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Stiffness Evaluation of Basalt Aggregates as Replacement Aggregates in Hot Mix Asphalt (HMA) Mixtures

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Abstract

Pavement deformation is a common problem in flexible pavements in Malaysia due to poor material quality and quantity. To address this issue, basalt aggregates are being used as replacement aggregates in Hot Mix Asphalt (HMA) mixtures. The study aims to analyze the characteristics and variability of basalt aggregates and asphalt binder materials, as well as evaluate the volumetric parameters of HMA using basalt aggregate. Additionally, a marshall stability test would been conducted to analyze the performance of the mix design using basalt aggregate. Based on the average percentage in review studies, the basalt aggregate employed in this study is 0, 25, 50, 75, and 100% by weight of total aggregate. The study would been carried out to assess the stiffness of asphalt mixtures using basalt aggregate at higher mix temperatures. The aggregate that would be used in this study were granite and basalt and asphalt binder grade 60/70 as a bonding agent. To mix the material, a marshall mix design would be used in this study. Then, a marshall stability test would be conducted to analyze the performance of the mix design using basalt aggregate. Based on the result of Marshall test, the stiffness value for optimal basalt aggregate mixture was obtained at 25% which is 80.376 kN/mm, while the control sample stiffness value is 77.941 kN/mm. The compressive test shown that all the samples are followed the JKR specification for stiffness which is more than 2.6 kN/mm. This experiment indicates that a mixture of asphalt and basalt aggregate replacement fulfilled the requirements and can still be employed for improving the pavement.

1. Introduction

Nowadays, roads are easily damaged and rarely last more than ten years. When overloaded vehicles pass through the road, this causes potholes and damaged the road. Hence, the basalt aggregates used in the mixture should be considered so that the road produced is stronger and lasts longer. Basalt has recently gained attention as a potential building material due to qualities such as high modulus of elasticity, high elastic strength, corrosion resistance, high-temperature resistance, extended working temperature range, and simplicity of handling. Therefore, basalt aggregate must be incorporated into the mixture to strengthen the road. In Malaysia, the Hot Mixed Asphalt (HMA) technology is extensively utilized in simplified terms, a reasonably dense pavement layer is formed by compacting an increased-temperature combination of asphalt binder and graded mineral aggregate [1].

A form of dark-colored, glassy, or crystalline volcanic rock called basalt aggregate. Volcanic rocks are created when the lava that is deep within the earth solidifies due to cooling near or on the surface. The classes of these rocks are determined by the amount of silicon dioxide they contain. Volcanic rocks are excellent aggregate materials because they are tough, long-lasting, and dense. Iron oxides, magnesium oxide, calcium oxide, silicon dioxide, and aluminium oxide are the main components of basalt. Natrium oxide, kalium oxide, phosphorus pentoxide, manganese oxide, and titanium dioxide are also present in trace amounts in the composition. Due to its high tensile strength, strong alkali resistance, high thermal conductivity, and the characteristics possessing. With its high tensile strength, high resistance to alkalis, high thermal conductivity, lack of carcinogens, high tolerance to aggressive chemicals like acid, and strong fatigue resistance, basalt stands out. Today, basalt is used in a wide variety of applications, including protective coatings, mineral-based insulation systems, highway materials, and railroad ballast [2].

Basalt aggregate is commonly utilized in engineering applications such as road foundations, concrete aggregate, asphalt pavement aggregate, railroad ballast, and drain field filter stone. It is also used to construct airport pavement and dam and breakwater rock fill. It is usually used in concrete mixes since it strengthens the mix more than regular limestone mixtures. This is owing to basalt's many properties, including high specific gravity, strong strength, density, durability, higher workability, low cost, and economic worth [3]. The layers of a flexible pavement construction are referred to as hot-mix asphalt (HMA) pavement. Asphalt binder, coarse aggregate, and fine aggregate make up the HMA mixture. A combination of coarse aggregate and asphalt binder makes up the conventional HMA. The average HMA mixture contains 5% air voids, 10% asphalt binders, and 85% aggregate [4]. Using binder- aggregate combinations, aggregate gradation, and binder modification procedures significantly improved the performance of the asphalt mixture. To guarantee that the final pavement will perform as expected, high-quality aggregates must be utilized in the HMA process [5].

HMA mixes are made with the employed binder in a temperature range of 140 - 160°C. The air void and the characteristic are what determine the HMA's functionality and durability. HMA is a common technology used in the pavement business and is referred to as a surface course to support the top layer. HMA is combined, positioned, and compacted at high temperatures but can be positioned at room temperature. However, HMA is the main method for placing roads and interstates [6]. The physical and mechanical characteristics of the materials utilized, production methods, and composition projects all influence the composition and performance of HMA used in road pavement. Depending on the type of mixture being built and the design process being employed, all HMA mixtures are typically planned to contain minor amounts of air space, ranging from around 3 to 5%. However, due to the presence of water, air spaces might result in moisture damage [7].

This study purpose to evaluate the performance and assess the volumetric properties of hot mix asphalt (HMA) mixture incorporating basalt aggregate material. Moreover, this project also examined to evaluate the characteristics and variability of basalt aggregates and asphalt binder material as well as conduct a comparative on effect of basalt aggregate to the stability at higher mix temperature [8].

2. Materials and Methods

In this study, two types of aggregates were used, which were granite and basalt, with the aggregate size determined by AC10. Furthermore, various aggregates percentages were used which are 0, 25, 50, 75, and 100%. It was to determine which range has the highest strength and durability. This percentage was determined based on previous study. Another material used in this study was asphalt binder grade 60/70 with 5% optimum asphalt binder content. The Marshall stability would be performed to evaluate the performance of the asphalt mixture [9].

2.1 Materials

The experiment for aggregates and material was conducted at Highway and Traffic Laboratory at University Tun Hussein Onn Malaysia (UTHM). Basalt aggregate is taken from JKR quarry Pusat Pekan Awah, Temerloh, Pahang. Besides, each material was tested with an appropriate experiment to record the strength or durability and size required for mixing the sample.

2.2 Methods

Numerous testings must be performed on the aggregate, before using aggregate in pavement construction. The test for determining aggregate quality are the sieve analysis test, flakiness and elongation index and aggregate impact value test. Each test carried out on aggregates has its own purpose such as strength, size, shape thickness and density. The quality of aggregates used in the pavement is a key contributing factor to its quality. The aggregates test techniques are dined in accordance with IS 2386 part 4, which aids in determining aggregate quality [10]. The experiment to determine the value of Hot Mix Asphalt or sample after mixing is Marshall Stability Test. Based on the result of the Marshall test, the value of the sample, which is the stability, density, flow, voids in total mixture (VTM) and voids filled with bitumen (VFB) can be determined. The mix's stability can be determined when the specimen is compacted with a maximum load at a temperature of 60°C.

For the test, the specimens needed to be heated to 60 ± 1 °C for at least two hours in the oven or for 30 to 40 minutes in a water bath. The specimens were taken out of the oven or water bath after two hours and placed in the lowest section of the broken head. The full assembly was put in place on the testing machine, the upper section of the specimen's breaking head is put in place and the flow meter is placed over one of the posts and set to zero. Then, the load is applied at a rate of 50 mm per minute until the maximum load reading is obtained.

3. Results and Discussion

The result of this study was that basalt aggregate may withstand pavement deformation such as crocodile cracking, rutting, and polishing when used as a replacement aggregate in Hot Mix Asphalt (HMA) mixture. By incorporating basalt aggregate into HMA, A mixture may be produced that can improve the performance of the road surface, increasing the durability and strength of the road due to the repetitive heavy load exerted.

3.1 Aggregate Properties

The aggregate test determined the size, volume and grade of aggregate required to produce high-quality pavement. Moreover, asphalt binder grade 60/70 were examined with softening and penetration test. Based on Fig. 1, the distribution curve of aggregates was constantly graded according to the AASHTO T27-88 specification.

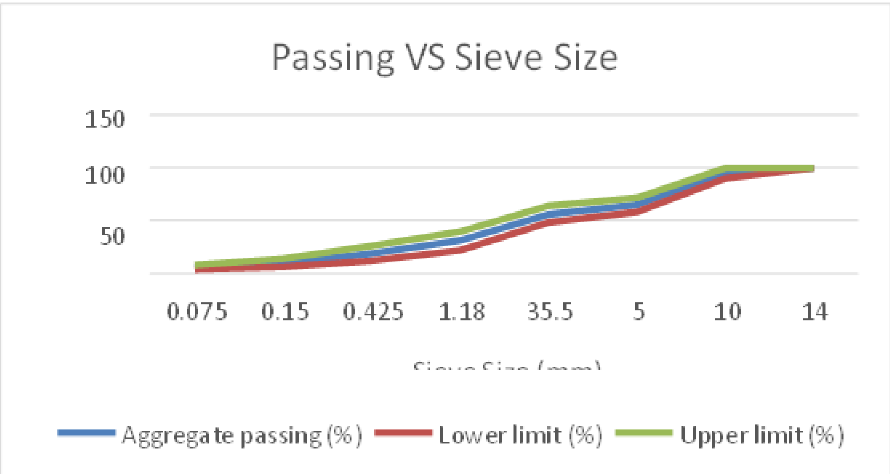


Fig. 1 *Distribution curve for aggregate*

In Table 1, there are results were obtained for basalt and granite aggregates and asphalt binder properties test. The aggregate value obtained from the test are in the range of 20-30% within the requirement for satisfactory road paving. The result of flakiness and elongation indexes showed that there were below the JKR specification limit which is 30% for both aggregates. Besides that, the average softening point for asphalt binder is 49.5°C and it for the JKR specification range of 48.0 to 56.0°C. The maximum distance for asphalt binder penetration is 0.4 mm, and the penetration index is -1.25. This indicates that the findings of the test have been accepted due to the use of asphalt binder in the mixture.

Table 1 *Material properties test*

Aggregate Test				
Aggregate type	Granite		Basalt	
Aggregate Impact Value (AIV)	29.71%		17.58%	
Flakiness and Elongation Index	20.47%	28.35%	25.80%	30.67%
Asphalt Binder Test				
Softening Point	49.5°C			
Penetration	5.64 mm			

3.2 Volumetric Properties

Accompanying discussions that further explain observations of the results are usually placed immediately below the results paragraph.

3.2.1 Analysis on Stability

Fig. 2(a) shows that the introduction of basalt aggregate into the asphalt mixture reduces its stability. The maximum stability of the basalt aggregate in the asphalt mixture was recorded at 25% basalt aggregates which are 26.02kN, while the control sample had a stability value of 28.994kN. This gives about a 10.24% reduction in stability. This shows that the control sample has the highest stability than the other sample. The result complies with the JKR specification where the value gets more than the required value which is 13kN.

3.2.2 Analysis on Density

Fig. 2(b) shows that the addition of basalt aggregates in the HMA mixture increases the density of the sample. The sample with 100% basalt aggregate replacement had the highest density of 2.35 mg/m^3, while the control sample had a density value of 2.25 mg/m^3. This gives about a 4% increase in density. This shows that the sample with basalt aggregates replacement had the highest density than the sample containing granite aggregates.

3.2.3 Analysis on Flow

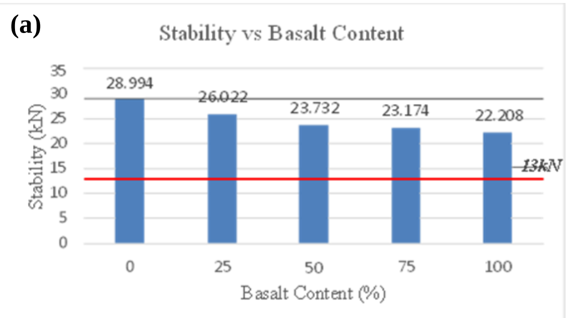
Fig. 2(c) shows that the replacement of basalt aggregates in asphalt mixture causes a reduction in the flow value except with 50% and 70% replacement. The sample with 50% basalt replacement had the highest flow value of 11.45 mm, while the control sample had a flow value of 9.49 mm. The result of flow complies with the JKR specification where the value gets is more than the required value which is 2.0 to 5.0 mm. The reduction in the flow values could be attributed to the increased stiffness of asphalt concrete, which will in turn to improve its permanent deformation resistance.

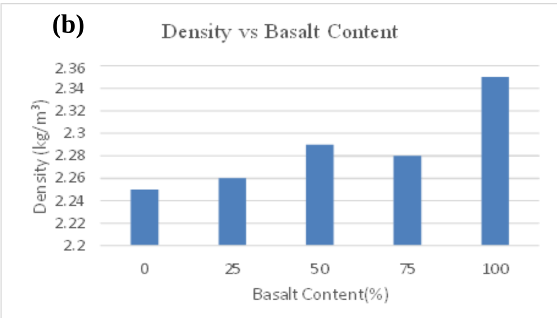
3.2.4 Analysis on Void in Total Mix (VTM)

Fig. 2(d) shows that the air voids decrease with the replacement of basalt aggregate. Following the compressive test, the control sample has the highest VTM value of -4.068, while the sample with 50% basalt replacement had the lowest value of -11.251. this indicates that the control sample has a higher percentage of voids than the other samples containing basalt aggregates. The highest value for VTM according to JKR specification does not fulfill the standard range which is 3.0 to 5.0%.

3.2.5 Analysis on Void that Filled with the Bitumen (VFB)

Fig. 2(e) compares the amount of basalt particles in the asphalt mixture to the number of voids filled with bitumen (VFB). It demonstrates how the VFB values for all samples increase with the increasing percentage of basalt aggregates in the asphalt mixture. Following the compressive test, the sample containing 100% basalt aggregates had the highest VFB value of 103.515%, while the control sample had the lowest FVB value of 73.702%. this shows that 100% of the basalt aggregates sample has more voids than the other samples. The highest VFB value did not follow the standard range which is 70 to 80%, according to JKR specification. However, the control sample was in the standard range and followed the JKR specification.





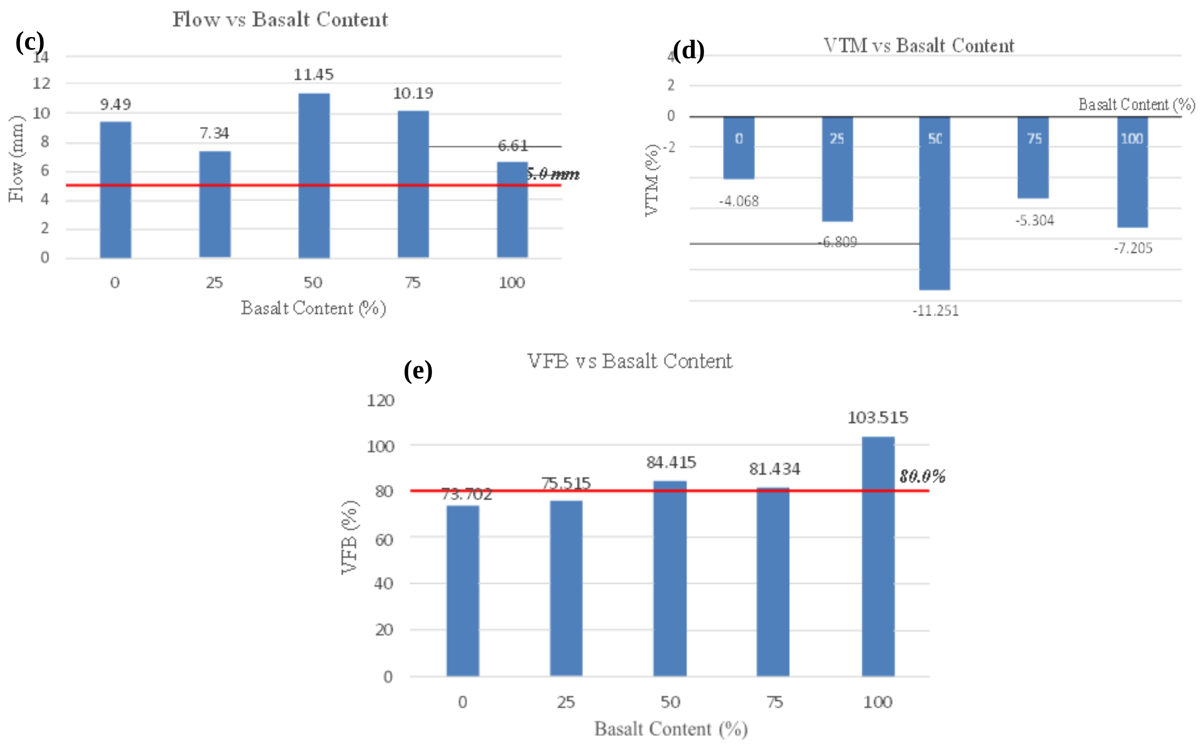


Fig. 2 *Volumetric properties (a) Graph stability vs basalt content; (b) Graph density vs basalt content; (c) Graph flow vs basalt content; (d) Graph VTM vs basalt content; (e) Graph VFB vs basalt content*

3.3 Performance of Asphalt Mixture

The stiffness of the sample was expressed in the Marshall compressive strength based on the values in Table 2 provided above. This graph indicates that the stiffness of granite is greater than that of basalts. The basalt aggregates 25% sample had a stiffness of 80.376kN/mm, more significant than the other samples. The results for samples with 0%, 50%, 75%, and 100% basalt aggregate replacement were 77.941kN/mm, 31.525kN/mm, 30.509kN/mm which is the lowest result, and 79.096kN/mm, respectively. The figure's stiffness curve shows that stiffness increased from 0% to 25% and then from 25% to 75% the stiffness decreased than from 75% to 100% the stiffness increased again. Consequently, all needed samples met the JKR Standard stiffness criterion. Fig. 3 shows the curve for stiffness vs sample with asphalt binder.

Table. 2 *Data for Marshall stability test*

Sample (%)	Asphalt Binder (%)	Corr. Factor	Stability (kN)		Flow (mm)	Stiffness (kN/mm)
			Mean	Corr		
0		1.00	28.994	28.994	0.3720	77.941
25		0.96	26.022	24.981	0.3108	80.376
50	5	1. 00	23.732	23.732	0.7528	31.525
75		0.96	23.174	22.247	0.7292	30.509
100		1.04	22.208	23.096	0.2920	79.096

(f)

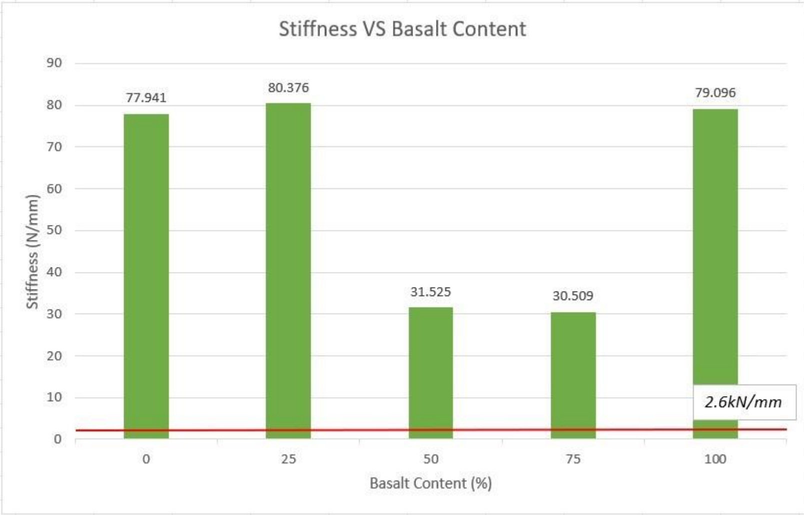


Fig. 3 *Stiffness versus basalt content*

Conclusion

The study investigates the use of basalt aggregate as a modifier for asphalt mixture. The study was based on the characteristic and variability, it shows that basalt aggregate is high tensile strength, strong alkali resistance, high thermal conductivity than granite. The result of the Marshall test shows that the modified sample has a higher indirect tensile strength compared to the control sample. Other than that, the density of asphalt concrete with the replacement of basalt aggregates is higher than unmodified asphalt, which indicates a high possibility of extending the asphalt pavement service life. Then, the flow caused by basalt aggregates in modified asphalt is lower than in unmodified asphalt binder at 25% and 100% basalt aggregates replacement. Besides, the results of VTM and VFB are different. The value of VTM decreases while the value of VFB increase with the increasing basalt aggregates percentage. All the samples use the same grade of 60/70 asphalt binder and 5% asphalt binder content. Generally, the study finds that basalt aggregate can be successfully used to modify asphalt.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design, data collection, draft manuscript, draft manuscript preparation:*** *Zaid Harun, Nur Athirah Mohd Nasir, Nurul Dianah Ruhaizat, Hazirah Bujang. All authors reviewed the results and approved the final version of the manuscript.*

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