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Research paper

Performance evaluation of hot mix asphalt (HMA) using glass fiber as a partial replacement of fine aggregate

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Abstract: Hot Mix Asphalt mixtures are often used as the top layer of pavement structures to build roads worldwide. Hot Mix Asphalt (HMA) mixtures combine bitumen and aggregate to produce roads. This paper aims to determine the optimum bitumen content (OBC) and investigate combining glass fiber in HMA with replacing a partial glass fiber of fine aggregate by Marshall Stability. The Hot Mix Asphalt was produced by mixing aggregate with 4% to 6% bitumen to obtain OBC to use in Hot Mix Asphalt Modified with glass fiber. Meanwhile, HMA modification was produced by mixing aggregate and OBC bitumen with 1% to 6% replacement glass fiber as a partial fine aggregate to improve the properties of Hot Mix Asphalt (HMA). Marshall Stability test, Aggregate Impact Value (AIV), Aggregate Crushing Value (ACV), Penetration Point, and Softening Point test was conducted. The effects of glass fiber in terms of stability, flow, stiffness, void in the total mix and void-filled bitumen in Marshall stability are investigated and compared with the control sample. The Optimum Bitumen Content (OBC) using Marshall Stability was chosen at 4.7% as OBC due highest stability value and passed in requirement standard JKR 2008. After analysis, the stability obtained for HMA Modified showed that adding 1%, 2%, and 3% glass fibers contributed to the highest stability values and passed the standards of parameters required by JKR 2008. Therefore, this paper can be concluded that the presence of glass fibers can significantly improve the performance of Hot Mix Asphalt (HMA).

Keywords: fine aggregate, glass fiber, hot-mix asphalt, Marshall stability, pavement materials

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1. Introduction

In Malaysia, the development of pavement infrastructure has rapidly become a necessity due to the role that roads serve in transportation planning. Due to its ability to handle heavy and recurring traffic volumes and the fact that it is installed in extraordinarily thick layers, flexible pavement is a great option for major highways and roads. The mixtures produced for flexible pavement should meet the standards for minimum strength, stability, and durability [1].

Hot Mix Asphalt (HMA) are considered a famous method due to its functions and well known in Malaysia. Hot Mix Asphalt (HMA) is one of the mixtures that can be utilized to implement pavement designs on heavily used roadways. The market developed significantly in popularity, rivalry, and efficiency while HMA was demonstrated to be the long-lasting and economical method of paving roads [2]. The mix design on HMA is another element that significantly affects the performance of the roadway.

The weather in Malaysia is unpredictable, with periods of extended temperatures and heavy rain. Consequently, issues with asphalt pavement, such as rutting and stripping, may have an impact. The majority of these problems, which appear as depressions formed in the pavement's wheel path, are brought on by an increase in the number of high-load cars on the road [3]. Glass fiber, which has the potential to enhance the qualities of construction materials, is the solution to asphalt's poor behavior. Glass fiber mixtures' mechanical characteristics improve when 3% bitumen is added, indicating that the fibers and aggregates are more strongly bonded [4].

Several different types of broken glass are used to produce glass fiber. Calcium, magnesium, boron oxide, and silica are all present in various proportions in crushed glass. The process of producing glass fiber involves transforming basic components into homogeneous liquids at high temperatures [5]. The performance of asphalt mixtures in terms of rutting and cracking has demonstrated a large potential improvement with the addition of glass fiber. It has also been asserted that adding glass fiber to asphalt mixtures improves their ability to recover and raises their resistance to rutting, moisture, and wear.

Due to its extensive surface area, glass fiber can also enhance the mixture's ability to absorb asphalt, which helps prevent cracking. At low temperatures, pavement cracks might be avoided by the glass fiber modified combination because it may be resistant to the beginning of cracks [3].

This paper reports on the performance of glass fiber replacement as a partial fine aggregate with 1%, 2%, 3%, 4% and 5%. In terms of strength and performance, 1%, 2% 3% glass fiber are better than 4% and 5% glass fiber because the considering did not pass the specifications specified in JKR Standard 2008. The replacement of 1%, 2%, and 3% glass fiber in fine aggregate is suitable for hot mix asphalt (HMA) experiments and road construction. The previous study made by Jasni et.al. [6] stated the 0.3% of glass fiber has the highest density value in the air voids; because it has a high density, it has fewer air voids. In addition, it is because it is less prone to moisture-induced damage and more uniform.

Glass fiber has a better resistance to crack propagation and can increase the flow value and voids in the mixture, which helps to prevent bleeding and rutting in high temperatures.Glass fibers have demonstrated significant potential in enhancing the durability of asphalt mixtures by improving their resistance to rutting and cracking, as indicated in studies [7–9]. Additionally, the incorporation of glass fibers in asphalt mixtures has been associated with advantages such as increased healing capacity and greater resistance to rutting, moisture, and fatigue.

Glass fiber can also improve the deformability and stability of asphalt concrete. Due to the excellent mechanical qualities of glass fibers, adding them to asphalt mixes enhances the strength and fatigue capabilities and increases ductility [3]. Study by Eisa [11] investigates the impact of adding glass fiber to hot mix asphalt (HMA) mixtures. Five HMA specimens were prepared using the Marshall mix design method, and various tests were conducted, including Marshall Stability and flow tests, to assess the properties of the mixtures with different glass fiber percentages. The other study reviews the mechanical impact of fibers in hot mix asphalt (HMA), focusing on the reinforcement effects of fibers in both qualitative and quantitative terms. It discusses the properties of fibers, characterization tests for fiber-modified bitumen, and the performance of bituminous mixtures containing different types of fibers. The review highlights how fibers improve fatigue resistance, permanent deformation, and stiffness of HMA, and suggests that certain fibers like coconut fibers and waste fibers are environmentally friendly alternatives [12].

Shanbara [13] explores the reinforcement effects of natural and synthetic fibers in mixtures, comparing them to traditional cold and hot mix asphalt. It focuses on the mechanical properties and water sensitivity of these mixtures, using glass fiber as a synthetic option and hemp, jute, and coir as natural fibers. The research demonstrates that fiber-reinforced CMA mixtures exhibit significant improvements in stiffness, rutting resistance, and moisture resistance, suggesting that such mixtures can offer high performance and durability under various environmental conditions.

The integration of innovative materials in Hot Mix Asphalt (HMA) has been a subject of significant interest within the pavement engineering community, aiming at enhancing the durability, resilience, and sustainability of asphalt pavements. Recent studies have explored various additives and modifiers, including polymers, rubber, and industrial by-products. However, the use of glass fiber as a replacement material in HMA is relatively underexplored, despite its potential to improve mechanical properties.

The current state of knowledge primarily focuses on the modification of asphalt mixtures with materials that either enhance the asphalt binder's performance or the aggregate's structural integrity. The planned research aims to fill this gap by assessing how glass fiber affects the mechanical properties, durability, and environmental impact of HMA pavements.

2. Methodology

2.1. Materials

Aggregate and bitumen were obtained from the quarry and bitumen were categorized in grade 60/70 means a penetration value between 60 and 70 in standard test parameters. The Portland cement used to produce Marshall sample in this research is ASTM Type Ordinary Portland cement (OPC) that pass it through the 75 mm sieve. Limestone was used as coarse aggregates and fine aggregates. Coarse aggregates of maximum sizes 20 mm while fine aggregates were passing 3.35 mm as follow standard ACW14.

The AC14W refers to a particular gradation of asphalt concrete designed primarily for wearing courses, characterized by its aggregate size distribution that meets specific standards for road surface layers intended to withstand direct traffic contact. The "AC" in AC14W stands for Asphalt Concrete, where '14' denotes the nominal maximum aggregate size of 14 mm, and 'W' signifies its application in wearing course layers, which are the topmost layers of pavement structures. In the context of this study, AC14W serves as the baseline mix for incorporating glass fiber to assess its impact on the HMA's mechanical properties and performance. The standard gradation for AC14W, as outlined in the Jabatan Kerja Raya (JKR) 2008 specifications.

Glass fiber was used as replacement as a partial fine aggregate with size not more than 3mm. In this study, chopped glass fiber strand was used. The fiber type was cut into 3mm lengths and added into the mixture in varying amounts between 0 and 0.5%. Figure 1 shows picture of glass fiber.

Fig. 1. Glass fiber

2.2. Sample Preparation

The weight of aggregates used to produce Marshall stability is 1200 g (ASTM D 1559) from the Mix design. Of the total mass of aggregates utilized, coarse and fine aggregates provide for 60% and 40%, respectively. Fine aggregates must be less than 3.35 mm in size, while maximum coarse aggregate must be 20 mm. The maximum aggregate gradation for aggregate ACW 14 is shown in Table 1.

For bitumen penetration, grade 60/70 should be added at 140–160°C. The percentage of glass fiber in the Marshall stability modified is 0% to 5% from the total weight fine aggregate. A chopped strand was used, which size 3mm in length. Asphalt concrete is a composite material in combination with fillers, admixtures, coarse and fine aggregates, and asphalt cement as a binder [10].

Table 1. Gradation limit of aggregate ACW 14 (Jabatan Kerja Raya (JKR), 2008)

Mix type	**Wearing course**	**Design gradation (percentage passing by weight)**
Mix designation BS sieve size (mm)	AC 14 Percentage passing by weight	
20	100	100
14	90–100	95
10	76–86	81
5	50–62	56
3.35	40–54	47
1.18	18–34	26
0.425	12–24	18
0.150	6–14	10
0.075	4–8	6

Three samples will be obtained for every percentage replacement of fine aggregate. The mixture of aggregate, bitumen, filler, and glass fiber was thoroughly mixed using a Marshall mixer machine. The mixture was poured into a heated mould, and 75 blows were compacted to the faces. The sample was compressed on two sides with the same blows. After blows, the samples were preserved in the lab at room temperature for 24 hours before de-moulding. Then, the samples were removed from the moulds and take weight before testing.

2.3. Mixture Design

Asphalt concrete is a composite material that includes fillers, admixtures, coarse and fine aggregates, and asphalt cement as a binder. For HMA, the total mass of the mix design should be 1200 g, which includes bitumen, filler, coarse aggregate, and fine aggregate. Three samples will be obtained for every percentage replacement of fine aggregate, for example, two samples for a bitumen replacement with two percent glass fiber. The bitumen utilised is 60/70 penetration grade, and utilising the Marshall Test in accordance with ASTM D1559, the optimum asphalt content for dense grade asphalt mix is determined to be 1–5% by mass of the overall mixture. For Hot Mix Asphalt (HMA), use Marshall Mix Design to prepare the sample. Determining an asphalt binder content that complies with minimal stability and range of flow characteristics requires using the Marshall Mix Design process. Table 2 shows the mixture design for Marshall Stability Test to find the Optimum Bitumen Content (OBC).

Table 2. Mixture design for Marshall Stability Test

Bitumen (%)	**Fine Aggregate (%)**	**Coarse Aggregate (%)**	**Filler (%)**
4	77	16	3
4.5	76.5	16	3
5	76	16	3
5.5	75.5	16	3
6	75	16	3

2.4. Testing

One of the aggregate testing was Aggregate Impact Value (AIV). It measures the resistance of aggregate to sudden impacts and impacts. The resistance to slowly applied compressive stress might be different from this. Through this test, the aggregate's ability to survive rupture from the impact of a moving weight is evaluated. The rate of weight loss of particles passing through a 2.36 mm sieve by hitting 25 times from a standard hammer and dropping under defined test conditions is the impact value of the aggregate.

Another aggregate testing was Aggregate Crushing Value (ACV). The aggregate crushed value (ACV) measures an aggregate's resistance to fracture under progressive compressive stress. If total power is greater than 30, the result can be abnormal. In that case, need to calculate the maximum power of 10% instead.The Aggregate Impact Value (AIV) and Crushing Value (ACV were conducted with standard ASTM C642.

Penetration test is based on ASTM D5. The bitumen penetration test took five seconds to accomplish while keeping the bitumen sample's temperature at 25°C and measuring the depth of penetration of a standard loaded needle. The denser bitumen, the less a needle can penetrate it. Therefore, the penetration depth is measured in 0.1 mm increments and given in penetration units.

To determine the bitumen's softening point, a ring and ball device submerged in distilled water (30 to 80°C) can be employed. After the bitumen has cooled for 30 minutes in the air, level the material in the ring by removing any excess with a hot, sharp knife and filling the bath with distilled water to a height of 50 mm above the upper surface of the rings. It is ideal to begin at 5°C. For bitumen softening points between 40 and 60°C and for softness points between 61 and 80° C, the sum of the two measurements' softening point values should not be more than 1.0°C and 1.5°C, respectively. The Test must be repeated if it is found to be invalid. Softening Test is conducted based on ASTM D36.

Marshall Stability test is conducted following ASTM D1559. The samples were established in a trial assembly, and a load was applied at a rate of 50.8 mm per minute. The test sample is examined at 60°C. First, the specimen's air, water, and saturated surface dried (SSD) weights will be measured in grams. Then, heat the specimens to 60°C in a water bath for 30–40 minutes before testing the sample. ASTM D1559 conducted Marshall stability. The result was to determine specific gravity, stability, total void mix (VTM), void-filled bitumen (VFB), flow and stiffness. All results will be compared with parameters JKR Standard 2008 in the Marshall test. Figure 2 shows the sample for Marshall testing.

Fig. 2. Sample for Marshall stability test

3. Result and Discussion

3.1. Quality Control Sample

Table 3 shows the result for the quality control sample, which was obtained using the Aggregate Impact Value (AIV), Aggregate Crushing Value (ACV), Softening point and Penetration point. The result Aggregate crushing value (ACV) for limestone is 19.44%, while the result Aggregate impact value (AIV) is 10.09%. Thus, these suggest that the aggregates could withstand a gradual or impact applied load. The result shows that the AIV and ACV value for limestone obtained is below the requirement of JKR Standard, which is 25%, making it suitable to apply in these experiments and road construction.

Table 3. The quality control result

Test	Result	JKR Standard
AIV, %	10.09	< 25
ACV, %	19.44	< 25
Softening Point, °C	49.45	49–56
Penetration mm	6.62	6–7

Based on the data for the three accurate determinations, the experiment obtained 6.63 PEN at point 1, 6.43 PEN at point 2, and 6.70 PEN at point 3 for an average of 6.62 PEN. The penetration experiment proves that the binder complies with the 6 mm to 7 mm specification, and the result penetration value of 6.62 mm indicates that it is suitable for usage because it satisfies with ASTM D5 specifications. Bitumen is a great option for use in these studies and different construction kinds because of its consistency.

The softening point of bitumen has been calculated using the ASTM D36 standard techniques. Bitumen 60/70 has a flash point of 250°C and a softening point of between 49°C and 56°C. The water temperature was held constant at 5°C for the duration of the experiment. As a result, the softening points of samples 1 and 2 are 49.7°C and 49.2°C, respectively. The average softening point for this bitumen grade class was 49.45°C, which is within the Malaysian Standard, and the results were in accordance with those standards.

3.2. Optimum Bitumen Content (OBC)

According to the JKR Standard 2008, the Optimum Bitumen Content (OBC) of Hot Mix Asphalt could be determined where in this study it was 4.7%. As a result, the stability at the maximum point is 5%, the bulk specific gravity at the maximum bulk density is 5%, the flow is 5.1%, the VTM is 4.74% from the mid-spec 4%, and the VFB is 4.65% from the mid-spec 75% as shown in Figure 1. Therefore, the average for OBC was 4.7%, and all results were approved in the JKR Standard 2008. Table 4 shows the result of Marshall stability for optimum bitumen content (OBC) and Figure 3 shows graph optimum bitumen content (OBC) determination.

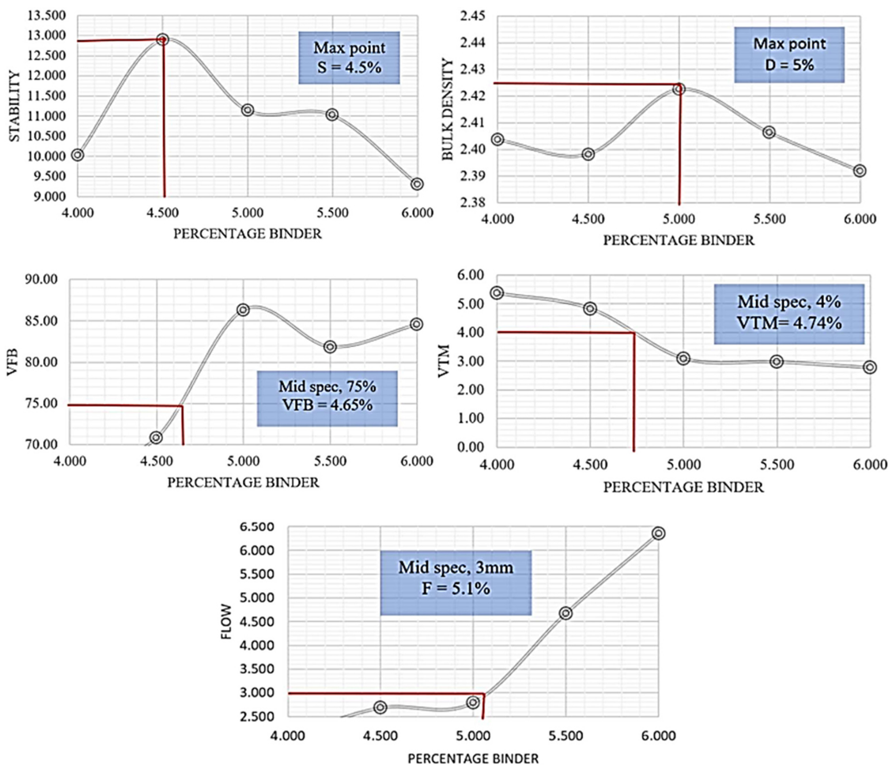

Fig. 3. Graph Optimum Bitumen Content (OBC) Determination

Table 4. Result Marshall Test for 4% To 6% Bitumen

Bitumen content (%)	Bulk Specific Gravity	Stability	(VFB)	(VTM)	Flow Units	Stiffness N/mm
4	2.40	10032	66.63	5.37	2.079	4.83
4.5	2.40	12894	70.85	4.83	2.680	4.82
5	2.42	11139	86.31	3.09	2.787	4.01
5.5	2.41	11023	81.85	2.97	4.676	2.58
6	2.39	9313	84.54	2.77	6.360	1.48

3.3. Marshall Stability of HMA with addition of Glass Fiber

Glass fiber was used to replace the fine aggregate, ranging from 1% to 5% glass fiber. 0% as the control sample. The analysis for the Marshall test for glass fiber is shown in Table 5. The Marshall stability test for glass fiber in Hot Mix Asphalt (HMA) has been performed with 4.7% optimal bitumen content (OBC) from control sample. Table 4 shows 0% to 3% glass fiber complied with the JKR criteria for 2008. Because it has less air voids, bitumen's stability and voids-filled value are better at 1%, 2% and 3% glass fiber than at 4% and 5%. There is too much glass fiber at HMA can affect the bonding between the bitumen, fibers, and aggregates. The mixture's characteristics will change if there is more than 3% replacement glass fiber. This is due to glass fiber content exceeding 3% may be more consistent and susceptible to deterioration brought on by moisture.

Table 5. Result Marshall Test for 0% To 5% Glass Fiber

Bitumen content (%)	Glass Fiber (%)	Stability	VFB	VTM	Flow Units	Stiffness N/mm
4.7	0	10322	72.33	4.74	2.079	4.97
4.7	1	10939	70.30	5.05	2.606	4.21
4.7	2	9545	78.48	4.02	3.704	2.59
4.7	3	11403	78.98	4.64	3.592	3.25
4.7	4	5291	63.50	6.81	6.025	0.88
4.7	5	7525	45.13	11.93	10.204	0.82

The highest stability value for the sample's density test shows that 3% glass fiber substitution is the best option. The flow value increases at the same rate as the percentage of glass fiber. Based on the JKR standard 2008, the flow value of glass fiber replacement in fine aggregate is only between 1% to 2%. The term VFB refers to the amount of effective bitumen that fills the space between the aggregated particles. The void filled with bitumen decreases as the percentage replacement of glass fiber (GF) increases. This is because the glass fiber particles (GF) take up the effective bitumen and reduce it. Therefore, only the VFB results obtained at GF contents of 0% to 3% were shown to be more effective in improving rutting and conformed to the Parameter Specifications JKR 2008 of 70 to 80% for use in the wearing course.

VTM result increases when the glass fiber replacement increases; however, only 0% to 3% passed standard JKR. Therefore, based on JKR specification, wearing course should have a VTM of 3.0% to 5.0% at the very least. Glass fiber replacement for 4% and 5% not suitable to be used because it exceeds parameter standard JKR 2008. The stiffness decreases after 3% glass fiber replacement. Based on JKR specification, wearing a course should have a Stiffness value more than 2000 N. This test to assess the sample's density shows that 0% glass fiber replacement has the highest stiffness value. The high-stiffness modulus asphalt concrete is stiffer and more resistant to bending [1]. The significant value for Stiffness is 0% to 3%. From all results, 1%, 2% and 3% replacement glass fiber in fine aggregate is suitable for hot mix asphalt (HMA) and road construction because all elements in the parameters meet the requirements of passing the JKR 2008 standard.

4. Conclusions

In conclusion, this study rigorously evaluated the performance of Hot Mix Asphalt (HMA) incorporating glass fiber as a partial replacement for fine aggregate, aligning with the anticipations set forth by the title. The findings unequivocally demonstrate that the inclusion of glass fiber, particularly at 1%, 2%, and 3% replacement levels, significantly enhances the Marshall Stability of HMA, thereby contributing to a more durable and resilient pavement structure. These optimal levels of glass fiber incorporation not only satisfy the JKR Standard 2008 specifications but also present a promising avenue for the enhancement of pavement quality, offering tangible benefits in terms of strength and performance. The strategic integration of glass fiber within the fine aggregate matrix emerges as a viable and beneficial modification to traditional HMA, paving the way for advancements in road construction materials and methodologies. This study's outcomes thus provide a substantial contribution to the existing body of knowledge, advocating for the judicious use of glass fiber in pavement engineering to achieve superior performance characteristics.

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