to examine the potential of glass cullet as a replacement of fine aggregate in road pavement. The laboratory testing that was performed is Marshall Stability-Flow Test where the asphalt mixture with optimum glass content varying from 5.00 %, 8.00 %, 10.00 %, and 15.00 % glass as a fine aggregate replacement has been observed to perform better than the conventional asphalt. From this study, the optimum glass percentage of 8.00 % is acceptable with the *Jabatan Kerja Raya (JKR)* standard specifications and it is recommended to be applied in the road pavement. By using glass cullet, not only it could reduce the production cost of natural aggregates, but also minimize the disposal of glass waste at the landfills.

Keywords: Glass Cullet, Asphalt Mixture, Fine Aggregate, Glass Waste, Marshall Test

1. Introduction

Malaysians produced close to 3 million tonnes of waste in the year 2018. Shockingly, only 0.06 % or about 1800 tonnes were recycled out of this huge amount while the rest were sent to landfills [1]. Glass bottle contributes a great amount of glass waste in landfill sites which classified as non-biodegradable waste that cannot be decomposed and become a source of pollution. Glass bottle has been in high demand for various usages like sauce bottle, alcohol drink bottle and more. However, the glass properties are quite special because it can be 100.00 % totally recycled and reused repeatedly without changes in their physical properties. Glass cullet known as the recycled crushed glass can be substituted for fine aggregates to reduce the consumption of natural aggregates in road paving.

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Nowadays, the trend is to decrease the consumption of natural resources by using recycled materials. Aggregates are important materials and a million tons of raw aggregate are required to act as load-bearing material in road pavement [2]. This causes the raw aggregate sources are in limited supply because it is generally manufactured from the mining area which resulted in the depletion of natural aggregates and becoming more expensive in the market. For that reason, the replacement of fine aggregates with glass cullet in asphalt mixture as a substitute to fresh aggregates can be taken as an innovative way of recycling and reusing waste materials. Moreover, there are certain engineering properties of glass a bit similar to normal aggregates that could improve the asphalt performance than the traditional one. So, this study will create a better quality of asphalt pavement than regular asphalt in road construction.

1.1 Objectives of the Study

The objectives of this study are:

i. To examine the potential of glass cullet as an alternative aggregate in the asphalt.
ii. To analyze the performance of glass cullet in asphalt.

1.2 Scope of the Study

To accomplish those objectives, the scope of the study will be made as in the following:

i. The results from the Marshall Test which is stability, flow, and stiffness was used to determine the mechanical properties of the asphalt mixture in the addition of glass cullet.
ii. The test results obtained were analyzed to find out the optimum glass percentages in asphalt that comply with the standard specifications of the road pavement by the JKR.

2. Methodology

The preparation of this methodology is very crucial to determine the Marshall Stability-Flow test results such as in Figure 1 below. The purpose is to ensure the methods used are suitable for the problem to be investigated and to make sure this study is on the right track to achieve the objectives stated.

Figure 1: Flow chart diagram

2.1 Materials

Based on this study, the preparation of materials for modified asphalt are asphalt mixture, coarse aggregate, and glass cullet as an exchange for fine aggregate.

2.1.1 Aggregates

Specified fine glass cullet and coarse aggregate were prepared followed by the JKR Standard Specification for Road Works. By using the sieve method, the aggregate grading was evaluated by passing the aggregate through a series of sieves stacked together, and those materials retained on each sieve is weighed. After that, the grading is generally calculated in the percentage passing through the different sizes of the sieve.

2.1.1.1 Glass Cullet

The glass cullet is collected from the disposal of glass bottle wastes at the recycling center or manufacturing factory. First of all, the glass bottles were categorized and cleaned from impurities before being crushed into smaller sizes following the specified gradation as in Figure 2 [3].

Figure 2: Gradation of glass cullet based on specified sieve size

2.1.1 Bitumen

Many types of bitumen grade in this study are widely used in road construction around the world such as 60/70, 70/80, and 80/100 penetration grade. This implies that the penetration value is within the range of the number shown. The penetration grade bitumen is measured through the penetration and softening point test.

2.2 Methods

There are two types of samples were prepared. The first sample was carried out for different percentages of bitumen without the crushed glass as a constant sample. As for the next samples, it was being mixed together with the crushed glass of aggregate weight 5.00 %, 8.00 %, 10.00 %, and 15.00 % into the bituminous mixture. Every sample was tested through the laboratory test to achieve certain requirements that have been set. Next, the result gained was compared with each sample to evaluate the performance of glass cullet as a fine aggregate substitution.

2.2.1 Sieve Analysis

A Sieve Analysis was conducted with the glass cullet and coarse aggregate that were applied in the asphalt mixture. A sample dry aggregate with weight is being separated through a series of sieves stacked together with a progressively smaller opening based on Figure 3 below [4]. After separated, the weight of particles will be retained on each sieve was calculated and compared to the total sample weight. The particle size distribution is then was expressed as a percent retained by weight on each sieve size. The grading must comply with the standard grading specified in BS 882:1992 like in the following:

A. Coarse aggregate – Aggregate passing sieve 28 mm and retained on sieve 2.4 mm.
B. Fine aggregate – Aggregate passing sieve 4.75 mm.

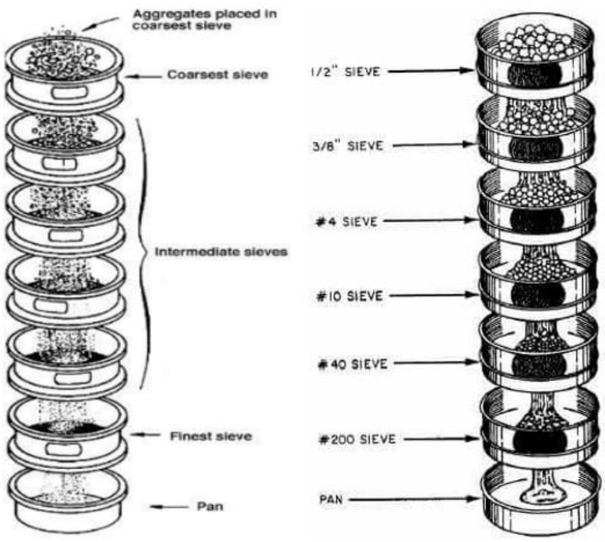

Figure 3: Sieve analysis

2.2.1 Marshall Stability-Flow Test

Marshall test is a mix design method to measure the performance of the asphalt mixture. In this test, the procedure is to identify the properties of the design mix especially stability, flow value, and finally the determination of optimum bitumen content (OBC). The stability of the mix will determine the maximum load that can be supported by the designed samples under ASTM D6927 guidelines. A flow test is performed to determine the potential flow in a sample during loading time.

Firstly, the testing was conducted with each sample is heated either in an oven for at least for 2 hours or submerged in a water bath at 60 ºC for about 30-40 minutes. Later, the cylindrical samples are taken out from the water bath or oven and situated under the position of breaking head based on Figure 4 and compression started. The maximum load reading is observed by applying load at a rate of 50 mm/minute until the maximum load (failure) is reached. The upper dial gauge displays the stability reading while the lower part reveals the flow value. After the results are collected, the determination of the optimum value of bitumen content was made.

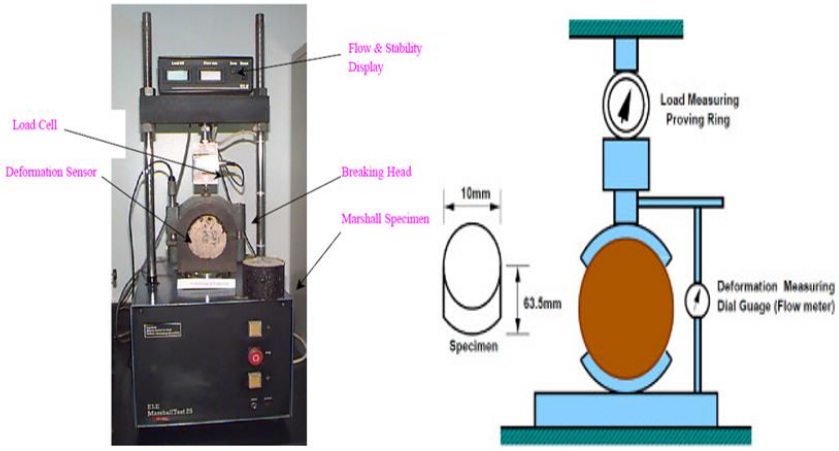

Figure 4: Marshall Test apparatus setup

3. Results and Discussion

The results illustrate the changes in asphalt performance when the addition of glass cullet and all data results were analyzed to find the ideal percentage of glass cullet needed in asphalt pavement. All results are collected were simplified in the following Table 1.

Table 1: Overview of data collected from the previous studies

Author	Bitumen Penetration Grade	Marshall Test			OBC (%)	Ideal Glass Cullet Content (%)
		Stability (kN)	Flow (mm)	Stiffness (kN/mm)		
Zakaria *et al.* (2017)	60/70	6.67	5.92	1.13	4.78	5
Alhassan *et al.* (2018)	60/70	17.79	3.37	5.28	5.90	8
Issa (2016)	70/80	13.92	2.87	4.85	5.00	10
Nigatu (2014)	80/100	7.90	4.40	1.80	5.68	15
Aashish & Tamrakar (2019)	VG30	17.50	2.30	7.61	4.73	10

3.1 Marshall Stability

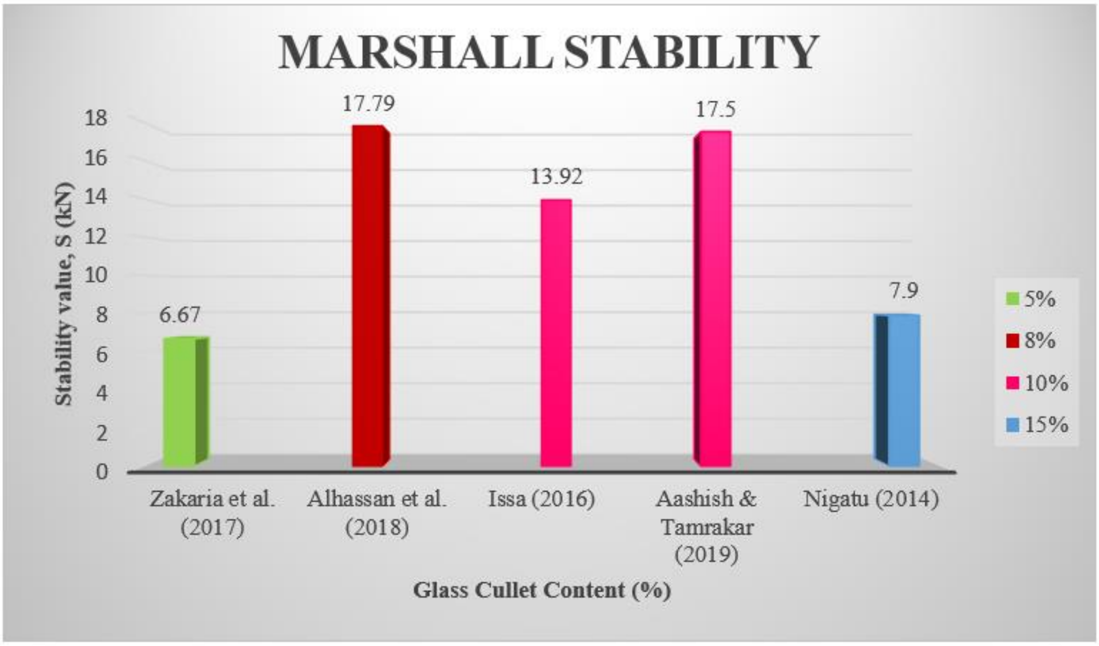

Figure 5: Marshall Stability results from previous studies

Figure 5 shows three (3) modified asphalt containing 8.00% and 10.00 % glass represent the highest stability values of 17.79 kN, 17.50 kN [5], and 13.92 kN [6]. Although using the same amount of 10.00 % glass cullet, there is a slight reduction of 3.58 kN in the stability value but still surpassed the JKR permissible limit. It can be influenced by the different penetration grades of bitumen used in lab testing. The difference in the stability indicates that the glass has better cohesion than the conventional aggregates. The standard requirement for the stability value must exceed 8 kN to have a durable asphalt pavement. Apart from that, some modified asphalt with lower stability values of 6.67 kN [7] and 7.9 kN [8] that exhibit 5.00 % and 15.00 % glass unable to achieve within the limits stated. It shows that these asphalt mixtures have low load-bearing in the performance of asphalt where it could lead to several types of distress namely deformations, surface cracks, potholes, and wheel ruts.

3.2 Marshall Flow

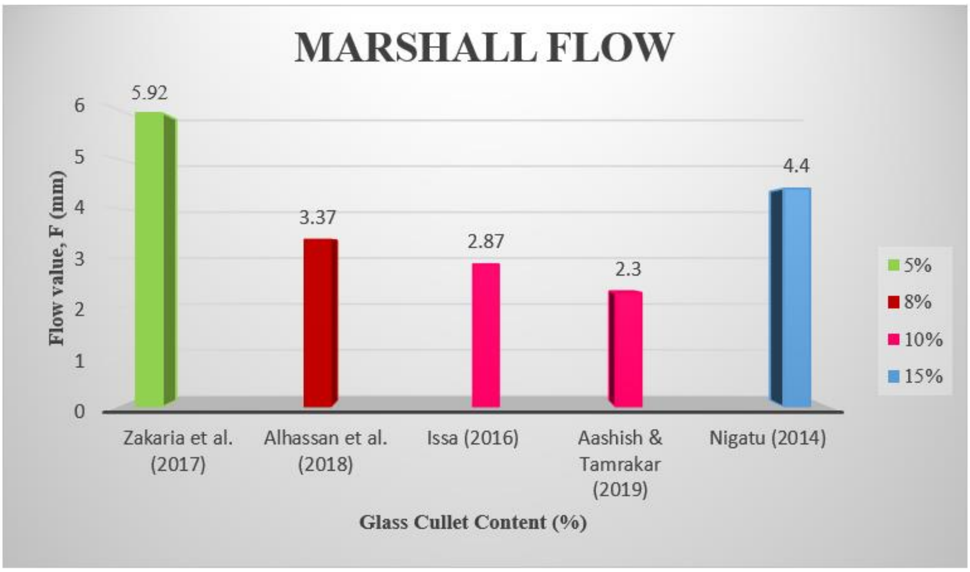

Figure 6: Marshall Flow results from previous studies

As Figure 6 above, it illustrates the flow values are gradually decreased when there is an increased amount of glass cullet except for 15.00 % of glass with the flow value of 4.4 mm. It is shown that a minimum amount of 5.00 % glass cullet and the maximum amount of 15.00 % glass cullet acquired the highest value of flow. It is clearly exceeding the JKR limitations as the acceptable value of flow is between 2.0 mm to 4.0 mm. This could happen because of the increase in the air void. It would contribute some damage such as rutting when the flow value is too low or exceeds the permissible limits. Thus, this will minimize the pavement service life. On the contrary, the lowest flow value is possessed by 10.00 % glass from 2.87 mm to 2.3 mm, but it still lies within the JKR limit of flow. This will be approved for the implementation in the production of hot mix asphalt.

3.3 Marshall Stiffness

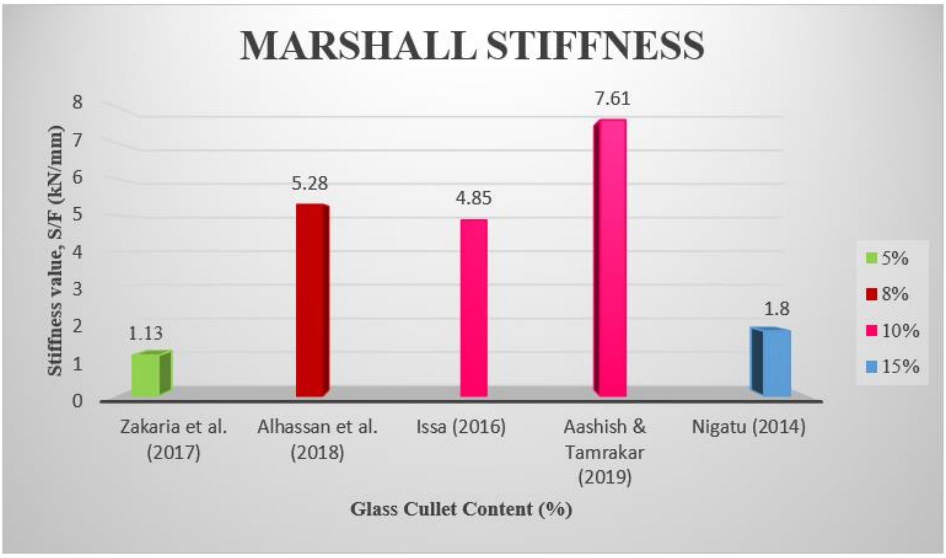

Figure 7: Marshall Stiffness results from previous studies

It is observed that in Figure 7, the chart exhibits an inconsistent value of stiffness when the addition of more glass content in the modified asphalt. The pattern changes in the charts is because of the number obtained from the stability and flow value. So, the highest stiffness value of 7.61 kN/mm is obtained by a 10.00 % glass cullet. This indicates that the range between 8.00 % to 10.00 % of glass cullet passed the permissible limit and can produce good workability of asphalt pavement. The approved limits for the stiffness value must be more than 2 kN/mm [9]. It turns out that when adding over 5.00 % and 15.00 % glass cullet, the asphalt pavement has lower stiffness and was recorded as a failure to meet the allowable limit [6]. For that reason, it is necessary to adopt bituminous material with good stability and flow as the asphalt pavement is always subjected to extreme traffic loads from time to time.

3.4 Optimum Bitumen Content (OBC)

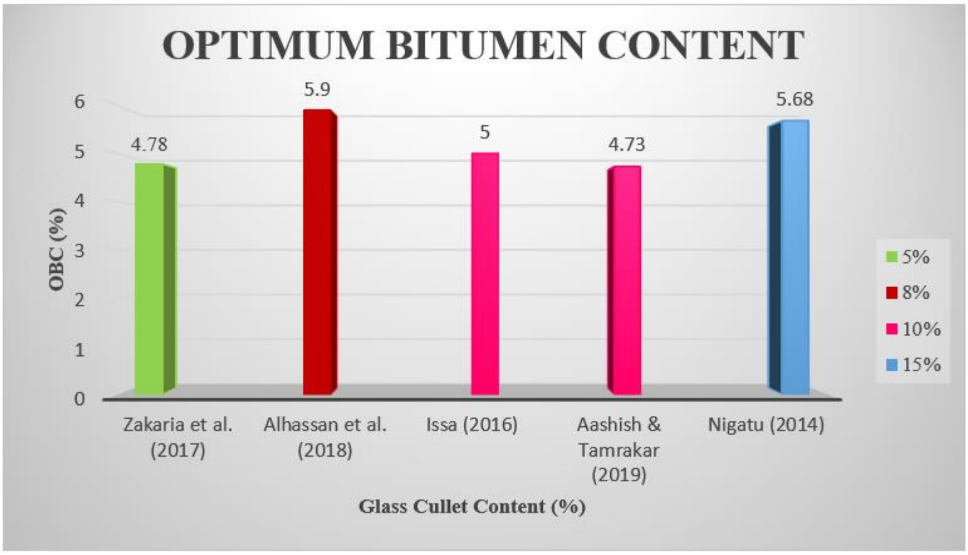

Figure 8: Optimum bitumen content from previous studies

Figure 8 above demonstrates the percentage of the glass cullet added affects the amount of bitumen content. An irregular pattern is presented where the highest value of optimum bitumen content can be reached by 5.90 % adding 8.00 % glass cullet meanwhile the lowest value is 4.73 % with 10.00 % of glass cullet. Even though with the addition of glass, the asphalt still gives better performance and has surpassed all the standard requirements except the other two samples of 8.00 % and 15.00 % which exceeds the limitation range. The standard requirement for the optimum bitumen content is within 3.50 % to 5.50 %. These asphalts still can be used in the asphalt application, but it may prone to some deformation on the performance. As Malaysia facing a hot and humid climate, it is very ideal to have a high ductility value with low penetration value for the pavement endure changes of temperature in Malaysia. The bitumen used must be rigid and strong enough to maintain the pavement. Overall, the most suitable bitumen grade for road pavement is 60/70 with 8.00 % glass cullet as it is more applicable in Malaysia weather.

3.5 Optimum Glass Content

The most optimum glass content that was chosen is 8.00 % of glass cullet as it meets all the criteria specified by the *Jabatan Kerja Raya (JKR)* although its optimum bitumen content slightly higher than the limits. It means that the binder provides extra bonding to interlock between the aggregates and glass cullet but, it can be adjusted through the percentage of bitumen. Also, it can be proven that the addition of 8.00 % glass into 60/70 bitumen grade exhibits better mechanical properties that influence the performance of modified asphalt. In Malaysia, bitumen with a 60/70 penetration grade is commonly used as a wearing course because it is more rigid and high tolerance to changes in temperature including good resistance to road distress.

4. Conclusions and Recommendations

It can be concluded that all the objectives mentioned have been successfully achieved. From the Marshall stability, flow, and stiffness results, this indicates using 8.00 % of glass cullet satisfy all the JKR allowable limits and it is very recommended to be applied in the road pavement. Not only it could reduce the production coat of natural aggregates, but also minimize the disposal of glass waste. So, the usage of glass cullet as fine aggregate replacement is technically feasible but requires some modifications to the mix design to improve the performance of asphalt.

A few recommendations that can be made through this study:

i. The addition of chemical additives as an anti-stripping agent such as hydrated lime can be applied to enhance the performance of asphalt.
ii. More laboratory tests can be conducted such as the Indirect Tensile Strength Test and Resilient Modulus Test to compare the performance of modified asphalt with conventional asphalt.
iii. Some aggregate tests should be carried out to determine the properties of aggregates and aggregate quality.
iv. JKR should allow the field application of glassphalt in Malaysia road pavement in order to evaluate the performance of asphalt.

Acknowledgement

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