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The Study on Marshall Design Parameter of Hot Mix Asphalt Mixture (HMA) Using Limestone Aggregate

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Abstract

In Malaysia, 80% of its roads are from flexible pavement rather than rigid pavement. The asphalt binder material is supplied by the quarry for its aggregates and from the manufacturer for its asphalt binder. In order, material such as limestone aggregate has been used to replace the material that commonly used in the mixture. Limestone aggregate is one of the most durable of all natural building materials. The main objective of this study is to overcome the weakness of the strength problem by using the method Marshall Stability Test. The material that was used for aggregate were limestone and granite. The properties for aggregate tested were Sieve Analysis, Aggregate Impact Value (AIV), Flakiness and Elongation. Furthermore, asphalt binder grade 60/70 penetration properties were performed by softening point and penetration testing. Next, the method used was a mixture design by Hot Mix Asphalt (HMA) and Marshall Mix design. Marshall stability test was employed to evaluate the performance of asphalt mixture. At 0, 25, 50, 70, and 100% of the aggregate total weight, the limestone was mixed with asphalt binder grade 60/70 penetration. The stiffness was demonstrated that the control sample is 74.481 kN/mm meanwhile, the optimal limestone mixture was obtained at 25% which is 69.664 kN/mm. The compressive test shown that all the sample are required followed the JKR specification for stiffness which is 2.6 kN/mm. Therefore, potential of limestone aggregate in asphalt mixture has been implement in road construction.

1. Introduction

The priority of highway pavements is to provide a smooth surface for vehicles to move safely. Asphalt mixtures with aggregate and asphalt binder are used in road construction, and Hot Mix Asphalt (HMA) mixes are commonly used [1]. The strength of the road pavement is important to ensure high safety for users, and the strength of the limestone and asphalt binder combination must be tested prior to the road paving procedure. Limestone is also important commercially, as it is a major supply of raw materials for the chemical industries. When heated to temperatures ranging from 140 to 160 °C, limestones dissolve calcium carbonate, releasing carbon dioxide and lime, which have important applications in the glass and construction industries [2].

Highway administrators are confronted with the problem of excess load or overload, which can result in damaged roads and economic losses [3]. Although asphalt mixture is the most efficient, smoothest, and most costeffective alternative, building materials, particularly aggregates, are in short supply. Limestone aggregate can be utilized to replace the current material because it is more resistant to weather and requires less asphalt binder. The investigates use of limestone as an ingredient in HMA mixtures to overcome strength deficiencies and improve bonding strength between aggregate and binder [4]. The characteristics of limestone can impact the toughness of the road, allowing heavy loads to be supported efficiently and reducing road construction weakness.

This study purpose to evaluate the performance and assess the volumetric properties of hot mix asphalt mixture incorporating limestone aggregate materials. Furthermore, this project also examined to evaluate the characteristics and variability of limestone aggregates and asphalt binder materials as well as conduct a comparative on effect of limestone aggregate to the stability at higher mix temperature.

2. Materials and Methods

Materials and methods used to figure out the performance of hot asphalt mixtures include the incorporation of limestone aggregate materials as an alternative material to replace and maximize strength and durability when faced with road loads. Granite is a typical material used in the construction of roads. However, this study focuses the utilization of alternative substances such as limestone. By the support from asphalt binder to combine the material together, it is to be expected that the durability was be higher with this combination.

2.1 Materials

There was material obtained and utilized in this research before starting with the test. First, the main component is limestone, which is utilized to determine its strength. There are other supporting materials, such as granite and asphalt binder. Asphalt binder is a material that is used for mixing with aggregates and builds up the structural stability capacity of the substance. Fig. 1 show the materials that were conducted for the test.

(a) (b) (c)

Fig. 1 *The materials for mixing preparation (a) Granite; (b) Limestone; (c) Asphalt binder*

2.2 Methods

The testing methods and processes were properly adhered to the AASHTO, ASTM, and JKR standards meanwhile this study used Marshall mix design and Marshall stability tests to investigate the performance of limestone aggregate [5]. The aggregates were sieved into appropriate sizes based on the gradation limit for asphaltic mixture AC10 approximately 1100g composition. The optimal asphalt binder grade 60/70 penetration content that was used is 5.2% [6]. Aggregates properties were tested according to several types, including sieve analysis, the aggregate impact value (AIV), and flakiness and elongation. Moreover, softening point and penetration also have been performed as asphalt binder properties for these studies.

2.2.1 Aggregates Properties

Aggregate testing is important in the construction sector since aggregates are utilized in a wide range of projects and must be evaluated for strength, toughness, hardness, form, and water absorption. Among the tests for aggregates properties were performed such sieve analysis, aggregate impact value and flakiness and elongation index. Sieve analysis is a process used to examine the particle size distribution of samples. The specimen AASHTO T27-88 evaluates and contrasts the weight of the particles retained on each sieve to the weight of the total sample in addition aggregate impact value (AIV) test shown the aggregate's toughness to withstand the impact of moving loads, and this testing was carried out exactly according to the specimen method MS 30: Part 10: 1195 by specification 76-86%. Moreover, the shape test involves two tests which is flakiness and elongation index. Flakiness is calculated by isolating the flaky particles and calculating their mass as a percentage of the sample's mass meanwhile, elongation is calculated by separating the elongation particles and expressing their mass as a proportion of the sample's mass.

2.2.2 Asphalt Binder Properties

Asphalt constitutes 4–8% of HMA by weight and 25–30% of the cost of an HMA pavement construction, depending on the type and quantity. Paving involves the use of asphalt emulsions, asphalt cuts, and foamed asphalt. Based on the testing, softening point and penetration were investigated as well in this research by used asphalt binder grade 60/70 penetration. The softening point value is particularly essential for thick-film materials like joint and crack fillers and roofing materials by preparing a specimen exactly as specified by ASTM D36-95. Furthermore, penetration was shown to be related to viscosity, and empirical correlations for Newtonian materials have been obtained and common method for determining the consistency of an asphalt binder substance at a specific temperature.

2.2.3 Marshall Mix Design Preparation

The Marshall method of mixed design's main components is the measurement of the two important characteristics of strength and flexibility, which were bulk specific gravity determination, stability and flow test, and density and voids analysis. During the Fig. 2, HMA process, asphalt binder is combined and mixed with heated aggregate. The amount of asphalt binder in the mixture must be sufficient to ensure a layer thickness around aggregate particles and provide adequate field compaction to reduce permeability and cracking [7]. In addition, the strength of the mixture was tested in terms of 'Marshall's Stability'.

(a) (b) (c) (d)

Fig. 2 *Marshall mix design preparation (a) Heating material; (b) Mix material; (c) Heating loose specimen. (d) Compaction machine*

2.2.4 Marshall Stability

According to Fig. 3, marshall stability is the maximum load that a specimen can withstand at a standard test temperature of 60°C. Several processes are involved, including aggregate selection, aggregate testing, asphalt binder selection, sample preparation, marshall sample compaction, marshall stability and flow testing, and result plotting. In accordance with the results, a variety of graphs might be plotted, such as density, bulk specific gravity, stability, and flow, VFA and VTM graphs [8].

Fig. 3 *Machine compression test*

3. Results and Discussion

The test was carried out to evaluate the performance of a hot mix asphalt mixture using limestone aggregate materials. For mixing aggregates with asphalt binder, different percentages of the aggregate total weight were employed. Sieve analysis, impact value, flakiness, and elongation, softening point, and penetration have been tested.

3.1 Material Properties

The aggregate test establishes the size, volume, and grade of aggregate required for a high-quality pavement. Sieve analysis, aggregate impact value, flakiness, and elongation have all been included. Moreover, the softening point and penetration of asphalt binder grade 60/70 penetration were examined as well in this research. The result was defined to determine the performance of an asphalt mixture. Based on Fig. 4, The grading curves for sample aggregate were consistently graded according to AASHTO T27-88 specifications.

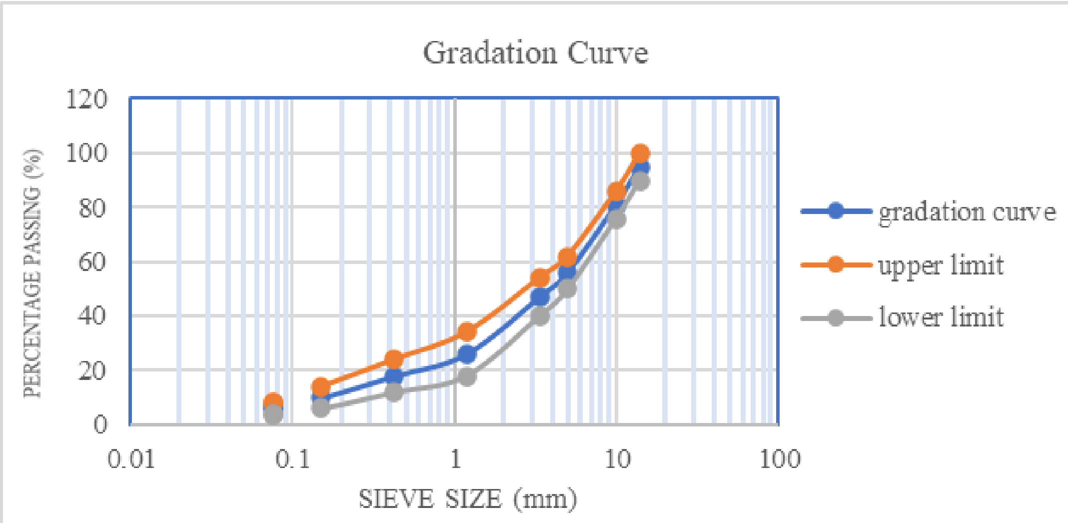

Fig. 4 *Grading curve for aggregate*

In Table 1, there are results were obtained for aggregate and asphalt binder properties test. The aggregate values obtained are suitable for road construction since there are in range within the 20-30% requirement for satisfactory road paving. The results for flakiness and elongation indexes were showed that there was below the limit which is 30% for JKR specification tested with two types of aggregates. Furthermore, the average softening point is 49.5°C and it's fulfilled the required JKR specifications, it ranges from 48 to 56°C. The estimated distance for this test is 0.3 mm, and the penetration index is -0.7. This indicates that the findings of the test have been accepted due to the use of asphalt binder in conventional paving.

Table. 1 *Material properties test*

Aggregate Test				
Aggregate type	Granite		Limestone	
Aggregate Impact Value (AIV)	32.72%		26.17%	
Flakiness and Elongation Index	13.596%	20.156%	27.394%	17.951%
Asphalt Binder Test				
Softening Point	49.5℃			
Penetration	6.31 mm			

3.2 Volumetric Properties

The performance of hot mix asphalt mixes incorporating limestone aggregate materials has been assessed utilizing the results of a test. Marshall Mix Design performed a volumetric properties analysis on HMA comprising 0, 25, 50, 70, and 100% limestone aggregate [9].

3.2.1 Analysis on Stability

The general pattern in Fig. 5(a) shows a graph with decreasing stability from control sample to 100%. Following the compressive test, the control sample obtained the highest load for stability, 38.410 kN. The minimal load for Marshall stability was determined to be 22.242 kN for the sample 100%. This shows that the control sample has a higher stability than the other samples containing limestone aggregate. According to previous study findings, granite and limestone have more stability when applied to load, however when compared to these two aggregates, granite has greater stability than limestone [10][11]. Granite has more stability than limestone.

3.2.2 Analysis on Density

Based on Fig. 5(b), the density and sample with limestone graph was generated, revealing an increasing pattern. The sample with 70% limestone aggregate has the maximum density after compression, 2.316 g/cm3, while the control sample has the lowest density, 2.255 g/cm3. This shows that the sample containing limestone aggregate has a higher density than the sample containing granite material.

3.2.3 Analysis on Flow

According to Fig. 5(c), the flow on limestone fluctuated between 25% and 50% at 60°C, then 70% and 100%. After compression, the sample containing 100% limestone had the maximum flow value of 1.5592 mm, while the sample containing 70% had the lowest flow value of 0.3696 mm. According to the previous study finding, the asphalt binder mixture of limestone has the highest value of flow or deformation because the limestone mixture requires more asphalt binder content compared to other mixture [10][12]. This indicates that the sample containing 100% limestone had the maximum flow value compared to the sample containing 70% limestone, but did not satisfy the JKR Standard required range of 2.0 to 5.0 mm.

3.2.4 Analysis on Void in Total Mix (VTM)

The void in total mix (VTM) of a sample has been shown in Fig. 5(d), and the general pattern exhibited a bell curve. Following the compressive test, the control sample had the highest VTM value of -4.253%, while sample 50% had the lowest value of -11.397%. This shows that the control sample has a higher percentage of voids than the other samples containing limestone aggregate. The greatest value for the air void in total mix (VTM) according to the JKR specification still does not follow the standard range of 3.0 to 5.0%.

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

The void filled with bitumen (VFB) of a sample was shown in Fig. 5(e), and the general trend demonstrated a bell curve. Following the compressive test, the sample containing 70% limestone aggregate had the greatest VFB value of 93.236%, while the control sample had the lowest value of 76.367%. This shows that the 70% limestone sample has more voids than the other samples. The greatest value for the void filled with bitumen (VFB) still did not follow the standard range of 70-80%, according to the JKR specification, however the value for sample 0% was in range and followed the JKR specification standard.

3.3 Marshall Stability Test

The stiffness of a sample was shown in Fig. 5(f), with the control sample value for stiffness being 74.481 kN/mm and the optimal limestone mixture was obtained at 25% which is 69.664 kN/mm. The compressive test shown that all the sample are required followed the JKR specification for stiffness which is 2.6 kN/mm. Furthermore, this experiment shown that a mixture of asphalt and limestone additions fulfilled the requirements and can still be employed for improving the pavement.

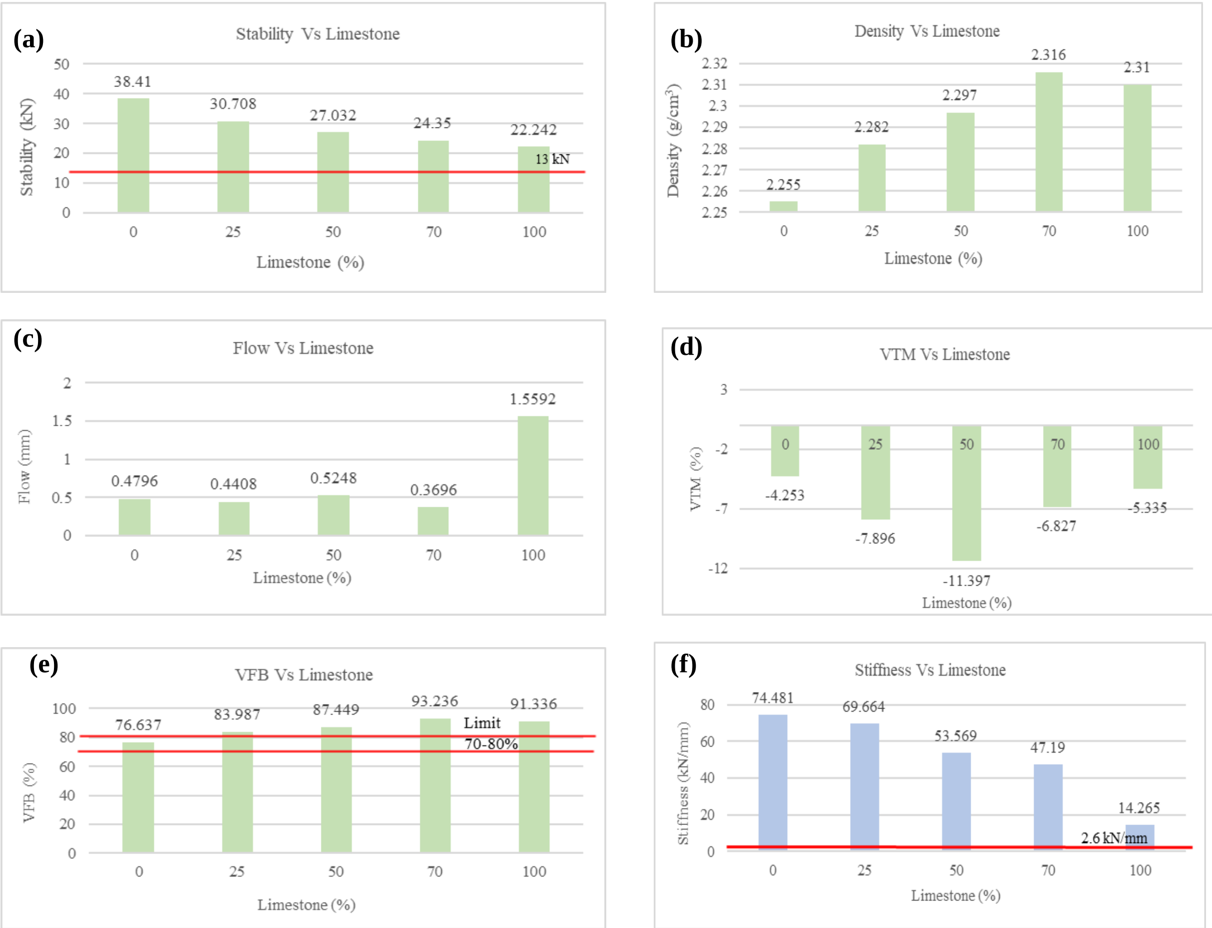

Fig. 5 *Volumetric properties (a) Graph stability with limestone; (b) Graph density with limestone; (c) Graph flow with limestone; (d) Graph VTM with limestone; (e) Graph VFB with limestone; (f) Graph stiffness with limestone*

4. Conclusion

From the test that have been done, it can be conclude that the stability of an asphalt sample was decreases when the amount of limestone in the mixture increases, and all the sample are still fulfilled the required for JKR specification which is the stability is higher than 13 kN. Furthermore, the incorporation of other materials into the asphalt mixture can increase the density of the sample, as control sample produced the lowest value. Moreover, the incorporation of 100% of limestone aggregate into the asphalt mixture results in a higher flow value because limestone requires higher asphalt binder content than other mixtures, the asphalt binder mixture of limestone has the highest value of flow or deformation. The void in total mix (VTM) is higher when the sample contains 50% of limestone and granite aggregate. The highest value of void filled with asphalt binder produced to 70% of limestone aggregate, and incorporating other materials into the asphalt mixture can increase the value of VFB. Other than that stiffness of an asphalt mixture decreases when the percentage of granite material decreases, but it increases when the sample containing of control sample.

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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:*** *Muhammad Hazim Abdul Hamid, Hairee Daniel Mohd Suffi, Nurul Aini Najwa Yusoff, Hazirah Bujang. All authors reviewed the results and approved the final version of the manuscript.*

References

[1] De Assis, S. R. H., de Queiroz, B. O., Araújo, C. C., Nunes, K. K. F., de Melo, R. A., & Lucena, L. C. D. F. L. (2017) Evaluation of limestone crushed dust aggregates in hot mix asphalt. *Construction and Building Materials*, *148*, 659-665. https://doi.org/10.1016/j.conbuildmat.2017.05.107

[2] Sidhu, B. S., Singh, M., & Singh, J. (2022) Investigation on limestone and granite as aggregates in bituminous concrete prepared using ETA and PPA modified bitumen. *Materials Today: Proceedings*, *48*, 1253-1257. https://doi.org/10.1016/j.matpr.2021.08.264

[3] Hatmoko, J. U. D., Setiadji, B. H., & Wibowo, M. A. (2019) Investigating causal factors of road damage: a case study. In *MATEC Web of Conferences,* (258), 02007. EDP Sciences. https://doi.org/10.1051/matecconf/201925802007

[4] Slebi-Acevedo, C. J., Lastra-González, P., Pascual-Muñoz, P., & Castro-Fresno, D. (2019) Mechanical performance of fibers in hot mix asphalt: A review. *Construction and Building Materials*, *200*, 756-769. https://doi.org/10.1016/j.conbuildmat.2018.12.171

[5] Al-Mansoori, T., Dulaimi, A., Shanbara, H. K., & Musa, S. S. (2021) Marshall Parameters of Hot Mix Asphalt with Variable Filler Types and Aggregate Gradations. In *IOP conference series: Materials Science and Engineering* (Vol. 1090, No. 1, p. 012038). IOP Publishing. https://doi.org/10.1088/1757-899X/1090/1/012038

[6] Baldi-Sevilla, A., Aguiar-Moya, J. P., Vargas-Nordcbeck, A., & Loria-Salazar, L. (2017) Effect of aggregate–bitumen compatibility on moisture susceptibility of asphalt mixtures. *Road Materials and Pavement Design*, *18(2),* 318-328. https://doi.org/10.1080/14680629.2017.1304248

[7] Sidhu, B. S., Singh, M., & Singh, J. (2022) Investigation on limestone and granite as aggregates in bituminous concrete prepared using ETA and PPA modified bitumen. *Materials Today: Proceedings*, *48*, 1253-1257. https://doi.org/10.1016/j.matpr.2021.08.264.

[8] Asri, S. Z. M., Khairuddin, F. H., Ng, C. P., Misnon, N. A., Yusoff, N. I. M., & Ibrahim, A. N. H. (2021) Palm Kernel Shell as Partial Coarse Aggregate Replacement in Asphalt Mixture: Optimum Binder Content and Volumetric Properties Investigation. In *Materials Science Forum* (1047), 179-185. Trans Tech Publications Ltd. https://doi.org/10.4028/www.scientific.net/MSF.1047.179

[9] Abuawad, I. M., Al-Qadi, I. L., & Trepanier, J. S. (2015) Mitigation of moisture damage in asphalt concrete: Testing techniques and additives/modifiers effectiveness. *Construction and Building Materials*, *84*, 437-443. https://doi.org/10.1016/j.conbuildmat.2015.03.001

[10] Al-Khateeb, G. G., Khedaywi, T. S., Obaidat, T. I. A. S., & Najib, A. M. (2013) Laboratory study for comparing rutting performance of limestone and basalt superpave asphalt mixtures. *Journal of Materials in Civil Engineering, 25(1),* 21-29. https://doi.org/10.1061/(ASCE)MT.1943-5533.0000519

[11] Kollaros, G., Kalaitzaki, E., & Athanasopoulou, A. (2017) Using hydrated lime in hot mix asphalt mixtures in road construction. *American Journal of Engineering Research (AJER)*, *6(7),* 261-266.

[12] Xiong, R., Zong, Y., Lv, H., Sheng, Y., Guan, B., Niu, D., & Wang, H. (2021) Investigation on anti-skid performance of asphalt mixture composed of calcined bauxite and limestone aggregate. *Construction and Building Materials*, *306*, 124932. https://doi.org/10.1016/j.conbuildmat.2021.124932