

Utilization of Jaddih Limestone from Bangkalan as a Filler as an Effort to Improve the Performance of Asphalt Concrete Mixtures and Deformation Resistance

Ibnu Sholichin^{1*}; Masliyah²

¹Department of Civil Engineering, Engineering Faculty, University of Pembangunan Nasional “Veteran” Jawa Timur, Indonesia

²Department of Civil Engineering, Engineering Faculty, University of Yos Soedarso Surabaya, Indonesia

Correspondent Author: Ibnu Sholichin^{1*}

Publication Date: 2026/05/29

Abstract: Road damage generally occurs due to weather factors, vehicle loads, and poor pavement mix quality. The quality of the pavement mix can be improved by adding filler to the asphalt concrete mixture. Optimal filler content can improve Marshall characteristics and increase deformation resistance. To improve the quality of the asphalt concrete mix, limestone filler is added. The limestone used in this study was Jaddih limestone from Bangkalan Regency. Limestone contains calcium carbonate (CaCO₃). CaCO₃ is the most stable crystalline phase and is widely used in industry. The CaCO₃ content of limestone is expected to act as a catalyst to improve the quality of the asphalt concrete mix. Test results showed an Optimum Asphalt Content (OAC) of 6,37% and an Optimum Filler Content of 3%. The WTM test showed the highest dynamic stability value with a 3% Jaddih limestone filler content, with a dynamic stability value of 926,569 tracks/mm and a deformation rate of 0,045 mm/min. Comparing the addition of 0% and 3% limestone content, the Dynamic Stability value increased by 119,12% and the Deformation Rate decreased by 5,4%. Therefore, the addition of 3% Jaddih limestone significantly improved the Marshall characteristic and deformation resistance.

Keywords: Asphalt, Filler, Jaddih Limestone, Deformation Resistance.

How to Cite: Ibnu Sholichin; Masliyah (2026) Utilization of Jaddih Limestone from Bangkalan as a Filler as an Effort to Improve the Performance of Asphalt Concrete Mixtures and Deformation Resistance. *International Journal of Innovative Science and Research Technology*, 11(5), 2277-2286. <https://doi.org/10.38124/ijisrt/26may1136>

I. INTRODUCTION

Flexible pavement is a type of road pavement that is widely used in Indonesia [1][2][3]. Apart from being more comfortable for vehicles to pass over, the construction costs are also cheaper compared to rigid pavement [4][5]. The downside of flexible pavement is its high maintenance costs. The disadvantage of flexible pavement is its high maintenance costs [6]. Annual maintenance is required to achieve the road's design life [7][8]. Types of road damage that occur with flexible pavement include cracks, potholes, deformation, surface defects, and flushing [9][10]. Causes of damage to flexible pavement include the use of substandard asphalt concrete mixtures. Efforts to improve asphalt mix quality include the addition of fillers to the asphalt concrete mix [11].

According to SNI 03-4142-1996, filler is an asphalt concrete mixture that passes a number 200 sieve or has a particle size of 0,075 mm and has non-plastic properties. Filler

serves to reduce the number of voids in the asphalt and aggregate mixture, thereby increasing the density, stability, and strength of the pavement [12][13]. The added filler must be dry, free of lumps, and pass the aggregate sieve test.

One filler that can be used in asphalt concrete is limestone. This limestone is ground until it is finely ground to resemble a powder. Limestone powder is a sedimentary rock composed of the minerals calcite and aragonite, which are two different varieties of calcium carbonate (CaCO₃). Physical characteristics that need to be considered are color, specific gravity, hardness, water content, porosity, void ratio, and degree of saturation [14].

Asphalt concrete mixtures should use anti-stripping agents to prevent asphalt peeling due to friction between vehicle tires and the asphalt surface [15][16]. Limestone is one alternative anti-stripping agent. Limestone can increase the durability of asphalt concrete mixtures in receiving repeated

traffic loads, such as vehicle weight and friction between vehicle wheels with the road surface [17]. In addition, it is also able to withstand wear and tear due to weather and climate influences such as air, water, or temperature changes [18]. Lime can also affect the performance of asphalt concrete mixtures by increasing the bond between asphalt and aggregate.

Madura Island, particularly Jaddih Hill in Bangkalan Regency, is a limestone region. The limestone potential in this region has not been optimally utilized. The use of Jaddih limestone filler as an asphalt concrete mixture is also a new innovation in optimizing local natural resources in Bangkalan Regency, Madura.

➤ *Limestone*

Bangkalan Regency has immense resource potential, particularly in agriculture, plantations, animal husbandry, and mining. This is supported by the region's generally hilly terrain. In the mining sector, Bangkalan Regency is quite abundant,

particularly in limestone mining. Processed limestone in Bangkalan Regency is limited to cottage industries. The natural limestone obtained is processed by firing to produce quicklime, also known chemically as calcium oxide (CaO). This combustion product is sold for building materials, mining factories, fisheries, and other purposes.

Limestone is a type of sedimentary rock containing carbonate compounds. Generally, limestone that is widely found in nature is limestone containing calcite crystals [19]. Limestone can be white, yellowish-white, gray, or even black. The formation of this color depends on the mixture present in the limestone, for example, clay, quartz, iron oxide, manganese, and organic elements [20]. The carbonate mineral commonly found in limestone is aragonite (CaCO₃), which is metastable because, over time, it can transform into calcite [21]. As is known, limestone contains mostly calcium carbonate minerals, around 90%-95%. From the results of chemical testing of Jaddih Bangkalan limestone, the results obtained are as shown in Table 1.

Table 1 Chemical Test Results of Jaddih Limestone, Bangkalan Regency, Madura

No	Chemical Composition	Wt (%)
1	Ca	94,53
2	Si	2,98
3	Fe	2,29
4	In	1,34
5	Ti	0,33
6	Mg	0,19
7	Lu	0,13
8	Mn	0,02

Calcium carbonate (CaCO₃) is the dominant compound found in limestone. Calcite is the most stable crystalline phase and is widely used in the paint, paper, magnetic recording, textile, detergent, plastic, and cosmetics industries [22]. This calcium carbonate can be converted into calcium oxide by calcination, making it easier to purify to obtain the calcium [23]. In this way, limestone can be utilized in the catalysis sector.

Based on the description above, Jaddih limestone is expected to act as a catalyst to improve the performance of asphalt concrete mixtures and their deformation resistance. The results of this study are expected to serve as a reference for further research on limestone and the asphalt concrete mixture industry.

➤ *Deformation Resistance in Asphalt Concrete Mixtures*

Fatigue cracks and deformation are common types of asphalt road damage. This is caused by the large number of heavy vehicles, such as buses and trucks, passing through the road [24]. Heavy vehicle loads cause strain and stress in each layer of the pavement [25]. The continued traffic load ultimately leads to fatigue cracks and deformation [26]. If fatigue cracks and deformation are left untreated, water will inevitably enter the cracks during the rainy season, transforming them into increasingly larger holes. Therefore, repairs should be made immediately with patching as soon as fatigue cracks and deformation occur. The strength and durability of the asphalt concrete mixture in the road surface

layer are related to its ability to withstand damage from temperature and loading [27]. Repeated loading causes stress and strain in the pavement structure, coupled with thermal stress due to temperature, causing the asphalt concrete mixture to deform and decrease in performance, ranging from fine cracks to rutting [28]. Damage can progress further because the road surface is no longer watertight, allowing water to weaken the bond between the rock and asphalt.

To prevent the reduction of the bond between the rock and asphalt, filler is needed. Filler is one of the additives that can increase adhesion and bonding power, as well as reduce the negative effects caused by water, thus producing a high-adhesion asphalt mixture [29]. If the bonding power between the aggregate and asphalt is not good, it can cause peeling (stripping), and the addition of filler aims to reduce the release of particles in the asphalt. Therefore, it is necessary to conduct tests using a filler that is expected to minimize road damage by water and extend the service life of a pavement with lower maintenance costs.

In addition to testing the Marshall characteristics, this study also conducted Dynamic Stability (DS) testing. Dynamic Stability testing is a method for determining deformation resistance [30]. Dynamic Stability expresses the number of wheel passes required to produce 1 mm of deformation. The larger the DS, the greater the protection of the asphalt concrete mixture is protected from rutting [31]. Equation 1 is used to calculate the Dynamic Stability value.

$$DS \text{ (passing/mm)} = \frac{42 \times (t_2 - t_1)}{d_2 - d_1} \times C_1 \times C_2 \dots\dots\dots(1)$$

Information :

- $t_1 = 45$ minutes, $t_2 = 60$ minutes so that
- $(t_2 - t_1) = 15$ minutes.
- $C_1, C_2 =$ correction factor = 1
- if $C_1 = C_2 = 1$ and $t_2 - t_1 = 15$ minutes, then we will get Equation 2.

$$DS = \frac{42 \times 15}{d_{60} - d_{45}} = \frac{630}{d_{60} - d_{45}} \text{ (passing/mm)} \dots\dots\dots(2)$$

Deformation Rate (RD):

$$RD \text{ (mm/minutes)} = \frac{D_2 - D_1}{d_2 - d_1} \dots\dots\dots(3)$$

With : $D_2 =$ Deformation Value at $t_2 = 60$ minutes

$D_1 =$ Deformation Value at $t_1 = 45$ minutes

II. METHODOLOGY

➤ Research Design

The test object in this study was an asphalt concrete mixture sample with a diameter of 10 cm and a height of 7,5 cm. The initial step in this study was to determine the optimum

asphalt content (OAC) with a variation of asphalt content of Pb-1%, Pb%, and Pb+1%. To determine the planned asphalt content, the Asphalt Institute method can be used. The calculation of the planned asphalt content is shown in Equation 4.

$$Pb = (0,035 \times A) + (0,045 \times B) + (K \times C) + F \dots\dots\dots(4)$$

Information:

- Pb = Optimum asphalt content (OAC)
- A = Percentage of aggregate retained on sieve No. 8
- B = Percentage of aggregate passing sieve No. 8 and retained on sieve No. 200
- C = Percentage of aggregate passing sieve No. 200
- K = 0,15 if the number that passes sieve No. 200 is between 11%–15%
- = 0,18 if the number that passes sieve No. 200 is between 6%–10%
- = 0,2 if the number that passes sieve No. 200 \leq 5%
- F = 0%–2% based on aggregate absorption value

The number of test objects to determine OAC for each variation of asphalt content is as shown in Table 2.

Table 2 Number of Test Objects to Determine OAC

Test Specimens	Asphalt Content	Number of Test Specimens
OAC 1	Pb-1%	5
OAC 2	Pb%	5
OAC 3	Pb+1%	5
Number of Test Specimens		15

(Source: Research Plan)

After obtaining the OAC value, filler material was added, consisting of Jaddih limestone from Bangkalan Regency, at varying levels of 0%, 2%, 4%, 6%, and 8% of the total

aggregate weight. The number of test specimens used to determine the OAC for each filler content variation is shown in Table 3.

Table 3 Determination of Optimum Filler Content

Asphalt Content	Jaddih Limestone Content (%)				
	0	2	4	6	8
Optimum (X)	5	5	5	5	5
Number of Test Objects					25

(Source: Research Plan)

The materials used in making the test objects were crushed stone as coarse aggregate with a size of 5/10 mm or 10/15 mm, stone ash as fine aggregate, asphalt, and Jaddih limestone, Bangkalan Regency, as filler.

➤ Material Quality Testing

This research is experimental, therefore, quality and material testing are required.

- Aggregate Testing Includes:

✓ Sieve Analysis

✓ Specific Gravity and Absorption

- Asphalt Testing

The asphalt used in this study was Pertamina asphalt with a penetration of 60/70. Several tests were conducted to assess the asphalt quality, including:

- ✓ Penetration
- ✓ Flash and Fire Points
- ✓ Softening Point
- ✓ Asphalt Specific Gravity

- Filler: The filler used was Jaddih limestone from Bangkalan Regency, which passed the 200 sieve.

➤ *Data Collection Method*

Data collection in this study was obtained from the results of the test specimens. Data collection was carried out by recording the results of the Marshall Test parameters on each test specimen. The Marshall test includes values for Void in Mix (VIM), Void in Mineral Aggregate (VMA), Void Filled with Asphalt (VFA), Stability, Flow, and Marshall Quotient (MQ).

- VIM is the volume of voids remaining after the asphalt concrete mixture is compacted.
- VMA is the volume of voids within the compacted asphalt concrete if the entire asphalt cover is removed, expressed as a percentage of the bulk volume of the compacted asphalt concrete.
- VFA is the portion of the VMA filled with asphalt, excluding asphalt absorbed into the pores of each aggregate particle.
- Stability is the ability of a road pavement to withstand traffic loads without experiencing permanent deformation, such as waves, grooves, and bleeding. The need for stability is proportional to the road's function and the traffic load it will serve.
- Flow is the magnitude of the plastic deformation of an asphalt mixture test specimen that occurs due to a load up to the point of failure, and is expressed in units of length.
- MQ is a measure that describes the quality of an asphalt concrete mixture based on the results of a compression test using the Marshall method. The MQ is obtained by dividing the stability value by the yield (flow) value of the asphalt concrete mixture.
- Deformation Resistance Testing

To determine the deformation resistance performance of the asphalt concrete mixture, three parameters are reviewed: Deformation Rate (RD) and Dynamic Stability (DS).

III. DISCUSSION

➤ *Material Testing Results*

Material testing in this study included aggregate and asphalt testing. Aggregate and asphalt testing were conducted in accordance with the testing procedures outlined in the Indonesian National Standard (SNI). Based on the tests, the coarse aggregate, fine aggregate, and asphalt met the specified requirements.

➤ *Determination of Planned Asphalt Content*

The planned asphalt content in this study was determined using the Asphalt Institute approach. The calculation of the planned asphalt content is shown in Equation 4. The test results yielded the following data:

$$A = 62\%; B = 32\%; C = 6\%; F = 1,68\%$$

$$K = 0,18 \text{ (Sieve No. 200 = 6\%)}$$

Therefore, the estimated planned asphalt content can be calculated using the Asphalt Institute method as follows:

$$\begin{aligned}
 Pb &= (0,035 \times A) + (0,045 \times B) + (K \times C) + F \\
 &= (0,035 \times 62) + (0,045 \times 32) + (0,18 \times 6) + 1,68 \\
 &= 6,37 \%
 \end{aligned}$$

Based on the estimated calculation of the planned asphalt content, the percentage variation in asphalt content can be determined as shown in table 4.

Table 4 Variation of Planned Asphalt Content

Asphalt Content Variation	Weight of Test Specimen (Grams)	Percentage (%)	Weight (Grams)
Pb-1	1200	5,37	66,44
Pb-0,5	1200	5,87	71,44
Pb	1200	6,37	76,44
Pb+0,5	1200	6,87	81,44
Pb+1	1200	7,37	86,44

(Source: Calculation Results)

➤ *Determination of Optimum Asphalt Content (OAC)*

The optimum asphalt content was determined using a graphical method by establishing Marshall parameter values that meet the 2018 General Bina Marga Specifications for asphalt concrete mixtures. The parameters for determining the

optimum asphalt content include VIM, VMA, VFA, Stability, Flow, and MQ values. Table 5 shows the test results of the specimens used to determine the Optimum Asphalt Content (OAC).

Table 5 Recapitulation of Test Object Results for Determining OAC

Characteristics	Conditions	Percentage				
		5,37	5,87	6,37	6,87	7,37
VMA (%)	min. 15	15,15	16,23	16,12	15,93	15,11
VFA (%)	min. 60	58,21	60,86	61,36	62,56	63,02
VIM (%)	3,5-5,5	3,2	4,1	4,6	4,2	5,6
Stability (kg)	min. 800	1250,34	1258,86	1355,21	1465,89	1297,84

Flow (mm)	min. 3	4,44	4,54	4,63	5,21	4,99
MQ (kg/mm)	min. 250	281,61	277,28	292,70	281,36	260,09

(Source: Calculation Results)

The results from Table 5 are used as reference parameters in determining the Optimum Asphalt Content, as in Figure 1.

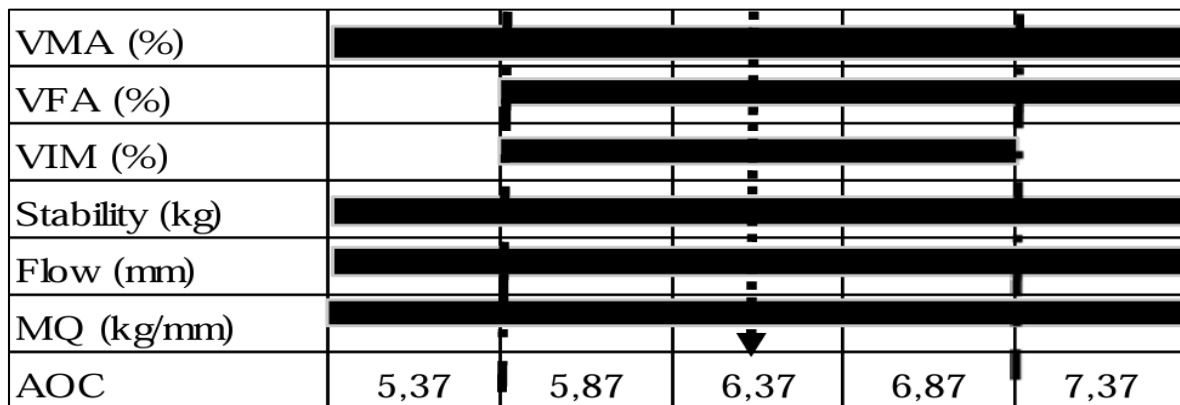


Fig 1 Graph of Optimum Asphalt Content Parameter Summary Results
(Source: Test Results)

From Figure 1, it can be seen that the value of the Optimum Asphalt Content, which will later be used to determine the Optimum Filler Content, is 6,37%.

➤ *Determining Optimum Filler Content*

- *Void in Mix (VIM)*

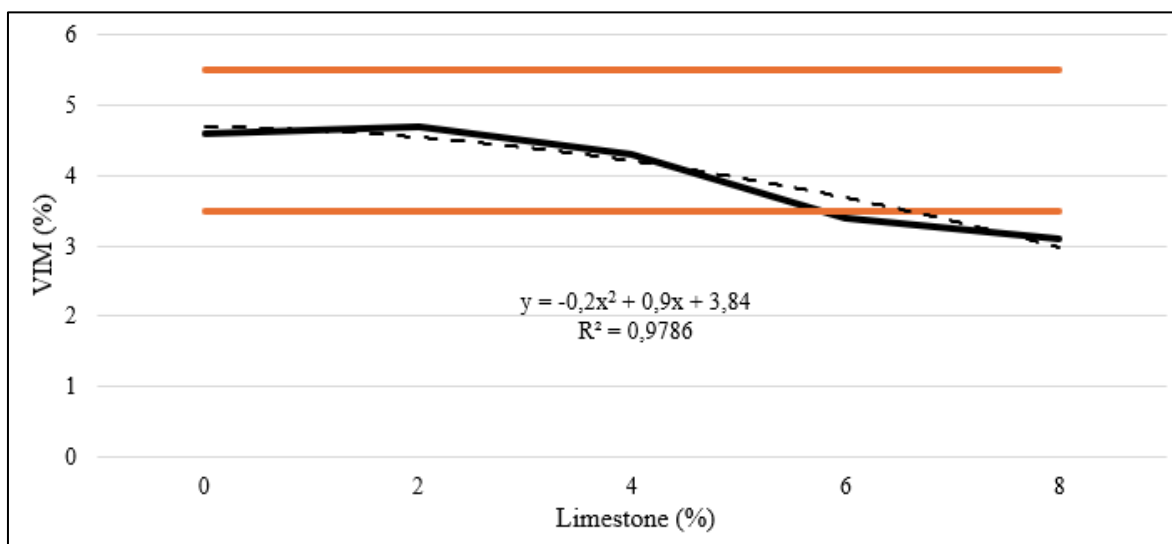


Fig 2 Graph of the Relationship Between VIM and Limestone Content
(Source: Test Results)

In Figure 2, the variations in filler content that meet the VIM value according to the 2018 Highway Specifications are 0%, 2%, and 4%. Then the VIM value decreases, as the percentage of variations in Jaddih limestone content increases.

A VIM value that exceeds the specified standard limit indicates that the limestone content in the asphalt concrete mixture is too high, resulting in a very low density of the mixture and causing the asphalt concrete mixture to be easily damaged/brittle.

- *Void in Mineral Aggregate (VMA)*

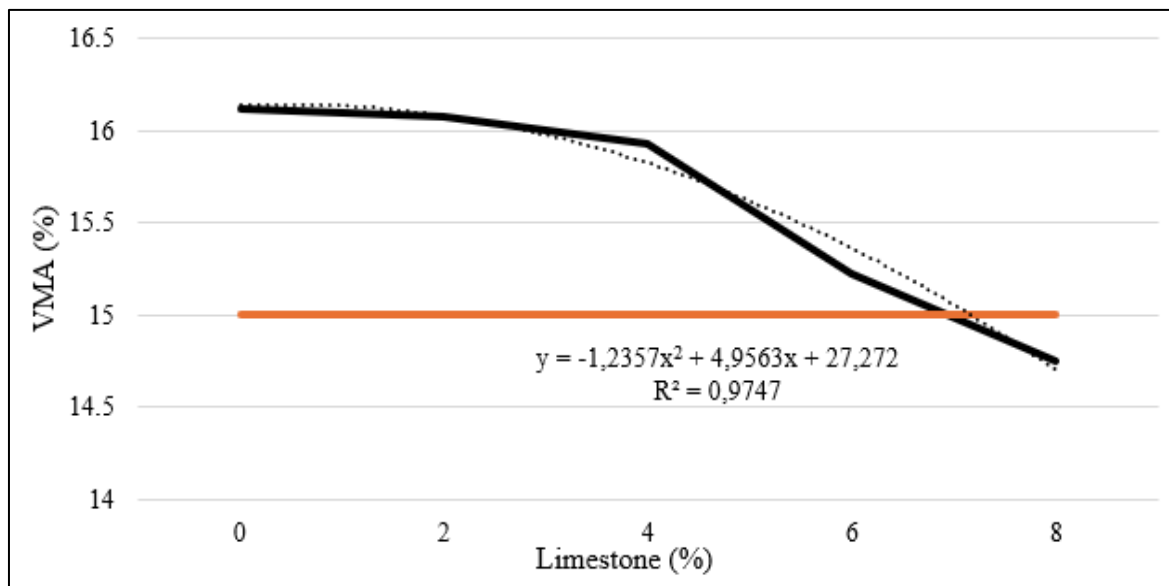


Fig 3 Graph of the Relationship between VMA and Limestone Content
(Source: Test Results)

The VMA value decreased with increasing variations in the Jaddih limestone filler content. This is because a higher percentage of Jaddih limestone (within the specified standard limits) can fill the voids between the aggregates in the asphalt concrete mixture, reducing the voids.

- *Void Filled with Asphalt (VFA)*

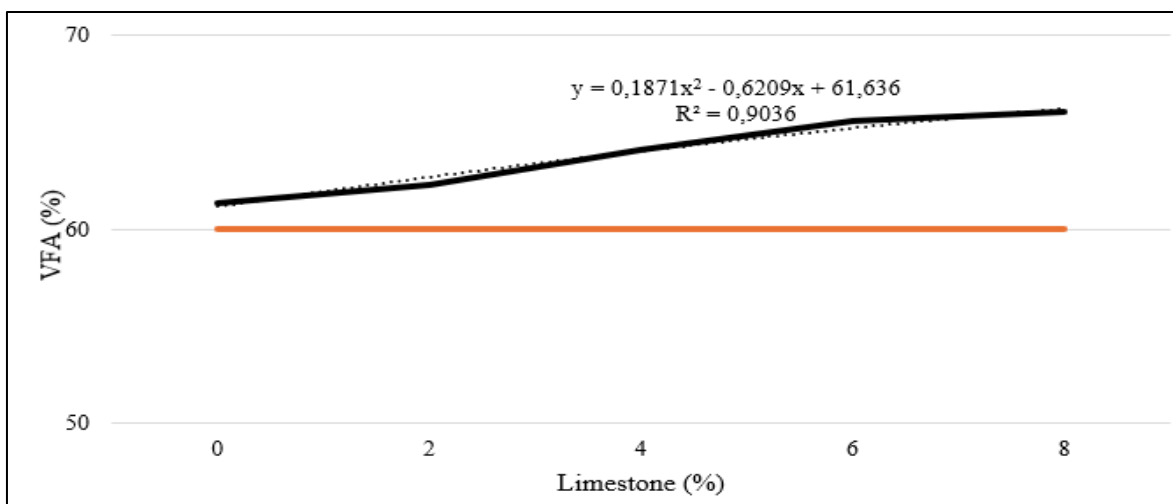


Fig 4 Graph of the Relationship between VFA and Limestone Content
(Source: Test Results)

In Figure 4, the VFA value increases with increasing percentage variations in Jaddih limestone filler content. This indicates that the asphalt-filled voids are capable of filling the

voids in the asphalt concrete mixture. In Figure 4, the VFA values for all filler content variations meet the specified standard values.

- *Stability*

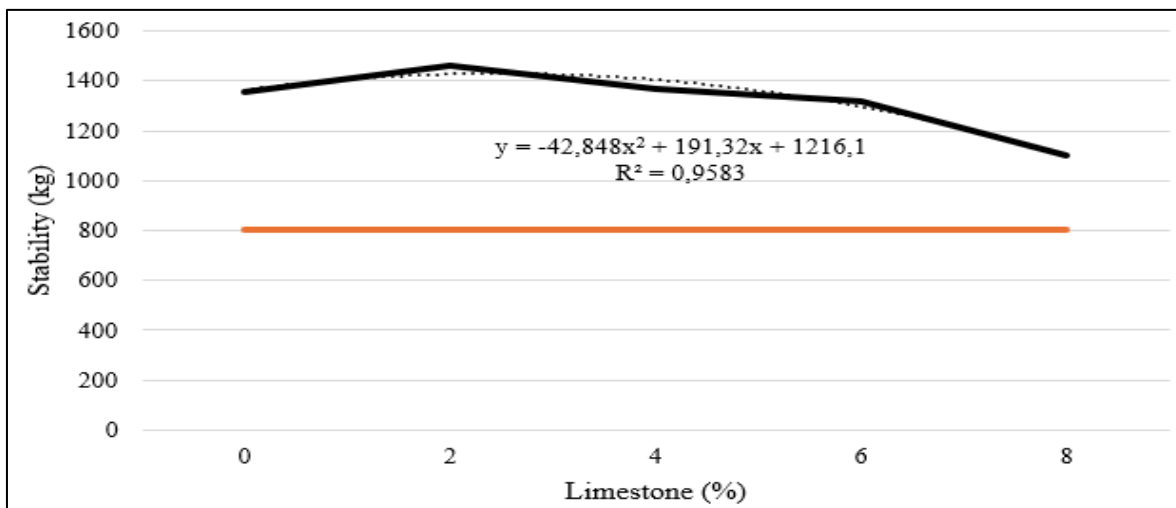


Fig 5 Graph of the Relationship Between Stability and Limestone Content (Source: Test Results)

Figure 5 shows an increase in the stability value of the Jaddih limestone filler content from 0% to 2%. However, the stability value decreases from 2% to 8%. This is because the higher limestone content results in adhesion to the asphalt concrete mixture, thereby increasing its stiffness. An asphalt concrete mixture that is too stiff can easily crack due to vehicle

loads and temperature changes. At this stability value, all filler content variations meet the specified standard values.

- *Flow*

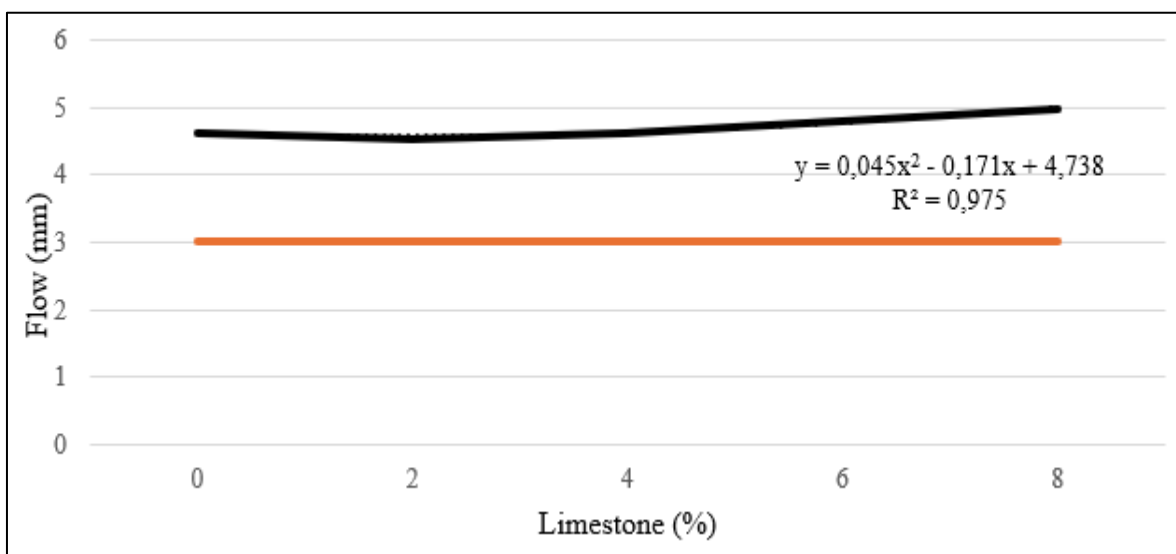


Fig 6 Graph of the Relationship between Flow and Limestone Content (Source: Test Results)

In Figure 6, the flow value decreases with variations in Jaddih limestone filler content from 0% to 2%. However, the flow value increases with an increase from 4% to 8%. The flow value of the asphalt concrete mixture must be limited to achieve the ideal mix value. A high flow value indicates that the asphalt

concrete mixture is plastic and easily deformed due to high traffic loads. This is indicated by the higher plastic yielding that occurs in the mixture with the addition of limestone, resulting in a lower stability value of the asphalt concrete mixture.

• *Marshall Quotient (MQ)*

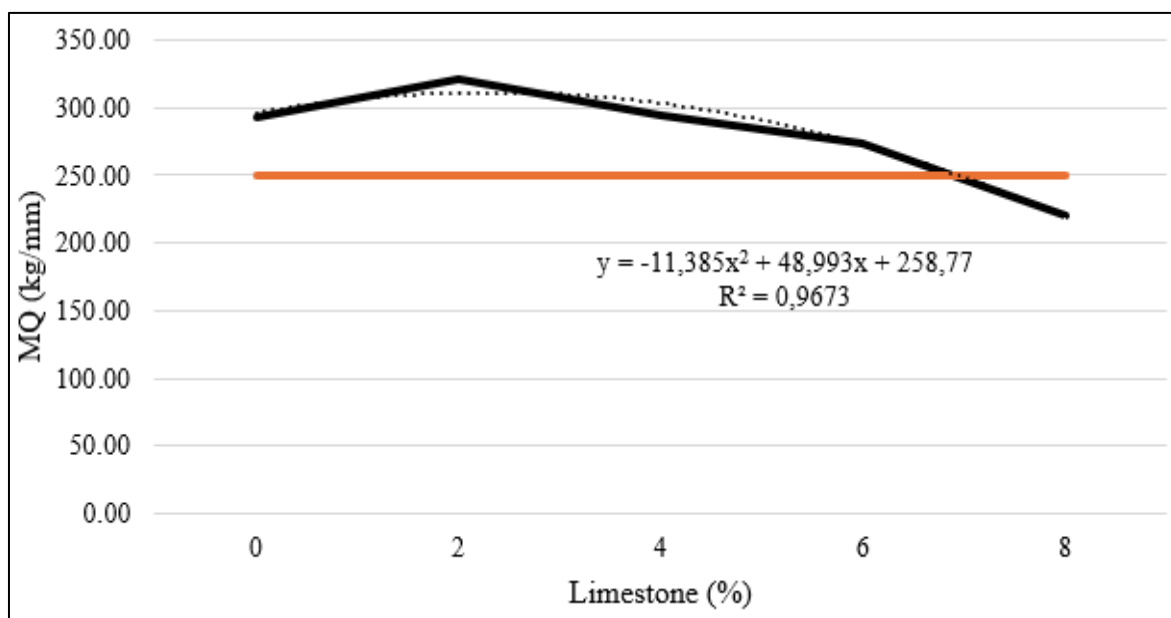


Fig 7 Graph of the Relationship between MQ and Limestone Content (Source: Test Results)

In Figure 7, the MQ value for the variation of Jaddih limestone filler content from 0% to 2% increased. However, at a percentage of 4% to 8%, the MQ value decreased. This is because the addition of a 2% filler content provides stiffness to the asphalt concrete mixture, so that the asphalt's ability to bind the aggregate to maintain its position increases, and the mixture

is less easily deformed when subjected to loads. A low MQ value indicates that the mixture has a low stability value with a high yield value, resulting in the mixture becoming softer and more easily deformed.

➤ *Determining the Optimum Filler Content*

VMA (%)	[Bar chart showing VMA values across 0, 2, 4, 6, 8% limestone]				
VFA (%)	[Bar chart showing VFA values across 0, 2, 4, 6, 8% limestone]				
VIM (%)	[Bar chart showing VIM values across 0, 2, 4, 6, 8% limestone]				
Stability (kg)	[Bar chart showing Stability values across 0, 2, 4, 6, 8% limestone]				
Flow (mm)	[Bar chart showing Flow values across 0, 2, 4, 6, 8% limestone]				
MQ (kg/mm)	[Bar chart showing MQ values across 0, 2, 4, 6, 8% limestone]				
AOC FILLER (%)	0	2	4	6	8

Fig 8 Determining the Optimal Limestone Filler Content (Source: Test Results)

From Figure 8, the graph of the recapitulation results of the optimum filler content parameters that meet the 2018 General Binamarga Specifications is 3%. The Marshall test results with a Jaddih limestone filler content of 3% have overall met the specified requirements. This shows that the addition of Jaddih limestone as a filler in the AC-BC mixture has a good effect and can be used for asphalt concrete mixtures.

➤ *Effect of Limestone Filler Addition on Deformation Resistance*

To determine deformation resistance, testing was conducted using a Wheel Tracking Machine (WTM). This test simulates deformation in the pavement due to vehicle traffic.

Table 6 Wheel Tracking Machine Test Results

Time (Minutes)	Number of Tracks	Deformation (mm)					
		0%	2%	3%	4%	6%	8%
0	0	0	0	0	0	0	0
1	21	0,52	0,44	0,38	0,48	0,46	0,76

5	105	1,32	0,97	0,78	1,08	1,25	1,88
10	210	2,22	1,67	1,34	1,25	1,66	2,86
15	315	3,31	2,43	2,32	2,41	3,99	3,33
30	630	4,76	4,32	3,99	3,75	4,58	5,45
45	945	6,49	6,27	5,77	5,32	7,32	6,15
60	1260	7,98	7,12	6,45	6,21	8,25	7,43
Dynamic Stability (DS)		422,8	741,2	926,5	707,9	677,4	492,2
Deformation Rate (RD)		0,099	0,057	0,045	0,059	0,062	0,085

(Source: Test Results)

Table 6 shows the results of the Wheel Tracking Machine (WTM) test on the optimum asphalt mixture with Jaddih limestone filler. The WTM test results show that the number of repeated passes and the duration of loading increase the dynamic stability of the asphalt concrete mixture. The highest dynamic stability value was achieved by adding 3% Jaddih limestone filler, with a DS value of 926,569 tracks/mm and an RD value of 0,045 mm/min. Compared to the non-limestone mixture, the DS value increased by 119,12% and the RD decreased by 5,4%. This indicates greater deformation resistance and a reduced deformation rate.

The WTM test results are comparable to the Marshall characteristic test results. Adding an optimal Jaddih limestone filler content reduces voids in the asphalt mixture and increases stability. However, higher Jaddih limestone filler content results in stiffer asphalt concrete mixtures and reduced binding capacity, resulting in decreased stability and accelerated road deterioration.

IV. CONCLUSION

➤ *Based on the Discussion, the Following Conclusions can be Drawn:*

- The test results showed an Optimum Asphalt Content of 6,37% and an Optimum Filler Content of 3%.
- Based on the WTM test, the Optimum Asphalt Content Mixture with a 3% Jaddih limestone filler content achieved the highest dynamic stability value, with a dynamic stability value of 926,569 tracks/mm and a deformation rate of 0,045 mm/minute.
- Comparing the addition of 0% and 3% limestone content resulted in a 119,12% increase in the DS value and a 5,4% decrease in the RD value.
- Based on the calculation of each asphalt characteristic parameter at the Optimum Asphalt Content with a percentage of 3%, the addition of Jaddih limestone significantly affected the Marshall characteristics and deformation resistance, and could be used as an asphalt concrete mixture.

ACKNOWLEDGMENT

Thank you to the Department of Civil Engineering at the University of Pembangunan Nasional "Veteran" Jawa Timur for assisting laboratory facilities so that the process runs successfully. Not to forget, thanks also to my family for their support so far that this journal can be finished.

REFERENCES

- [1]. C. O. F. Rigid and F. Pavements, "JOURNAL OF GREEN SCIENCE AND TECHNOLOGY A LITERATURE STUDY: BEHAVIORAL OBSERVATION OF THE," vol. 9, no. 1, pp. 41–54.
- [2]. A. Mulyawan, S. M. Saleh, and R. Anggraini, "Simulation of road treatment costs based on life-cycle cost analysis," IOP Conf. Ser. Mater. Sci. Eng., vol. 933, no. 1, 2020, doi: 10.1088/1757-899X/933/1/012024.
- [3]. L. Siahaya, B. S. Subagio, and A. J. Susilo, "Development of Flexible Pavement Structure Using the Local Materials of Sarmi, Papua, Indonesia - Based on Indonesian National Specification," Int. J. GEOMATE, vol. 24, no. 103, pp. 34–41, 2023, doi: 10.21660/2023.103.3479.
- [4]. D. Rusida, W. Oetomo, and R. Marleno, "Cost and Time Comparison Research Between Rigid Pavement and Flexible Pavement on the Temuireng-Jetis Road Section, Mojokerto District," Asian J. Eng. Soc. Heal., vol. 4, no. 3, pp. 499–511, 2025, doi: 10.46799/ajesh.v4i3.567.
- [5]. T. P. Hariyanto, W. Oetomo, and R. Marleno, "Comparative Analysis of Cost and Time Between Flexible and Rigid Pavement on the Siwalanpanji Kemiri," Asian J. Soc. Humanit., vol. 3, no. 10, pp. 1837–1845, 2025, doi: 10.59888/ajosh.v3i10.584.
- [6]. Y. Oktopianto, A. Antonius, and A. Rochim, "An Artificial Neural Network Approach for Predicting Pavement Distress: A Case Study Toward Sustainable Road Maintenance," Adv. Sustain. Sci. Eng. Technol., vol. 7, no. 3, pp. 1–12, 2025, [Online]. Available: <https://doi.org/10.26877/asset.v7i3.2133>
- [7]. M. Ummah, "Critical Aspects of Quality Management in Flexible Pavement Construction," Sustain., vol. 11, no. 1, pp. 1–14, 2019, doi: 10.5281/zenodo.14542660.
- [8]. S. Al Maghawri, O. R. Ibrahim, Y. Gamil, and R. Al Sheikh, "Comparing between the Flexible Pavement Design Methods Based on Durability and Cost-Effectiveness," Civ. Eng. Archit., vol. 11, no. 6, pp. 3775–3788, 2023, doi: 10.13189/cea.2023.110639.
- [9]. R. S. N. Alaamri, R. A. Kattiparuthi, and A. M. Koya, "Evaluation of Flexible Pavement Failures-A Case Study on Izki Road," Int. J. Adv. Eng. Manag. Sci., vol. 3, no. 7, pp. 741–749, 2017, doi: 10.24001/ijaems.3.7.6.
- [10]. H. S. E. M. S. K. S. U. A. Hayat, "Analysis of Flexible Pavement Distresses," vol. 12, no. 4, pp. 145–155, 2023.

- [11]. Y. M. Jebur et al., "Effect of Filler Type and Content on The Mechanical Properties of Asphalt Mixtures," *AIP Conf. Proc.*, vol. 3009, no. 1, 2024, doi: 10.1063/5.0190471.
- [12]. T. Al-Mansoori, A. Dulaimi, H. K. Shanbara, and S. S. Musa, "Marshall Parameters of Hot Mix Asphalt with Variable Filler Types and Aggregate Gradations," *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 1090, no. 1, p. 012038, 2021, doi: 10.1088/1757-899x/1090/1/012038.
- [13]. Z. Jwaida, Q. A. Al Quraishy, R. R. A. Almuhanha, A. Dulaimi, L. F. A. Bernardo, and J. M. de A. Andrade, "The Use of Waste Fillers in Asphalt Mixtures: A Comprehensive Review," *CivilEng*, vol. 5, no. 4, pp. 801–826, 2024, doi: 10.3390/civileng5040042.
- [14]. S. A. Taqieddin and H. M. Humidi, "Physical and Engineering Properties of Some Selected Jordanian Basalt," *Int. J. Innov. Educ. Res.*, vol. 5, no. 5, pp. 16–45, 2017, doi: 10.31686/ijer.vol5.iss5.649.
- [15]. S. Shu, C. Zhuang, S. Zhao, Y. Hao, H. Guo, and Y. Ye, "Study of Anti-Stripping Measures to Improve the Adhesion of Asphalt to Granite Aggregates," *Coatings*, vol. 12, no. 12, 2022, doi: 10.3390/coatings12121954.
- [16]. Y. Ye, Y. Hao, C. Zhuang, S. Shu, and F. Lv, "Evaluation on Improvement Effect of Different Anti-Stripping Agents on Pavement Performance of Granite-Asphalt Mixture," *Materials (Basel)*, vol. 15, no. 3, pp. 1–21, 2022, doi: 10.3390/ma15030915.
- [17]. Y. C. S. Poernomo, S. Winarto, Z. B. Mahardana, D. A. Karisma, and R. Ajiono, "The Limestone as a Materials Combination of Base Course on the Road Pavement," *IOP Conf. Ser. Mater. Sci. Eng.*, vol. 1125, no. 1, p. 012019, 2021, doi: 10.1088/1757-899x/1125/1/012019.
- [18]. E. A. Awad and K. A. Al-Haddad, "Validity of Limestone Aggregates for Using in Asphalt Concrete Mixtures for Surface Layer of Roads," *Iraqi Geol. J.*, vol. 56, no. 1, pp. 29–41, 2023, doi: 10.46717/igj.56.1A.4ms-2023-1-16.
- [19]. N. Serge Pactworld, A. Panigrahi, N. Serge Research scholar, S. Logeshkumar, A. M. Panigrahi Phil Resarch scholar, and G. Senthil Kumar Associate Professor, "International journal of basic and applied research A comprehensive study of crystalline limestone:A case study from Khondalite supergroup rocks belonging to Usilampatti Block, Tamil Nadu, S. India," *Number 12 UGC Approv. J.*, vol. 8, no. December, 2018, [Online]. Available: www.pragatipublication.com
- [20]. M. F. Qodri and R. A. Sopamena, "Mineralogical and geochemical characterization of the Wonosari formation limestone at Gunungkidul Indonesia as preliminary investigation of Portland cement raw material," *IOP Conf. Ser. Earth Environ. Sci.*, vol. 1151, no. 1, 2023, doi: 10.1088/1755-1315/1151/1/012026.
- [21]. F. Munawaroh, L. K. Muharrami, T. Triwikantoro, and Z. Arifin, "The Simple Method of Synthesizing Calcite and Aragonite from Indonesian Limestone," *Iran. J. Chem. Chem. Eng.*, vol. 41, no. 1, pp. 71–78, 2022, doi: 10.30492/ijcce.2022.103588.3475.
- [22]. W. Nagaki, N. Doki, M. Yokota, and K. Yamashita, "Control of Crystal Size and Morphology of Calcium Carbonate Crystal Polymorphism," pp. 38–45, 2021, doi: 10.4236/msce.2021.94005.
- [23]. S. Fathiyah, S. Mohamad, S. Mohamad, and Z. Jemaat, "Study of calcination condition on decomposition of calcium carbonate in waste cockle shell to calcium oxide using thermal gravimetric analysis STUDY OF CALCINATION CONDITION ON DECOMPOSITION OF CALCIUM CARBONATE IN WASTE COCKLE SHELL TO CALCIUM OXIDE USIN," no. April, 2019.
- [24]. V. Kumar, A. A. Jegan, and B. Kumar, "Investigating the effect of overloaded vehicles on asphalt pavement : a case study in India," *Discov. Civ. Eng.*, 2025, doi: 10.1007/s44290-025-00263-3.
- [25]. S. El-hamrawy, M. Ali, and U. Heneash, "The Effects of Truck Axle Loads and Tire Pressure on the Responses of Flexible Pavement Civil Engineering Department , Faculty of Engineering , Kafrelsheikh University , Kafr- Elsheikh , Saad EL-Hamrawy , Momen Ali , and Usama Heneash " The Effects of Tru," vol. 45, no. 3, pp. 439–446, 2022.
- [26]. D. M. Setiawan, "E ffect of truck and train loading on permanent deformation and fatigue cracking behavior of asphalt concrete in fl exible pavement highway and asphaltic overlayment track," 2023.
- [27]. C. S. Paglia, "Introduction to the durability and damage of asphalt mixes Christian Paglia e Livia Guerini University of Applied Sciences of Southern (SUPSI)," no. November, 2023.
- [28]. A. H. Albayati, "Factors Affecting Asphalt Concrete Permanent Deformation : Experimental Dataset for Uniaxial Repeated Load Test Factors affecting asphalt concrete permanent deformation : Experimental dataset for uniaxial repeated load test," *Data Br.*, vol. 53, no. February, p. 110224, 2024, doi: 10.1016/j.dib.2024.110224.
- [29]. R. Ullah, I. Hafeez, S. Bilal, A. Zaidi, and S. Haider, "Study the Effect of Substitution Filler on performance of Asphalt Mixture," no. May 2021, 2020, doi: 10.28991/cej-2020-03091576.
- [30]. S. Liu and J. Zhang, "Research on dynamic stability of large deformation roadway with application of segmented resistance anchor bolt," pp. 1461–1470, 2022, doi: 10.21595/jve.2022.22677.
- [31]. G. T. Cho, Y. Kim, S. Kim, and K. Kim, "Problems in dynamic stability assessment of asphalt concrete in Korea and suggestion," vol. 10, no. 1, pp. 14–26, 2020.