Marshall Characteristics, Refusal Density and Abrasion Value on Hot Rolled Asphalt (HRA) Mixtures Using Laterite Stone as Replacement Aggregate

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ABSTRACT

This research examines the mechanical performance and durability of various mixtures of laterite material and crushed stone used in asphalt mixes. The materials used included AC 60-70 asphalt from Pertamina, coarse aggregate from crushed stone from a local quarry, laterite stone from a quarry in Central Kalimantan, and fine aggregate from a local quarry. The Marshall tests provided data on stability, flow, density, Volume of Voids in Mineral Aggregate (VMA), Volume of Voids in Mix (VIM), Volume Filled with Asphalt (VFWA), and Marshall Quotient (MQ). The Marshall test on the 100% laterite mixture showed that set A11-A13 had good density with moderate VMA and VIM values, as well as high stability and MQ. The slightly high flow indicated moderate elasticity. Set A21-A23 showed an increase in density with higher VMA and lower VIM, which improved stability but reduced MQ, indicating greater elasticity. Set A31-A33 showed a significant increase in stability and VFWA with higher flow, indicating high elasticity while remaining strong against load. Set A41-A43 had higher density and VFWA, slightly reduced stability, and lower MQ, indicating greater elasticity. Set A51-A53 had the highest density with very low VIM and high VFWA, showing very good cohesion but low stability and high flow, indicating significant elasticity and vulnerability to deformation. In the 50% laterite and 50% crushed stone mixture, set A11-A13 showed good density with moderate VMA and VIM, high stability and MQ, although the high flow indicated moderate elasticity. Set A21-A23 had increased density with higher VMA and lower VIM, resulting in better stability under load but reduced MQ, indicating increased elasticity. Set A31-A33 had significant stability and high VFWA with higher flow, indicating high elasticity but strong resistance to load. Set A41-A43 showed high density and VFWA with slightly reduced stability and low MQ, indicating greater elasticity. Set A51-A53 had the highest density with very low VIM and high VFWA, showing excellent cohesion but low stability and high flow, indicating significant elasticity and vulnerability to deformation. The density of the 100% crushed stone mixture ranged from 2.216 gr/cc to 2.232 gr/cc, indicating a dense and compact mixture. VMA increased from 16.70% to 19.04%, indicating an increased capacity of the mixture to hold asphalt, while VIM decreased from 5.91% to 4.05%, indicating increased density of the asphalt mix. VFWA increased from 64.65% to 78.72%, indicating improved pore filling by asphalt contributing to the cohesion of the mix. Stability ranged from 1,148.8 kg to 1,329.8 kg, indicating the mixture's ability to withstand deformation and load pressure. Stability was fairly high (1,117.84 kg) but lower MQ (291.602 kg/mm) indicated lower resistance to deformation compared to RA1-RA3. Set RC1-RC3 had the same density as RB1-RB3 (2.233 gr/cc), but higher VMA (11.64%) and larger VIM (4.37%), and lower VFWA (62.590%), indicating less efficient pore filling. The lowest stability (887.36 kg) and the lowest MQ (242.191 kg/mm) indicated suboptimal mechanical performance and higher vulnerability to deformation. In the abrasion test using the Los Angeles machine, laterite stone showed an abrasion value of 27.2%, indicating good resistance to abrasion and impact, suitable for construction applications requiring aggregates with high resistance to mechanical wear. Crushed stone experienced a mass loss of 30.9% after the abrasion test, still within the upper limit acceptable for road construction, but this aggregate is more prone to degradation when exposed to heavy traffic loads or extreme weather conditions. Aggregates with high wear tend to be more brittle, which can lead to a decrease in the quality and longevity of roads or structures built.

Keywords: Marshall Standard; refusal density; abrasion.

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INTRODUCTION

In the current era of development, road transportation plays a very important role. Development is almost evenly distributed in every region, both in urban and remote areas. Good road conditions affect the smooth flow of traffic and economic progress of each region, so good pavement planning and continuous maintenance are needed so that road conditions remain safe and comfortable for vehicles to pass.

Hot Rolled Asphalt (HRA) mixture consists of a mixture of asphalt and gap graded aggregate using a mortar proportion of between 50% and 80% of the total mixture, while the proportion of coarse aggregate is approximately 30% to 40%, Stability in the HRA mixture is influenced by the stiffness of the mortar and not the interlocking properties between the aggregate grains. The position of the coarse aggregate seems to float in the mortar, so the deformation that occurs is deformation of the mortar.

Asphalt is a solid or semi-solid material which is a hydrocarbon compound, dark brown or pitch black in color from the petroleum distillation process. Oil asphalt used for road paving is often referred to as cement asphalt. As one of the construction materials, asphalt paving is a small component, generally only 4%-10% by weight or 10%-50% by volume.

Aggregate is a collection of crushed stone grains, sand or other minerals obtained from nature or processed. Aggregate plays a role in supporting and distributing the load of vehicle wheels to the base soil layer (Sukirman, S, 1992). Each region has various types of aggregates, and there are areas that do not have standard aggregates, especially for lowland areas that have rocks with high soil content such as Laterite Stone.

With the use of Laterite Stone as a Substitute material, it is expected that it can be used as an alternative material in replacing aggregates in the Asphalt mixture, especially in Hot Rolled Asphalt (HRA), without reducing the advantages of the Hot Rolled Asphalt (HRA) mixture. There are 3 research objectives, namely, 1) to see the results of the marshall characteristic test on the Hot Rolled Asphalt (HRA) mixture using Laterite stone as a substitute for Coarse aggregate, 2) to see the results of the refusal density test on the Hot Rolled Asphalt (HRA) mixture using Laterite stone as a substitute for Coarse aggregate, 3) to see the results of the Abrasion value test on the Hot Rolled Asphalt (HRA) mixture using Laterite stone as a substitute for Coarse aggregate.

Flexible asphalt pavement is the most common type of pavement used on highways. This asphalt has flexible properties, so it can adjust to loads and weather conditions. The flexible pavement structure consists of several layers, with the top layer being a mixture of asphalt and aggregate, which provides a smooth and traffic-resistant surface (Syaiful S, Rusfana H, 2022). The layers below, such as the base layer and sub-base layer, function as supports and load distribution. One of the advantages of flexible pavement is its ability to absorb deformation and pressure without cracking. This makes it suitable for supporting heavy vehicle loads and providing driving comfort. However, this material is also susceptible to permanent deformation, such as grooves or rutting, especially if there is a decrease in the quality of the material or construction. Flexible asphalt pavement requires routine maintenance, such as patching or repaving, to maintain surface quality and the safety of road users. Resistance to water and extreme weather is also a major challenge because it can trigger damage such as cracking due to temperature changes or waterlogging (Syaiful S, Lasmana L, 2020; Syaiful S, 2020).

Asphalt

Asphalt is a solid or semi-solid material which is a hydrocarbon compound, dark brown or jet black in color consisting of asphalteness and malteness. If heated to a certain temperature, asphalt can become soft/liquid so that it can wrap aggregate particles when making asphalt concrete or can enter the pores in spraying/watering. If the temperature starts to drop, the asphalt will harden and bind the aggregate in place (Sukirman, S, 1992).

The asphalt that is often used in field implementation, especially in Indonesia, is hard asphalt from petroleum distillation with the type AC 60-70 and AC 80-100, with the consideration that the asphalt penetration is relatively low, so that the asphalt can be used on pavements with high traffic and is resistant to hot weather. This asphalt is asphalt that is used in a liquid and hot state and will form a solid at room temperature (Sukirman, S, 1992).

Hydrocarbons are the main raw material of asphalt which is commonly called bitumen, so asphalt is also often called Bitumen. The bitumen used in the planning of Hot Rolled Asphalt is a type of hard Bitumen with a penetration hardness level of 40-50 or penetration of 60-70. The asphalt penetration requirements are listed in Table 1 below.

Table 1. Requirements for several types of asphalt

No	Types of Examination	Pen.40		Pen.60		Pen.80	
		Min.	**Max.**	**Min.**	**Max.**	**Min.**	**Max.**
1	Penetration 25℃. 100 gr5 seconds (0.1 mm)	40	59	60	80	80	99
2	Softening point (Ring and Ball (℃)	51	63	48	58	46	54
3	Flash point (Cleveland open cup (℃)	200	-	200	-	200	-
4	Ductility 25℃ 5 cm per minute (cm)	75	-	100	-	100	-
5	Solubility CCL_4 (wt%)	99	-	99	-	99	-
6	Weight loss 163℃, 5 hours (wt%)	-	0,4	-	0,4	-	0,6
7	Penetration after weight loss	75	-	75	-	75	-
8	Specific gravity 25℃	1	-	1	1	1	-

Source: Bina Marga, 1983

Aggregate

Aggregate is a collection of crushed stone grains, sand or other minerals obtained from nature or processed. Aggregate plays a role in supporting and distributing the load of vehicle wheels to the base soil layer (Sukirman, S, 1992).

The selection of the type of aggregate that is suitable for use in pavement construction is influenced by several factors including, size and gradation, strength and hardness, surface texture shape, adhesion to asphalt and cleanliness and chemical properties (Kerbs and Walker, 1971).

Hot Rolled Asphalt uses gap graded aggregates, namely gradations that in their grain size do not have one or contain a few grains with a certain size or some aggregate sizes are removed.

Based on their size, British Standard Institution 594, (1985) groups aggregates into 3 (three) Fractions, namely:
1) Coarse aggregates are aggregates that are retained by the BS sieve. 2.36 mm.

2) Fine aggregate is aggregate that passes BS sieve. 2.36 mm and retained by BS sieve. 0.075 mm.
3) Filler is the fraction of fine aggregate that passes BS sieve. 0.075 mm

British Standard Institution (1985) requires the composition of coarse aggregate, fine aggregate and mixed aggregate used in Hot Rolled Asphalt mixtures. The requirements for coarse aggregate, fine aggregate and mixed aggregate for Hot Rolled Asphalt mixtures can be seen in Table 2 below.

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Table 2. Coarse aggregate gradation requirements for Hot Rolled Asphalt

Layer thickness (mm)	**35**
Coarse aggregate content (%)	15/30
Nominal rock size (mm)	10/14/2020
Sieve size mm	Passed the filter (%)
50	-
37,5	-
28,0	-
20,0	100
14	85-100
10,0	01-100
6,3	0-60

Source: British Standard Institution 594, 1985

Table 3. Grading requirements for fine aggregate of Hot Rolled Asphalt

Sieve size (mm)	**Percentage passing (%)**
5,00	100
2,360	95-100
0,600	75-100
0,212	15-100
0,075	0-5

Source: British Standard Institution 594, 1985

Table 4. Aggregate gradation requirements for Hot Rolled Asphalt mixes

Sieve Size	**Percentage passing through the sieve (%)**	
	Specifications	**Mean Value**
4 mm (1/2")	100	100
10 mm (3/8")	85-100	92,5
6,3 mm (1/4")	60-90	75
2,36 mm (#8)	60-72	66
0,600 mm (#30)	25-45	35
0,212 mm (#70)	15-30	22,5
0,075 mm (#200)	8-12	10

Source: British Standard Institution 594, 1985

Filler

Filler is a fine-grained material that functions as filler granules in the manufacture of asphalt concrete mixtures. Filler is defined as a fraction of mineral dust that passes sieve no. 200 (0.075 mm) can be in the form of lime dust, chalk dust, dolomite dust or Portland cement. Filler must be dry with a maximum water content of 1%. The addition of filler to the hard layer mixture causes the hard layer to experience a reduction in pore content. Filler particles occupy the cavities between larger particles, so that the space between larger particles, so that the space between large particles is reduced. In general, the addition of this filler is intended to increase the stability and density of the mixture (Bina Marga 1983).

Laterite Stone

Laterite Stone is hardened soil resembling stone from the deposition of substances such as nickel and iron. Laterite itself is formed naturally which contains many elements and nutrients that form the soil layer to harden like stone. In the past, laterite stone was often used as a material for making bricks because when damp laterite is easy to cut, but after being exposed to air for a long time it will harden like a stone (Understanding rocks and types of rocks, 2013)

Laterite stone as part of ultramafic rock is also composed of olivine minerals which are rich in Fe and Mg elements, which allows laterite deposits to form and produce iron ore as one of the vital resources (Best, 2003; Sufriadin, 2017; Rahmatillah et al., 2023). Characteristics of Laterite Stone: Red in color, sharp angled, light density, light weight and high clay content.

Hot Rolled Asphalt (HRA) Mixture

Hot Rolled Asphalt (HRA) is a flexible hard layer construction with uneven graded (gap graded) using a mortar proportion of between 50% and 80% of the total mixture, while the proportion of coarse aggregate is approximately 30% to 40% which is determined based on the planning of the thickness of the pavement layer. The stability of the mixture depends on the stiffness of the mortar and not on the interlocking properties between the aggregate grains. The advantages of this type of mixture are that it is resistant to wear, more flexible and has high flexibility, so it can accommodate heavy loads without experiencing fatigue adhesion, and also has weather resistance and ease of workability. This mixture also has disadvantages including being less rigid, less resistant to deformation and requiring 1% to 2% more bitumen than other mixtures such as asphalt concrete.

In planning the HRA mixture, the use and determination of the type of material components need to be considered carefully. Coarse aggregate (retaining BS 2.36 mm sieve) can be crushed stone or gravel, fine aggregate (passing BS 2.36 mm sieve and retained by BS 0.075 sieve) can be used as natural sand or fine crushed stone fragments, while for mineral fillers, cement (portland cement) limestone dust or other rock dust can be used with an aggregate size passing BS 0.075 mm sieve. The asphalt used in this mixture is a type of hard bitumen with a penetration hardness level of 40-50 or penetration of 60-70. HRA planning is based on the BS 594:1985 specification which includes the foundation layer, subbase and surface layer (Hana Agus MS and Fatkhunnajah E, 2022).

Pavement Characteristics

A pavement layer is said to be good if it has high stability, high flexibility, high durability, sufficient skid resistance and is easy to work on (workability). Pavement also provides comfort for passing traffic, as well as relatively cheap manufacturing and maintenance costs (Sukirman, S, 1992).

To obtain a mixture as required, the following mixture characteristics must be considered:

Stability

Stability is the ability of the road pavement layer to receive traffic loads without changes in shape such as waves, grooves (rutting), or bleeding (Sukirman, S, 1992). Variables that affect the stability of the hard pavement layer include cohesion and internal friction. This internal friction is a combination of friction and locking resistance of the aggregate mixture (The Asphalt Institute, 1983).

Durability

Durability is the resistance of the road pavement layer to the effects of weather and traffic loads (The Asphalt Institute, 1983). Durability is used on the surface layer, so that the surface layer can withstand wear due to the effects of weather, water, temperature changes and wear due to friction from vehicle wheels.

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Flexibility

The flexibility of a pavement mixture indicates the ability to

Withstand deflection and bending, for example in adjusting to the underlying subgrade without cracking (The Asphalt Institute, 1983). To increase flexibility, the use of aggregates with open gradations is very appropriate, but with this use the stability value will be obtained which is not as good as when using dense gradations. The nature of asphalt, especially its ductility, greatly affects the flexibility of the pavement.

Marshall Characteristic Parameters

Marshall characteristic parameters are obtained from Marshall test data plotted on a graph. related to the addition of asphalt content. Below you can see the results of the analysis of data processing from the Marshall test (The Asphalt Institute, 1983). The stability value of the mixture tends to increase with increasing asphalt content, until it reaches the maximum point, stability decreases again.

Density

The density value indicates the level of density and density of a mixture of aggregate and asphalt pavement. The density value increases until it reaches the optimum point, then decreases with increasing asphalt content, as shown in Figure 1 below.

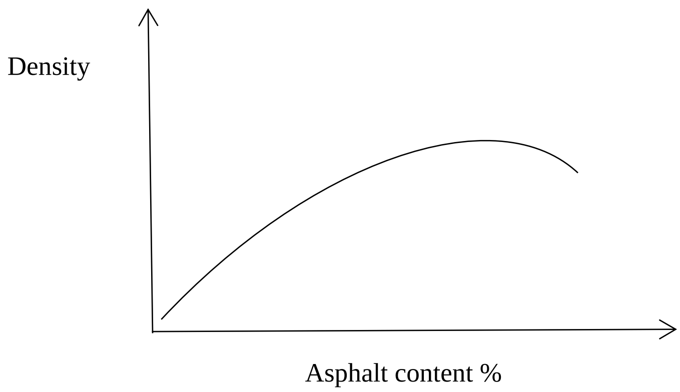

Figure 1. Graph of the relationship between asphalt content and Density value

The density value is obtained from equations 1 and 2 below.

$$g = \frac{c}{f} \quad (1)$$

$$f = d - e \quad (2)$$

With:
g = Density value (gr/cc)
c = Dry specific gravity before soaking (gr)
d = Weight of water-saturated test object (gr)
e = Weight of test object in water (gr)
f = Volume of test object (cc)

Void In Mix (VIM)

VIM is the percentage of air voids to the total volume of the mixture after compaction. The VIM value decreases with increasing asphalt content, as shown in Figure 2 below.

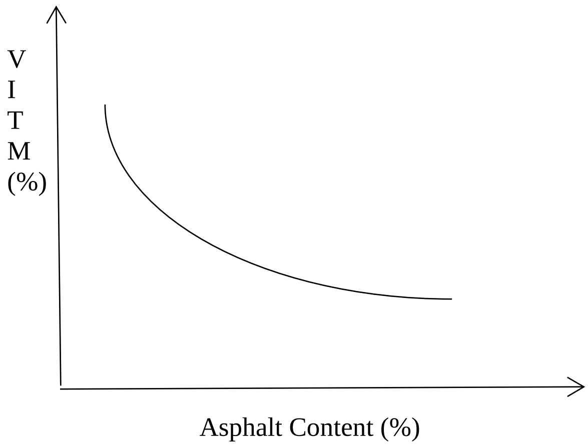

Figure 2. Graph of the relationship between asphalt content and VIM value

VIM value is obtained from equations 3 and 4 below.

$$\text{VIM} = 100(100\text{x}\frac{g}{h}) \quad (3)$$

$$\text{h}= \frac{(100}{(\frac{\%\,Agregate}{Bj.Agregate}+(\frac{\%\,Asphalt}{Bj.Asphalt}} \quad (4)$$

With

G = sample density (gr/cc)
h = theoretical maximum density of the mixture (gr/cc)

Void Filled with Asphalt (VFWA)

VFWA is the percentage of voids in the mixture filled with asphalt, the value of which will increase based on the increase in asphalt content to a certain limit, where the voids are full, meaning that the voids in the mixture are completely filled with asphalt, as shown in Figure 3 below.

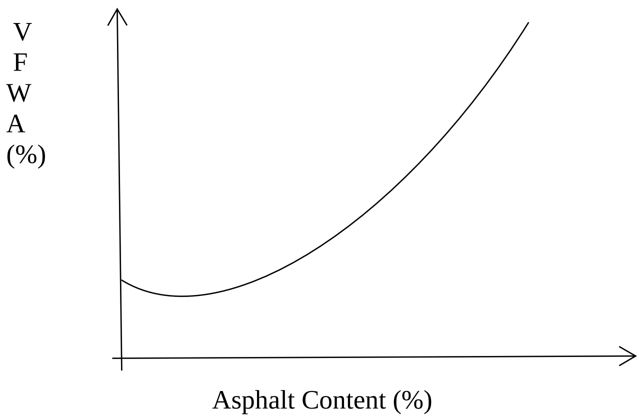

Figure 3. Graph of the relationship between asphalt content and VFWA value

The VFWA value is obtained from equations 5 to 8 below.

$$\text{VFWA} = 100\ \text{x}\left(\frac{i}{l}\right) \quad (5)$$

$$\text{I} = \frac{bxg}{Bj.Agregate} \quad (6)$$

$$\text{J} = \frac{(100-b)xg}{Bj.Agregate} \quad (7)$$

$$\text{I} = 100\text{-j} \quad (8)$$

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With:
b = Percentage of asphalt to the mixture (%)
g = Sample unit weight (gr/cc)

Void in the Mineral Aggregate (VMA)

VMA is the percentage of voids between aggregate grains, including voids filled with air and those filled with effective asphalt. The VMA value decreases to a minimum point and then increases with increasing asphalt content, as shown in Figure 4 below.

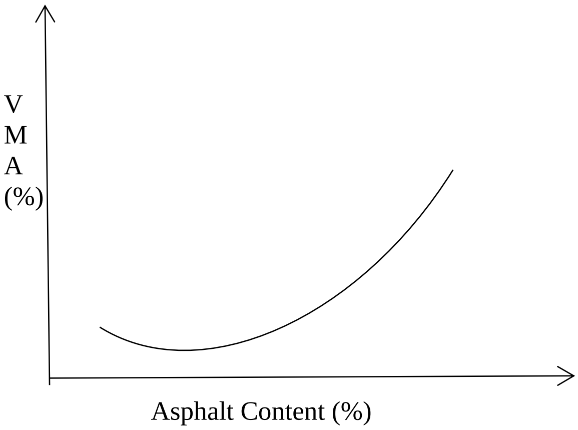

Figure 4. Graph of the relationship between asphalt content and VMA value

VMA value is obtained from equations 9 to 10 below.

$$J = \frac{(100-b)xg}{Bj.Agregate} \quad (9)$$

$$Vma=100-j \quad (10)$$

With:
b = Percentage of asphalt to the mixture (%)
g = Sample unit weight (gr/cc)

Stability

Stability is the load that can be supported by the asphalt concrete mixture until plastic fatigue occurs. The increase in stability coincides with the increase in asphalt content to a certain limit (optimum) and decreases after exceeding the optimum limit. This occurs because asphalt as a binding material between aggregates can become a lubricant after exceeding the optimum limit, as shown in Figure 5 below.

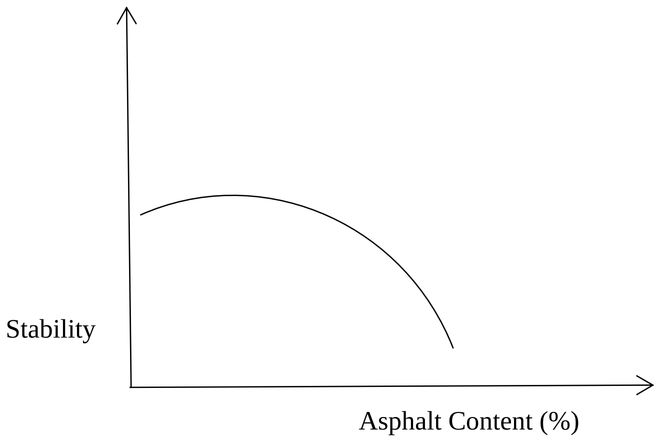

Figure 5. Graph of the relationship between asphalt content and stability value

The stability value is obtained from the following equation 11.

$$S= p \times q \qquad (11)$$

With:
S= Actual stability number (kg)
p= Stability watch reading x tool calibration
q= Test object correction number

Flow

Flow states the amount of settlement (test object deformation) of a mixture with a high fatigue number and low stability above the maximum limit will tend to be plastic. If the mixture with a low fatigue number and high stability below the optimum limit will tend to be brittle and easily cracked when loaded. The flow value increases with increasing asphalt content, as shown in Figure 6 below.

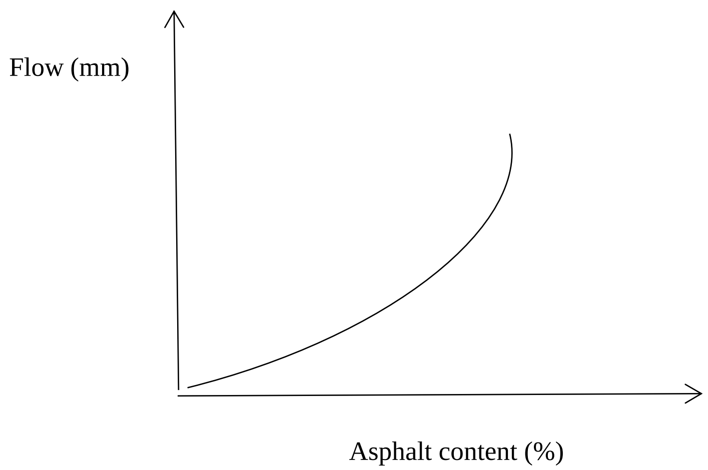

Figure 6. Graph of the relationship between asphalt content and Flow value Marshall Quotient (MQ) Marshal Quotient is a comparison between stability and flow values.

The Marshall Quotient value in pavement planning is used as an approach to the pavement flexibility value. The Marshal Quotient value increases to a maximum point and then decreases with increasing asphalt content, as shown in Figure 7 below.

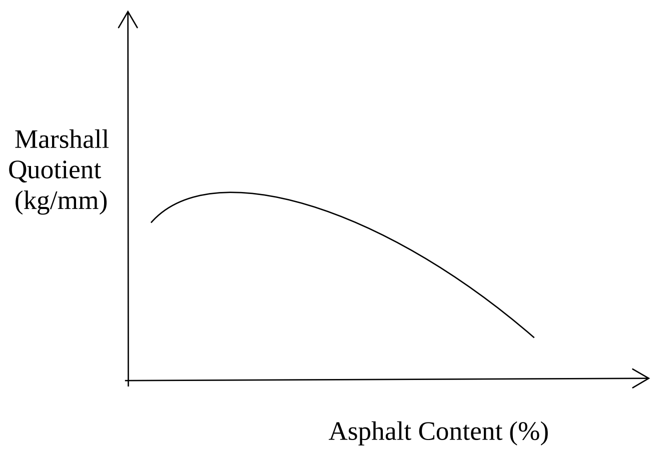

Figure 7. Graph of the relationship between asphalt content and Marshall Quotient value

The Marshall Quotient value is obtained from the following equation 12.

$$MQ=\frac{S}{R} \qquad (12)$$

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With: S = Stability Value (kg) R = Flow Value (mm) MQ = Marshall Quontient Value (kg/mm) Refusal Density Absolute Density (Refusal Density) is the highest (maximum) density that can be achieved by the mixture so that the mixture cannot become denser, as a requirement for air cavities in the asphalt mixture.

Abrasion Value Abrasion or aggregate wear is the process of destruction or breaking of aggregates in this case coarse aggregates due to mechanical processes such as forces that occur during the road construction process (filling, spreading, compaction), service to traffic loads and chemical processes, such as the influence of humidity, heat, and temperature changes throughout the day. The abrasion value is a value that indicates the resistance of coarse aggregates to destruction (degradation) due to mechanical loads. The abrasion value is determined by conducting an abrasion experiment (Los Angeles Abration Test) in the laboratory using the Los Angeles abrasion tool.

RESEARCH METHODS
Organize Research

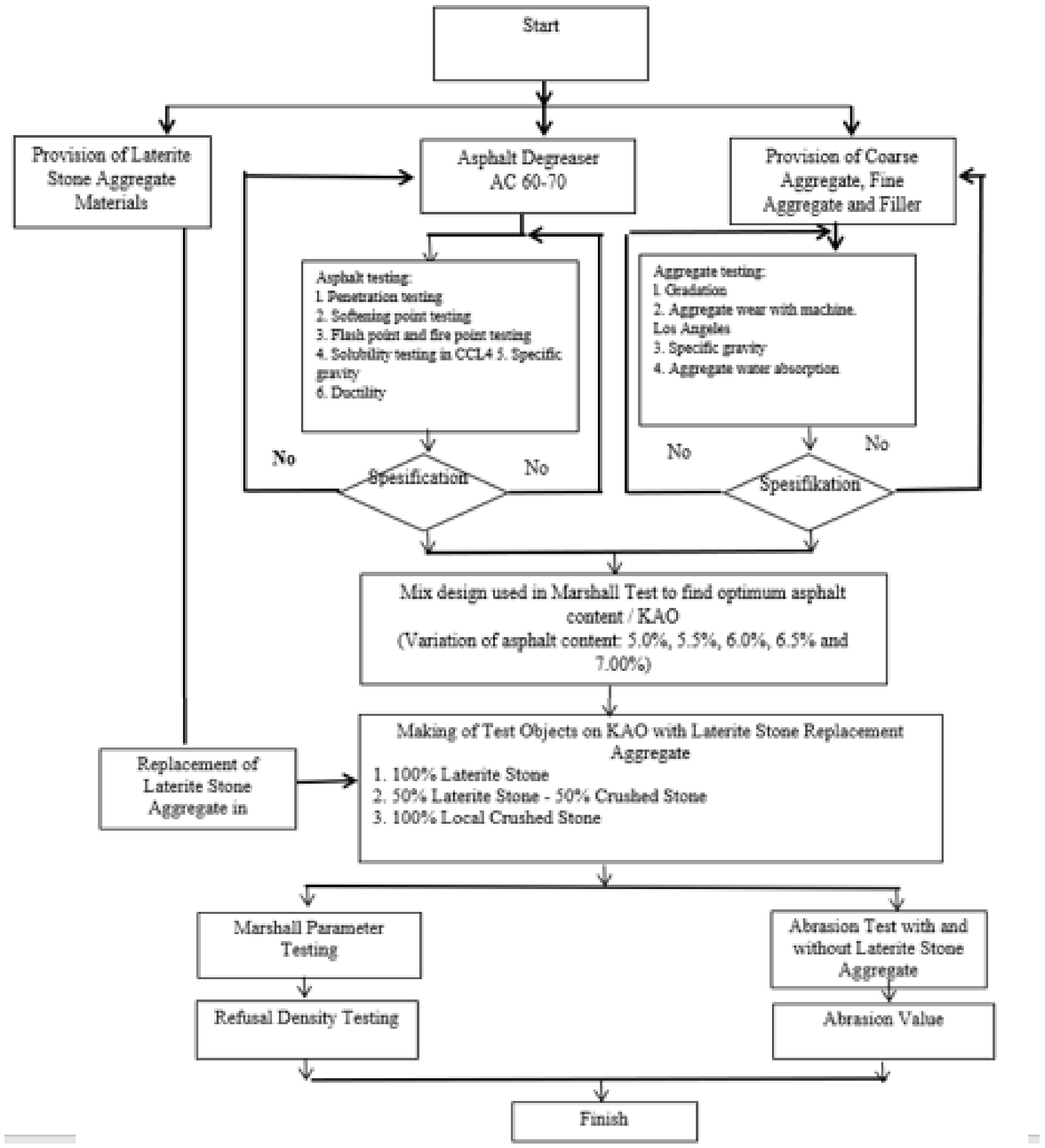

Figure 8. Laboratory Research Flowchart

RESULTS AND DISCUSSION

In this study, the materials used have gone through a series of laboratory tests at the Faculty of Engineering, Department of Civil Engineering, Syiah Kuala University, Banda Aceh. The tests include the Marshall Standard Test which aims to determine the stability and melting of the asphalt mixture. Then there is the refusal density which measures the maximum density of the mixture to assess the resistance to deformation. In addition, abrasion value testing is also carried out to evaluate the resistance of the aggregate to erosion and testing. The results of this test will be the basis for the selection and adjustment of the composition of the materials used, thus ensuring the optimal quality and durability of the planned structure.

Marshall Standard Test Results on Asphalt Mixtures with Variations in 100% Laterite Asphalt Content

Table 5. Asphalt Content Pen. 60/70 with Marshall Parameters

Marshall Characteristics							
No. Test Object	Density	VMA	VIM	VFWA	Stability	Flow	MQ
(Average)	(gr/cc)	(%)	(%)	(%)	(kg)	(mm)	(kg/mm)
A11-A13	2,099	15,86	5,71	64,09	1.561,2	3,4	463,25
A21-A23	2,102	16,18	5,01	69,10	1.754,8	3,9	455,19
A31-A33	2,096	16,85	4,70	72,16	2.213,5	4,7	477,7
A41-A43	2,104	16,98	3,77	78,41	2.083,1	4,9	433,94
A51-A53	2,112	17,12	2,83	83,53	1.380,3	6,5	220,61
Optimum Asphalt Content (KAO) 5.90%							

Marshall testing is a standard method to evaluate the performance of asphalt mixtures by measuring various parameters, such as density, Volume of Voids in Mineral Aggregate (VMA), Volume of Voids in Mix (VIM), Void Filled with Asphalt (VFWA), stability, flow, and Marshall Quotient (MQ). Based on the data provided, we can analyze the various characteristics of five sets of test specimens identified as A11-A13, A21-A23, A31-A33, A41-A43, and A51-A53. Each set of test specimens has an average value for each parameter measured. The first set (A11-A13) shows a density of 2.099 gr/cc with a VMA of 15.86% and a VIM of 5.71%. The VFWA value is 64.09%, indicating the pore volume filled by asphalt, and the stability achieved is 1,561.2 kg. The flow recorded was 3.4 mm, indicating plastic deformation occurred before failure. The MQ for this set was 463.25 kg/mm, indicating the strength and stiffness of the mixture to deformation.

In the second set (A21-A23), there was a slight increase in density to 2.102 gr/cc with VMA also increasing to 16.18%. The VIM decreased to 5.01%, indicating that the mixture was denser with fewer pores. The VFWA value increased to 69.10%, indicating that more pore volume was filled by asphalt, increasing cohesion in the mixture. Stability increased significantly to 1,754.8 kg, followed by flow of 3.9 mm. The MQ for this set decreased slightly to 455.19 kg/mm compared to the first set, indicating that the mixture was more resistant to deformation although slightly more elastic.

The third set (A31-A33) showed even better characteristics with a density of 2.096 gr/cc, a VMA of 16.85%, and a lower VIM of 4.70%. VFWA increased to 72.16%, indicating more pores filled with asphalt. Stability increased significantly to 2,213.5 kg, and a higher flow of 4.7 mm indicated that the mix was able to withstand higher loads with more significant deformation. The MQ for this set was 477.7 kg/mm, indicating a balance between strength and flexibility. The fourth set (A41-A43) had a density of 2.104 gr/cc, with a VMA of 16.98% and an even lower VIM of 3.77%. VFWA increased to 78.41%, indicating that almost all pores were filled with asphalt, providing increased cohesion in the mix. Stability decreased slightly to 2,083.1 kg, with a higher flow of 4.9 mm. MQ decreased to 433.94 kg/mm, indicating that although this mixture is quite strong, it is more elastic than the previous set.

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The fifth set (A51-A53) showed the highest density at 2.112 gr/cc and the highest VMA at 17.12%. VIM decreased significantly to 2.83%, indicating that this mixture is very dense with very few pores. VFWA reached 83.53%, which almost covered all the pores by asphalt, indicating a very high level of cohesion. However, stability decreased drastically to 1,380.3 kg and flow increased sharply to 6.5 mm, indicating that this mixture is more elastic and more susceptible to plastic deformation. MQ decreased drastically to 220.61 kg/mm, indicating that although this mixture is very cohesive, it is very elastic and less resistant to heavy loads.

Relationship Between Asphalt Content Pen. 60/70 With Marshall Parameters 100% Laterite

Relationship Between Stability and Asphalt Content

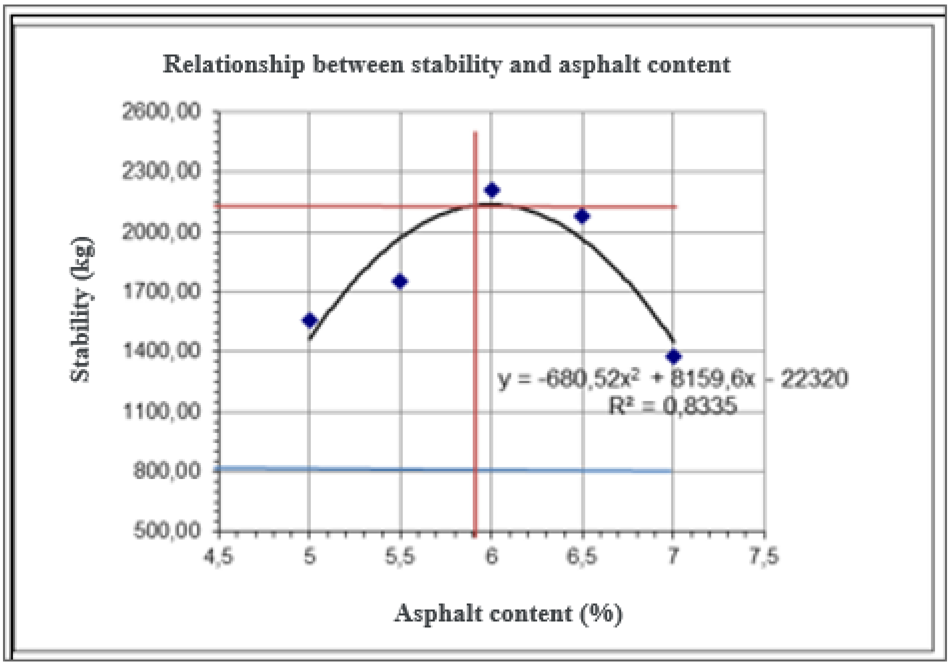

Figure 9. Graph of the relationship between stability and asphalt content

The relationship between asphalt mixture stability and asphalt content at 7.0% with 60/70 penetration shows a significant trend. Based on data from five groups of test specimens (A11-A13 to A51-A53), it can be seen that the addition of asphalt content can generally increase the stability of the mixture to a certain optimal point. For example, in the A31-A33 set which has the highest stability of 2,213.5 kg, the asphalt content is close to the optimal value where the mixture has a very strong bond between the aggregate and asphalt, so that it can withstand deformation well. Further addition of asphalt content as seen in the A51-A53 set with a stability of 1,380.3 kg, actually causes a decrease in stability. This is because excess asphalt fills the pores in the mixture, reduces friction between aggregates, and increases the possibility of plastic deformation. In this condition, the mixture becomes too flexible and is unable to withstand loads well. The decreasing stability in the A51-A53 set emphasizes the importance of maintaining asphalt content at an optimal level to achieve a balance between the strength and flexibility of the mixture. Asphalt with 60/70 penetration has medium viscosity characteristics, which are ideal for achieving this balance at an asphalt content of 7.0%. However, if the asphalt content exceeds the optimal limit, this viscosity can actually cause the mixture to become too soft and less stable. The coefficient obtained with an R2 value of 0.8335 shows that there is a strong relationship between the asphalt content and the stability of the mixture measured. This means that changes in asphalt content have a significant impact on the stability of the mixture, and the model built based on this data is accurate enough to predict stability based on the asphalt content used.

Relationship between Flow and Asphalt Content

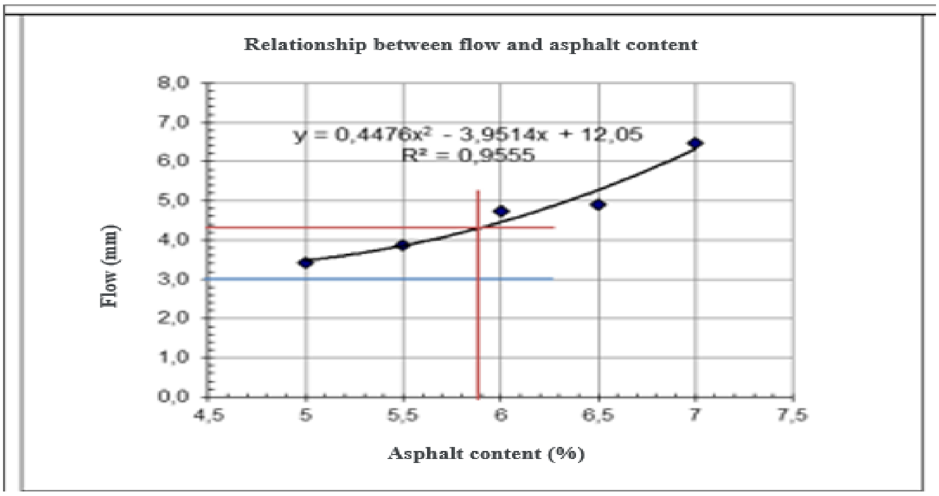

Figure 10. Flow relationship graph with asphalt content

Based on data obtained from five groups of test specimens (A11-A13 to A51-A53), there is a significant relationship between flow value and asphalt content at 7.0% with 60/70 penetration in the Marshall test. The data shows that the flow value increases with increasing asphalt content. The first set (A11-A13) recorded a flow of 3.4 mm, indicating low plastic deformation. With increasing asphalt content, the flow also increased, reaching 6.5 mm in the fifth set (A51-A53), indicating that the mixture became softer and experienced greater deformation when subjected to load. This increase in flow value reflects that mixtures with higher asphalt content tend to be more plastic and more easily deformed. This can be interpreted as a sign that the mixture becomes more flexible and less resistant to heavy loads. The lower flow value in the first set indicates a mixture that is strong enough to withstand deformation well, providing a balance between strength and flexibility. On the other hand, high flow values in the A51-A53 set indicate that the mixture is too soft, which can be risky for significant deformation and long-term structural failure. The coefficient of determination (R2) of 0.9555 indicates that there is a very strong relationship between flow values and asphalt content in the asphalt mixture. In this context, R2 is used to measure how well asphalt content can explain the variability of flow values in the model. An R2 value close to 1 indicates that the model is very effective in predicting flow values based on the asphalt content used.

Relationship between VMA and Asphalt Content

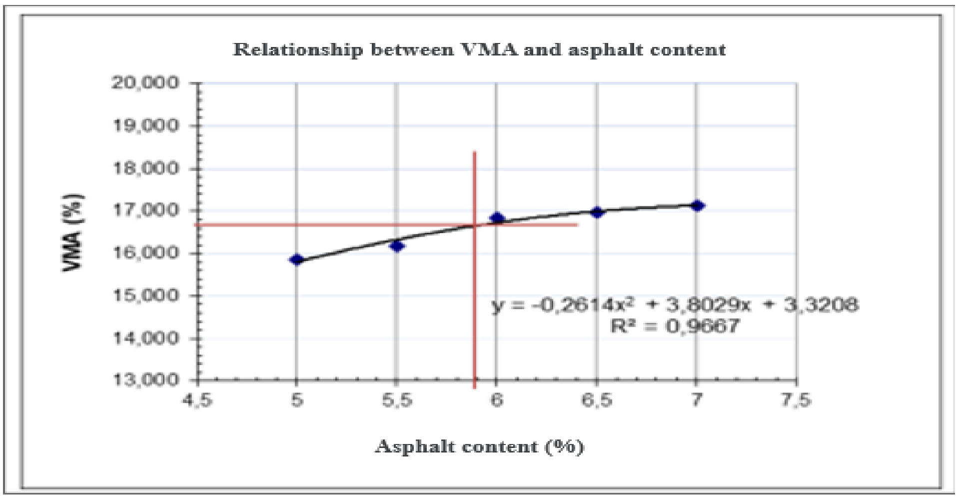

Figure 11. Graph of the relationship between VMA and asphalt content

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Based on data from five groups of test specimens (A11-A13 to A51-A53), it can be seen that there is a close relationship between the Voids in Mineral Aggregate (VMA) value and asphalt content at 7.0% with 60/70 penetration in the Marshall test. VMA is a measure of the percentage of void volume in mineral aggregates available to be filled by asphalt and air after the aggregate is compacted. The data show an increase in VMA from 15.86% in the first group (A11-A13) to 17.12% in the fifth group (A51-A53). This increase reflects that along with the addition of asphalt content, the volume of voids in the aggregate filled by asphalt also increases, which produces a mixture that is more flexible and able to withstand deformation well. Higher asphalt content causes more space between aggregates to be filled, thereby increasing the VMA value. This shows a positive correlation between asphalt content and VMA, where increasing asphalt content contributes to increasing VMA which reflects more space in the aggregate to accommodate asphalt. This condition is important to ensure that the asphalt mixture has enough space to accommodate asphalt, which can increase flexibility and resistance to traffic loads and weather changes. Asphalt with 60/70 penetration at 7.0% asphalt content provides the right balance to fill the space in the aggregate, maintaining flexibility without sacrificing the structural strength of the mixture. However, if the asphalt content is too high, the risk of deformation and instability of the mixture can increase because excess asphalt can cause the mixture to become too soft. The results of the R2 value of 0.9667, the relationship between asphalt content and VMA shows a very strong linear correlation. Increasing asphalt content causes an almost proportional increase in VMA, indicating that asphalt significantly affects the volume of voids in the aggregate. Thus, this model is very valid for use in predicting VMA values based on the asphalt content used in the mixture.

Relationship between MQ and Asphalt Content

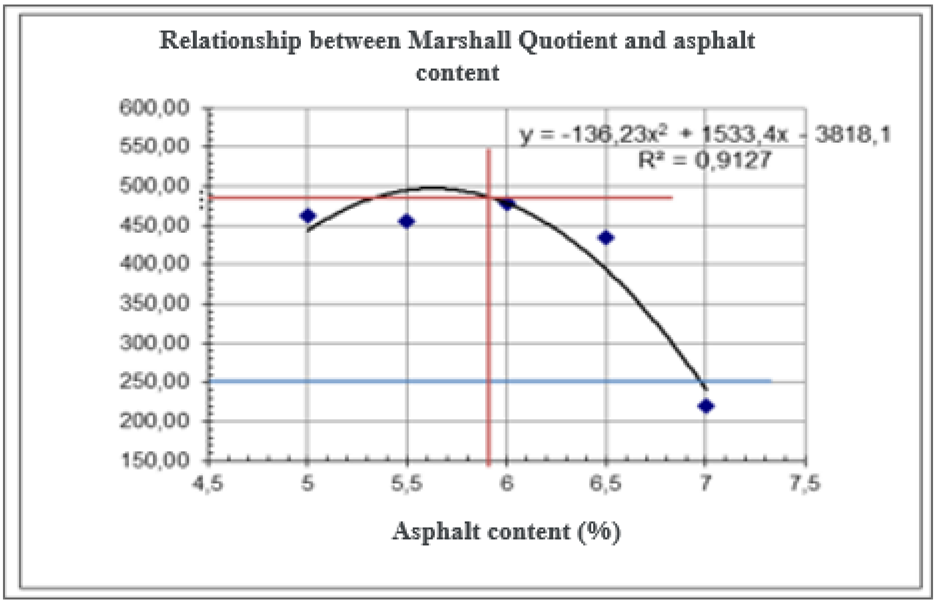

Figure 12. Graph of the relationship between MQ and asphalt content

In the analysis of asphalt mixtures, the MQ (Marshall Quentient) parameter is very important because it indicates the stiffness of the mixture. From the test data, it can be seen that the MQ value varies depending on the asphalt content in the mixture. The MQ value on test specimen numbers A11-A13 is 463.25 kg/mm, while in A51-A53 it is only 220.61 kg/mm. Although not always linear, generally increasing asphalt content tends to increase the MQ value. This shows that mixtures with higher asphalt content have greater stiffness, because more asphalt makes the mixture stiffer. However, this relationship can be influenced by other factors such as the composition of additional materials in the asphalt mixture. The R2 value obtained from the relationship between MQ and asphalt content R2 0.9127 or around 91.27% of MQ variability can be explained by the asphalt content in the observed data. This shows that the relationship between the two variables (MQ and asphalt content) is relatively strong, with high asphalt content tending to cause consistently higher MQ values.

Relationship between VIM and Asphalt Content

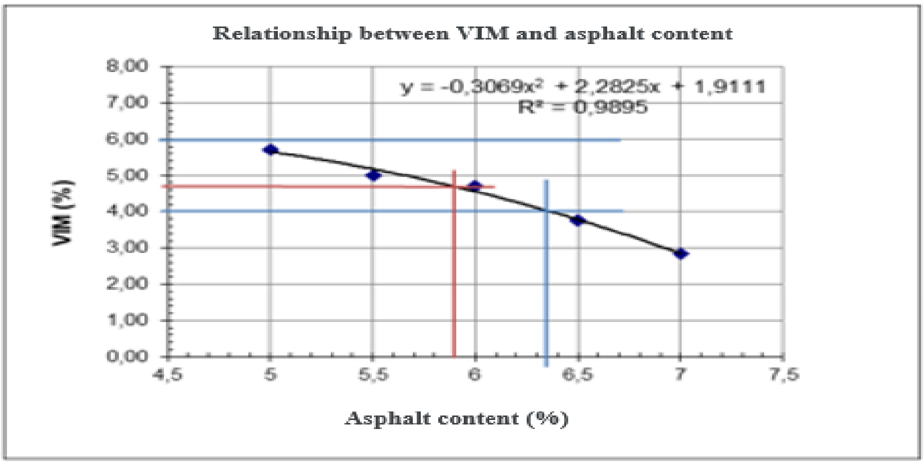

Figure 13. Relationship graph of VIM with asphalt content

In the analysis of asphalt mixtures, the relationship between VIM (Voids in Mineral Aggregate) and asphalt content is very significant. Based on the average data for various test samples (A11-A13, A21-A23, A31-A33, A41-A43, A51-A53), it can be observed that VIM shows a decreasing trend with increasing asphalt content, which in this case is 7.0 PEN60/70. Specifically, the VIM value for each sample decreases gradually from 5.71% in A11-A13 to 2.83% in A51-A53. This indicates that the higher the asphalt content in the mixture, the fewer voids are formed between the mineral aggregates. These voids, or VIM, are important parameters that affect the strength and density of asphalt mixtures. This pattern reflects the effective control of the internal structure of the asphalt mixture by the asphalt content. By reducing the amount of VIM, the asphalt mixture can improve its resistance to deformation and its structural ability. The R2 coefficient of 0.9895 obtained in the relationship between VIM (Voids in Mineral Aggregate) and asphalt content indicates that the relationship between the two variables is very strong and reliable. This indicates that the decrease in VIM observed with increasing asphalt content (7.0 PEN60/70) can be substantially explained by the model used. Thus, the use of higher asphalt content in asphalt mixtures tends to consistently result in a decrease in VIM, thus optimizing the strength and resistance of the mixture to service conditions.

Relationship of VFWA with Asphalt Content

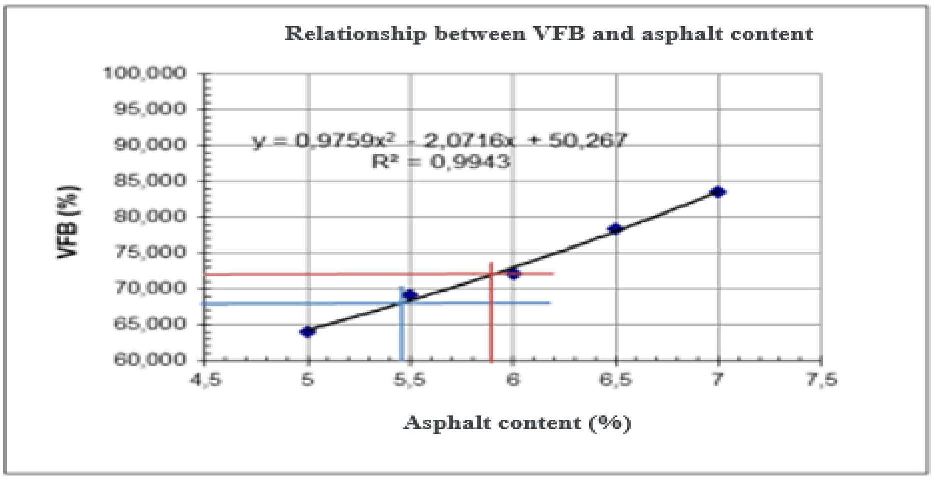

Figure 14. Relationship graph of VFWA with asphalt content

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In the analysis of asphalt mixtures, the relationship between VFWA (Voids Filled with Asphalt) and asphalt content becomes very relevant. Based on the average data given for the test samples (A11-A13, A21-A23, A31-A33, A41-A43, A51-A53), it can be seen that VFWA shows a consistent tendency to increase with the increase of asphalt content, which in this case is 7.0 PEN60/70. Specifically, the VFWA value of each sample shows a gradual increase: from 64.09% in A11-A13 to 83.53% in A51-A53. This indicates that the higher the asphalt content in the mixture, the more voids in the mixture are successfully filled with asphalt. This higher filling rate can increase the density of the asphalt mixture and improve its structural performance. This pattern reflects the effective control exerted by the asphalt content on the internal structure of the asphalt mixture. By increasing VFWA, the asphalt mixture can optimize its bearing capacity against traffic loads and extend its service life. The R2 coefficient of 0.9943 obtained from the relationship between VFWA (Voids Filled with Asphalt) and asphalt content shows that the relationship between the two variables is very strong and very reliable, indicating that about 99.43% of the VFWA variability can be explained by the asphalt content in the observed data. Increasing the asphalt content (in this case, 7.0 PEN60/70) consistently contributed to the increase in VFWA values in the tested asphalt mixtures. The use of higher asphalt content tends to result in more effective filling of voids in the mixture with asphalt, which can increase the strength and durability of the mixture against various environmental and traffic conditions.

Relationship of Density with Asphalt Content

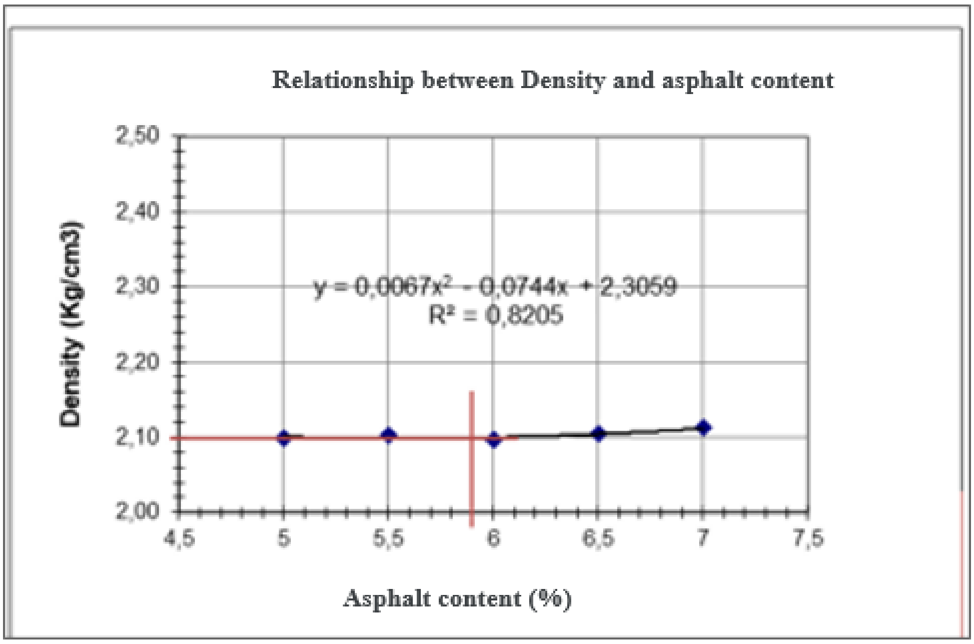

Figure 15. Density relationship graph with asphalt content

The density of the asphalt mixture varies from 2.096 gr/cc to 2.112 gr/cc, with the highest value recorded in samples A51-A53 and the lowest value in samples A31-A33. Although the asphalt content is kept constant at 7.0 PEN60/70, this difference reflects the influence of other mixtures that affect the final density. In general, increasing the asphalt content in the asphalt mixture tends to increase the density, indicating a denser and stronger mixture. High density is an important indicator of road resistance to traffic loads and environmental conditions, and can affect the service life of the road.

Optimum Asphalt Content (OAC)

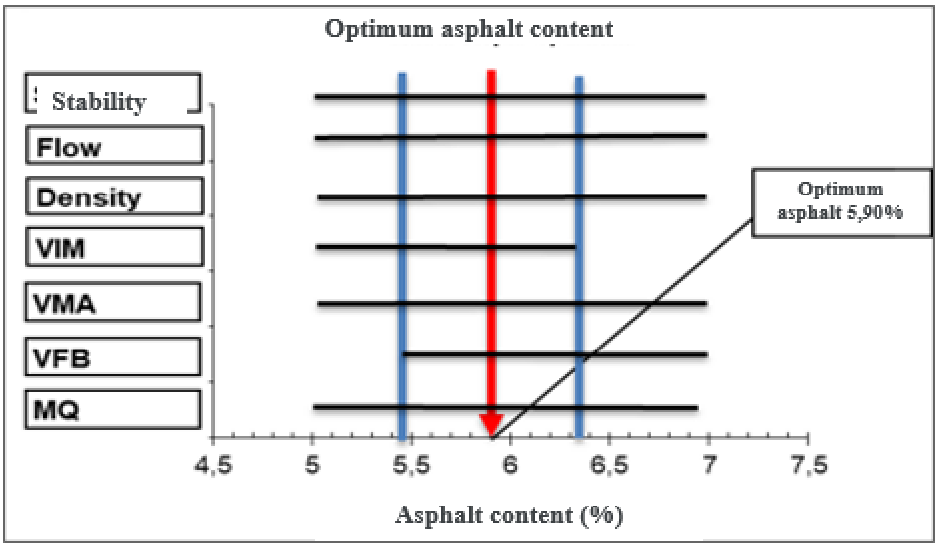

Figure 16. Optimum asphalt content (OAC) graph

At an optimum asphalt content of 5.90%, the asphalt mixture achieved a stability of 1850.0 kg. This stability indicates that the mixture has good resistance to traffic loads. A high stability value like this indicates that the asphalt mixture is able to withstand deformation and has a high enough bearing capacity to be used on road pavements. The flow or plastic deformation measured on the mixture was 5.3 mm. This flow value indicates that the asphalt mixture has a deformation ability that is still within acceptable limits, indicating a balanced mixture between stiffness and flexibility. This is important to prevent cracks in the road surface under repeated traffic loads. The Marshall Quotient (MQ) of 355 kg/mm indicates a balance between stability and flow, reflecting a good combination of strength and flexibility of the asphalt mixture. A higher MQ value is usually desirable because it indicates that the mixture is more resistant to plastic deformation that occurs under load. Porosity or Volume of Air Voids (VIM) was recorded at 4.7%. This VIM is within the desired range for road pavements, indicating that the mixture has enough air voids to allow for slight thermal expansion and deformation, but not so much that it can cause a decrease in structural performance. The Volume of Voids in Mineral Aggregate (VMA) of 17.3% indicates the total amount of void volume in the asphalt mixture that is filled by asphalt and air. A higher VMA usually indicates that there is sufficient space for the asphalt needed to properly bond the aggregate, increasing the resistance of the mixture to deformation and damage. The Volume of Voids Filled with Asphalt (VFWA) of 72% indicates the proportion of the aggregate void volume that has been filled by asphalt. This indicates that most of the voids are filled by asphalt, which is good for water resistance and deformation, ensuring better performance of the asphalt mixture in the long term. The density of the mixture reached 2.09 kg/cm^3, indicating a good asphalt mixture density. Optimal density helps ensure the structural strength and stability of the mixture, which is essential to support repeated and heavy traffic loads. Overall, these data indicate that the asphalt mixture with an optimum asphalt content of 5.90% has balanced mechanical and physical characteristics and is in accordance with the desired technical specifications for road pavement construction. The combination of high stability, controlled deformation, and good density indicates that this mixture will perform well in real field use.

Marshall Standard Test Results on HRA Mixtures with Variations in Asphalt Content of 50% Laterite - 50% Crushed Stone

Table 6. Asphalt Content Pen. 60/70 with Marshall Parameters

Marshall Characteristics							
No. Test Object	Density	VMA	VIM	VFWA	Stability	Flow	MQ
(Average)	(gr/cc)	(%)	(%)	(%)	(kg)	(mm)	(kg/mm)

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A11-A13	2,159	16,55	6,12	63,01	1.275,1	3,5	364,04
A21-A23	2,157	17,08	5,62	67,10	1.321,4	3,6	382,68
A31-A33	2,158	17,49	4,98	71,62	1.472,9	3,8	428,65
A41-A43	2,163	17,70	4,12	76,87	1.334,0	4,5	349,27
A51-A53	2,157	18,38	3,79	79,36	1.123,6	5,0	256,51
Optimum Asphalt Content (KAO) 6,15%							

Marshall asphalt mixture with a composition of 50% laterite and 50% crushed stone showed adequate characteristics based on the test data provided. With an average density value between 2.159 g/cc to 2.163 g/cc, this mixture showed sufficient density to withstand traffic loads. VMA values ranged from 16.55% to 18.38%, indicating sufficient void space for interlocking of aggregate and asphalt. VFA, which ranged from 63.01% to 79.36%, indicated that asphalt was able to fill the void space between aggregates well, which is important for the stability of the mixture. The stability of the mixture, which varied from 1,123.6 kg to 1,472.9 kg, indicated the ability of the mixture to withstand shear forces. Flow values, which ranged from 3.5 mm to 5.0 mm, indicated sufficient deformability during the forming process. Marshall Quotient (MQ) of the mixture, which is in the range of 256.51 kg/mm to 428.65 kg/mm, reflects a balanced comparison between its stability and deformability.

Relationship of Asphalt Content Pen. 60/70 With Marshall Parameters 50% Laterite - 50% Crushed Stone

Relationship of Stability with Asphalt Content

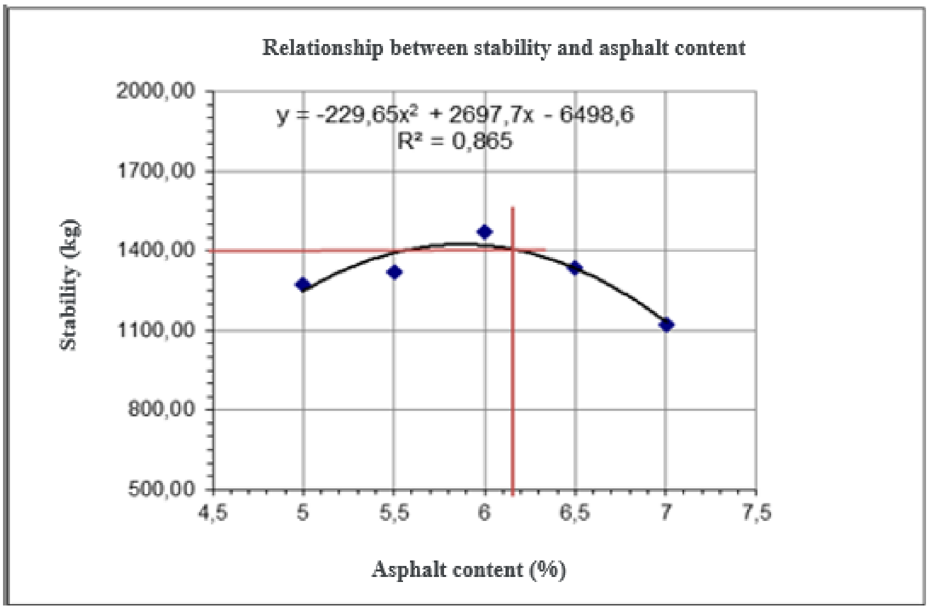

Figure 17. Stability relationship graph with asphalt content

In the analysis of the relationship between asphalt mixture stability and asphalt content, the data shows that the higher the asphalt content, the stability of the mixture tends to increase. The data presented shows that in the case of A31-A33, with a higher asphalt content (1,472.9), the stability reaches 1,472.9 kg, the highest among all measurements. On the other hand, in the case of A51-A53 with a lower asphalt content (1,123.6), the stability decreases to 1,123.6 kg. This pattern shows a general trend where increasing asphalt content tends to contribute positively to the stability of the asphalt mixture. The relationship between stability and asphalt content shows a mathematical model that can be described by the quadratic equation y = -229.65x^2 + 2697.7x - 6498.6, with a coefficient of determination R2 = 0.865. The high R2 value indicates that about 86.5% of the variability in asphalt mixture stability can be explained by the asphalt content used in the mixture.

Relationship between Flow and Asphalt Content

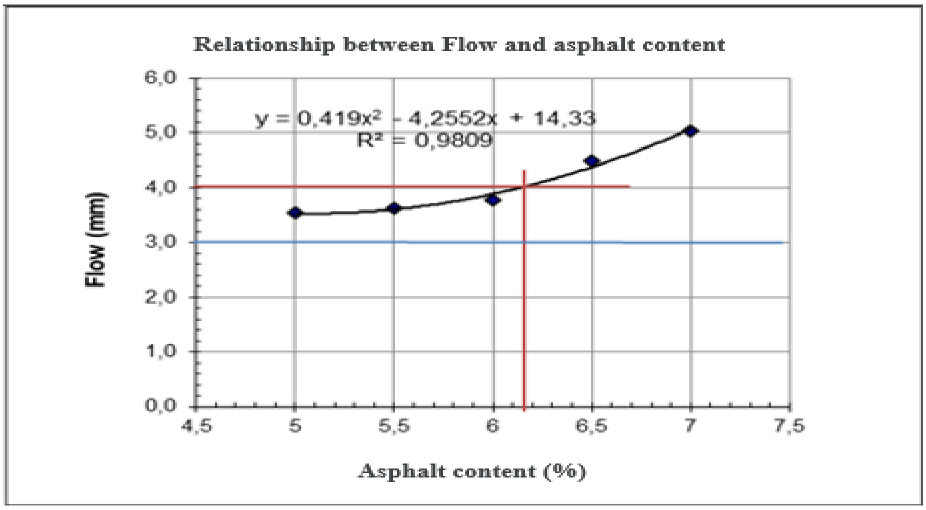

Figure 18. Flow relationship graph with asphalt content

Based on the analysis of the relationship between the flow properties of the asphalt mixture and the asphalt content, the data shows that there is a tendency for the flow value to increase with increasing asphalt content. In the A11-A13 test with an asphalt content of 7.0 pen 60/70, the flow value was 3.5 mm. However, in the A51-A53 test with a higher asphalt content, namely 7.0 pen 60/70, the flow value increased to 5.0 mm. This shows that the higher the asphalt content in the mixture, the higher the observed flow value. This phenomenon can be explained by the rheological properties of asphalt which change with increasing asphalt content. Higher asphalt content tends to produce a softer or more plastic asphalt mixture, which in turn increases the flow value. This relationship is important in asphalt mixture design because flow is an important indicator of the mixture's ability to flow and adapt to different road surfaces and traffic loads. The relationship between flow and asphalt content shows y = 0.419x2 − 4.2552x + 14.33 and with a coefficient of determination R2 = 0.9809 it can be concluded that the relationship between asphalt mixture flow and asphalt content is very strong and well defined. The high coefficient of determination indicates that about 98.09% of the variability in asphalt mixture flow can be explained by the asphalt content used in the mixture indicating a significant correlation between these two relationships. This equation provides a clear picture of how the asphalt mixture flow will react to changes in asphalt content.

Relationship between VMA and Asphalt Content

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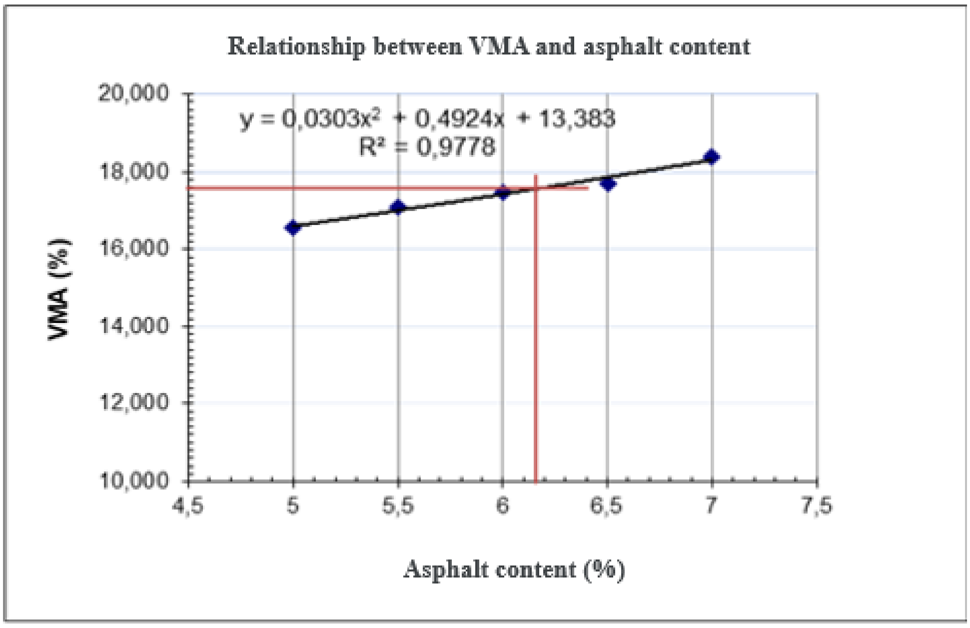

Figure 19. Graph of the relationship between VMA and asphalt content

Based on the results of the analysis of the relationship between Voids in Mineral Aggregate (VMA) and asphalt content in the asphalt mixture, the data shows an interesting trend. In the A11-A13 test with an asphalt content of 7.0 pen 60/70, the VMA value was 16.55%. Consistently, the VMA value increased along with the increase in asphalt content in the A21-A23 test (17.08%), A31-A33 (17.49%), A41-A43 (17.70%), and A51-A53 (18.38%). This indicates that the higher the asphalt content, the greater the VMA recorded in the asphalt mixture. This phenomenon can be explained by the mechanical properties of the asphalt mixture which are influenced by the asphalt content. Higher asphalt content tends to produce a more homogeneous and denser mixture, which can result in an increase in the percentage of air space (voids) available between the aggregates. This reflects the increase in VMA, which practically indicates the volume of unfilled air in the asphalt mixture. The results of the R2 coefficient show the relationship between VMA and asphalt content y = 0.0303x2 + 0.4924x + 13.383 and with the determination coefficient value of R2 = 0.9778 it can be concluded that the relationship between VMA (Void in Mineral Aggregate) and asphalt content (x) is quadratic. The high determination coefficient indicates that about 97.78% of the variability in VMA can be explained by the asphalt content used in the mixture. The quadratic equation provides an overview of how VMA will react to changes in asphalt content. When the asphalt content is increased or decreased, VMA will change according to the pattern described by the equation.

Marshall Quantient Relationship with Asphalt Content

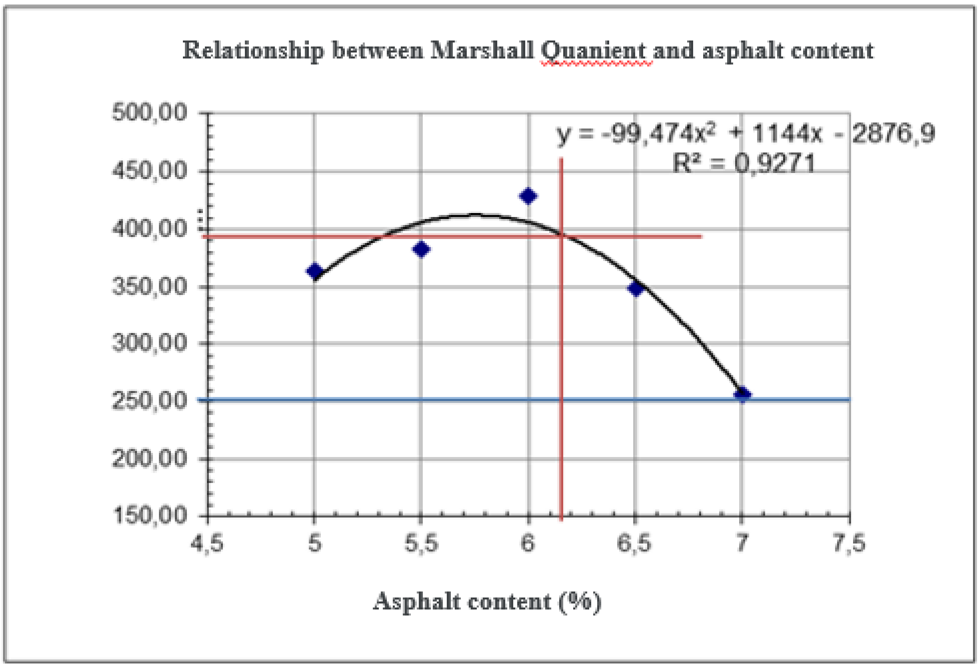

Figure 20. Graph of the relationship between quantient and asphalt content

Based on the analysis of the relationship between Marshall Quotient (MQ) and asphalt content in the asphalt mixture, the data shows a significant variation in the MQ value along with changes in asphalt content. In the A11-A13 test with an asphalt content of 7.0 pen 60/70, the MQ value was 364.04 kg/mm. The A21-A23 test showed an increase in the MQ value to 382.68 kg/mm, indicating that the addition of higher asphalt content resulted in an increase in MQ. This phenomenon is largely thought to be due to the increase in the stability of the asphalt mixture produced by the increase in asphalt content. However, in the A41-A43 and A51-A53 tests, the MQ value decreased again to 349.27 kg/mm and 256.51 kg/mm respectively, although the asphalt content remained at 7.0 pen 60/70. This shows that the relationship between MQ and asphalt content may not always be linear and can be influenced by various other factors such as aggregate grain distribution, mixture composition, and mixing method. The results of the determination coefficient test also show that the relationship between quantient and asphalt content Y = −99.47X2 + 1144X − 2876.9 with a determination coefficient value of R2 = 0.9933 the relationship between quantient in the asphalt mixture and asphalt content is quadratic. This equation shows that changes in asphalt content can have a significant impact on quantients that follow a parabolic pattern or a downward open curve determined by the negative X2 coefficient. The high determination coefficient of 0.9933 indicates that about 99.33% of the variability in quantient can be explained by the asphalt content used in the asphalt mixture. This confirms that this quadratic equation can be used effectively to model and predict quantient responses to variations in asphalt content.

Relationship of VIM with Asphalt Content

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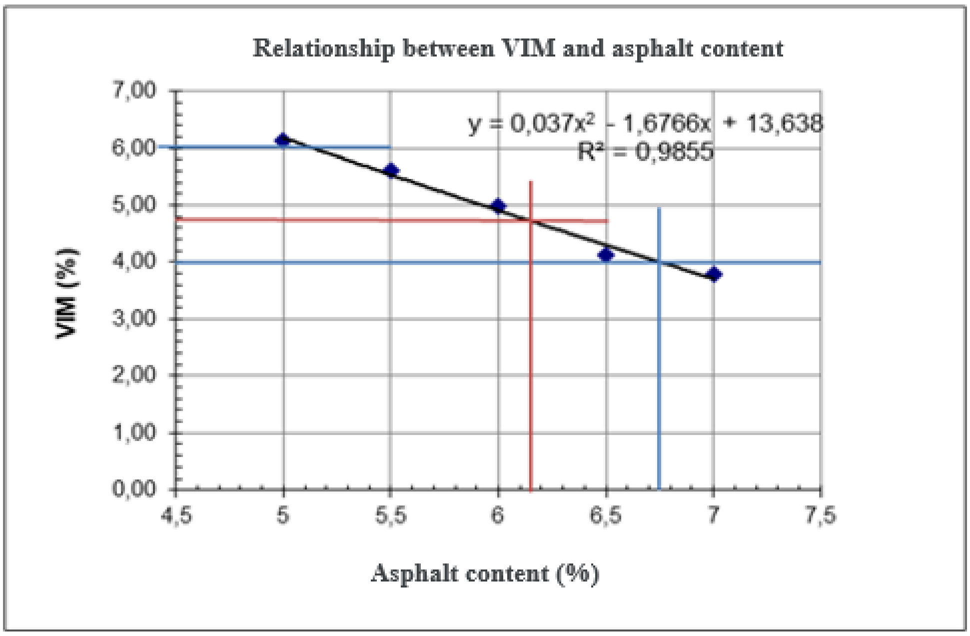

Figure 21. Graph of the relationship between VIM and asphalt content

Based on the results of the analysis of the relationship between Voids in Mix (VIM) and asphalt content in the asphalt mixture, the data shows a consistent decreasing pattern in VIM values along with increasing asphalt content. In the A11-A13 test with an asphalt content of 7.0 pen 60/70, the VIM value was 6.12%. Gradually, the VIM value decreased to 5.62% in the A21-A23 test, then to 4.98% in A31-A33, 4.12% in A41-A43, and finally to 3.79% in A51-A53, all with the same asphalt content. The decrease in VIM value with increasing asphalt content indicates that the asphalt mixture tends to become denser or contains less air space (voids) when the asphalt content is increased. This can be attributed to the effect of better binding between the binder (asphalt) and aggregate in the mixture, thereby reducing the amount of available air space. The results of the determination coefficient test of the relationship between VIM and asphalt content show that Y = 0.037X2 − 1.6766X + 13.638 with R2 = 0.9855 the relationship between the Volume of Immovable Materials (VIM) in the asphalt mixture and the asphalt content is quadratic. This equation indicates that the effect of asphalt content on VIM is not linear, but follows a parabolic pattern or an upward open curve, which is determined by the positive X2 coefficient. The high determination coefficient of 0.9855 indicates that about 98.55% of the variability in VIM can be explained by the asphalt content used in the asphalt mixture.

Relationship of VFWA with Asphalt Content

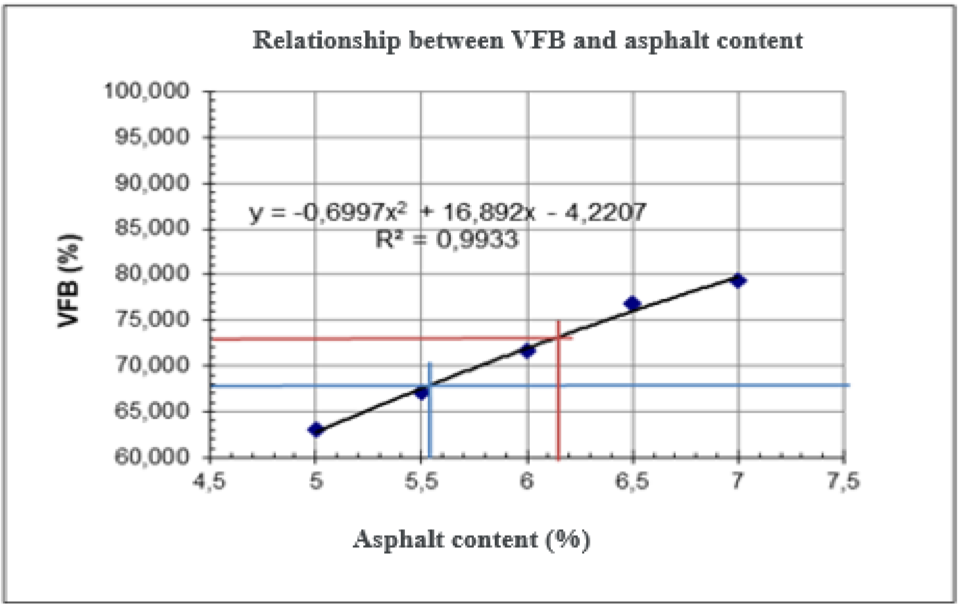

Figure 22. Graph of the relationship between VFWA and asphalt content

Based on the results of the analysis of the relationship between Voids Filled with Asphalt (VFWA) and asphalt content in the asphalt mixture, the data shows a consistent increase in the percentage of VFWA along with the increase in asphalt content. In the A11-A13 test with an asphalt content of 7.0 pen 60/70, the percentage of VFWA was 63.01%. In the next test, A21-A23, the VFWA value increased to 67.10%, and continued to increase in A31-A33 (71.62%), A41-A43 (76.87%), and reached 79.36% in A51-A53, all with a constant asphalt content. The increase in the VFWA value with a higher asphalt content reflects that the asphalt mixture is filled with more asphalt, reducing the air space filled by the binder (asphalt). This can indicate an increase in cohesion between the binder and aggregate in the mixture, which is important for increasing the structural strength and resistance to deformation of the asphalt mixture. The results of the determination coefficient also show the relationship between VFB and asphalt content $Y = -0.6997X2 + 16.892X - 4.2207$ with a determination coefficient value of $R2 = 0.9933$, it can be concluded that the relationship between the Volume of Fine Aggregate (VFB) in the asphalt mixture and asphalt content (X) is quadratic. This equation shows that changes in asphalt content can have a significant effect on VFB in the form of a parabolic pattern or a downward open curve which is clarified by the negative value of the X2 coefficient. The high determination coefficient, which is 0.9933, indicates that about 99.33% of the variability in VFB can be explained by asphalt content.

Relationship of Density with Asphalt Content

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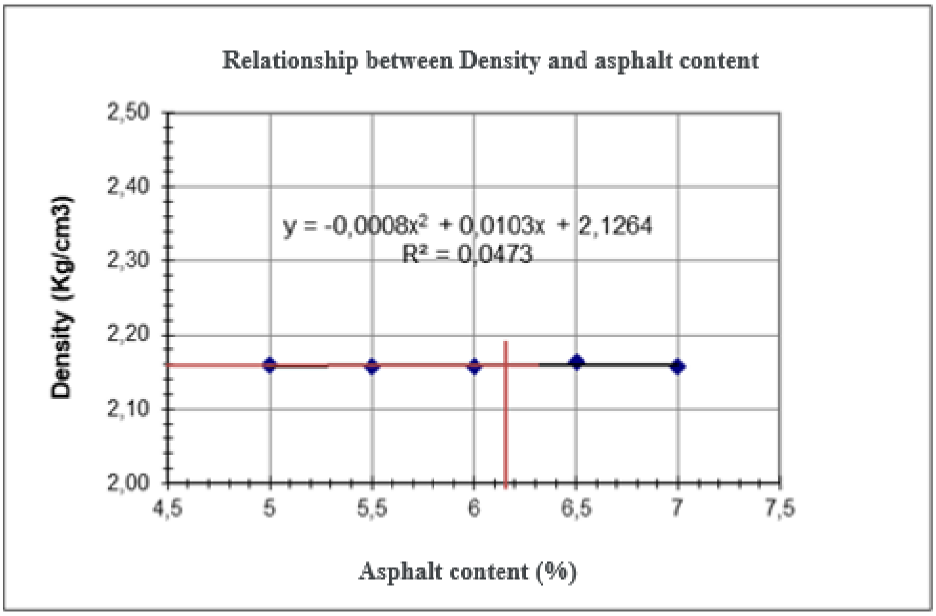

Figure 23. Graph of the relationship between density and asphalt content

Based on the results of the analysis of the relationship between density and asphalt content, the data shows a small variation in density values along with changes in asphalt content. In the A11-A13 test with an asphalt content of 7.0 pen 60/70, the average density was 2.159 gr/cc. The density value remained stable or only varied slightly in subsequent tests, namely 2.157 gr/cc for A21-A23 and A51-A53, and 2.158 gr/cc for A31-A33. However, there was a small increase in the A41-A43 test, where the density reached 2.163 gr/cc. The small increase in density in the A41-A43 test may be related to a more even distribution of the binder (asphalt) or better aggregate density in the mixture. In general, a high asphalt mixture density indicates a denser mixture and the potential to provide better structural performance and resistance to deformation. The results of the R2 coefficient of the relationship between density and asphalt content show that Y = −0.0008X2 + 0.0103X + 2.1264 with a determination coefficient value of R2 = 0.0473, it can be concluded that the relationship between density in the asphalt mixture and asphalt content is quadratic. This equation shows that changes in asphalt content can affect the density of the asphalt mixture non-linearly with a pattern that is clarified by the negative X2 coefficient. However, the low determination coefficient value of 0.0473 indicates that only about 4.73% of the variability in density can be explained by asphalt content. This indicates that this equation may not be accurate enough or there may be other factors that have a significant influence on the density of the asphalt mixture other than asphalt content. In an applied context, although this quadratic relationship is identified, the low R2 value indicates that in practice, there are other complexities that need to be considered in optimizing the density of the asphalt mixture. Factors such as aggregate type, mixture proportion, or mixing conditions can also play an important role in achieving the desired density for stable and durable roads.

Optimum Asphalt Content

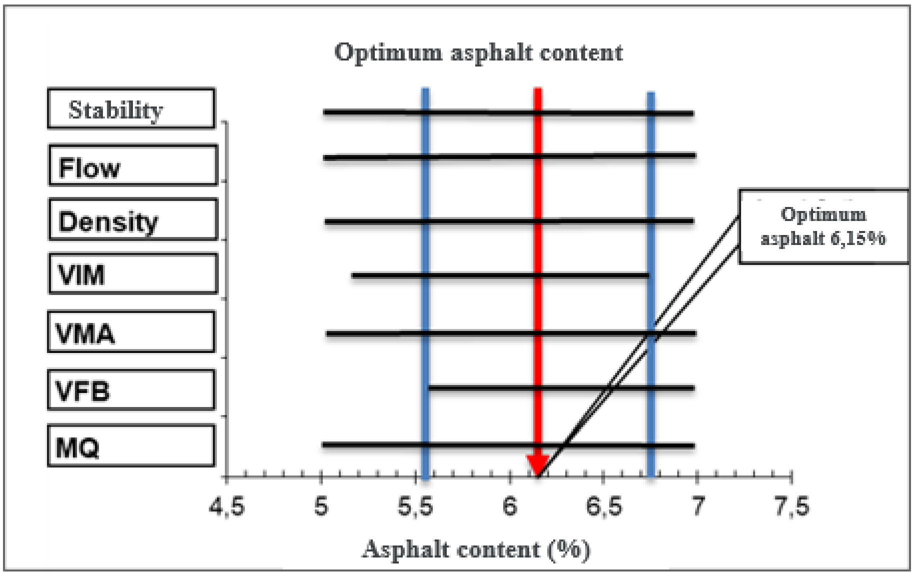

Figure 24. Optimum asphalt content graph

The optimum asphalt content analysis in asphalt mix design illustrates the point at which the mix achieves an optimal balance between various mechanical and functional properties. Based on the data provided, the optimum asphalt content is 6.15%. At this point, the asphalt mix shows a maximum stability of 14,300 kg, reflecting the mix's ability to withstand shear forces caused by traffic loads and road operational environments.

In addition, the flow or deformability of the mix at the optimum asphalt content is 4.1 mm, indicating the mix's ability to flow and adapt to the road surface well. The Marshall Quotient (MQ) at this asphalt content reaches 340 kg/mm, indicating the quality of the mix in terms of strength and stability relative to the volume weight of the mix. Simultaneously, the percentage of Voids in Mix (VIM) at the optimum asphalt content is 4.7%, while Voids in Mineral Aggregate (VMA) reaches 17.6%. The percentage of Voids Filled with Asphalt (VFWA) reaches 73%. Low VIM indicates a dense mixture with little air space filled by the binder, while a fairly large VMA indicates a sufficient aggregate volume filled with binder. High VFWA indicates the efficiency of binder use in filling the space between aggregates. The final result of the asphalt mixture density at the optimum asphalt content is 2.23 kg/cm3, indicating a good level of density. This high density is important to ensure the structural strength and resistance to deformation of the asphalt mixture under severe operational conditions.

Test Results Aggregate Wear Testing With Los Angeles Machine on Laterite Stone SNI 03-2417-1991.

Table 7. Results of abrasion testing on laterite stone

Gradation A		**Testing**	
Pass sieve		**I**	**II**
Pass	**Retained**	**Weight (a)**	**Weight (a)**
76,2 (3”)	63,5 (2 ½”)		
63,5 (2 ½”)	50,8 (2”)		
50,8 (2”)	36,1 (1 ½”)		
36,1 (1 ½”)	25,4 (1”)	1.252,9	
25,4 (1”)	19,1 (3/4”)	1.252,8	
19,1 (3/4”)	12,7 (½”)	1.255,5	
12,7 (½”)	9,52 (3/8”)	1.252,1	
9,52 (3/8”)	6,35 (¼”)		
6.35 (¼”)	4,75 (No 4)		
4,75 (No 4)	2,36 (No. 8)		

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Total Weight (a)	**5.013,3**
Weight retained on sieve No. 12 After experiment (b)	**3.652,0**

Aggregate wear testing using the Los Angeles machine is a standard method for measuring aggregate resistance to abrasion and impact. This test is very important in determining the quality of aggregates used in road and building construction, where wear-resistant aggregates will provide better performance and longer service life. Based on SNI 03-2417-1991, the test is carried out on laterite stone with gradation A to determine its wear level. In this test, laterite stone with a certain size is placed in the Los Angeles machine together with a steel ball, then rotated for a certain period of time. The test is carried out once (I) to ensure consistency of the results. The sieve sizes used vary from large sieves (76.2 mm or 3 inches) to small sieves (2.36 mm or No. 8). The initial weight of the aggregate before the test is recorded as weight a, which is 5013.3 grams. After the test, the aggregate retained on sieve No. 12 (with a hole size of 1.70 mm) is recorded as weight b, which is 3,652.0 grams. Wear is calculated using the following formula:

a. = 5.013,3 gram
b. = 3.652,0 gram

$$\text{Wear and tear} = \frac{a - b}{a} \times 100\ \% = \mathbf{27{,}2\ \%}$$

The test results showed that the wear of the laterite stone was 27.2%. This value illustrates that 27.2% of the initial weight of the aggregate was damaged or broken during the testing process. According to SNI 03-2417-1991, the wear value obtained provides an indication of the aggregate's resistance to abrasion and impact, which is an important factor in assessing the suitability of the material for use in construction. The wear value of 27.2% is within the acceptable limit for the use of aggregates in road construction and other structures, which generally requires a maximum wear of around 30-40% depending on the project specifications and the end use of the material. Laterite stone with this wear shows fairly good resistance to abrasion and impact, which means it can be used effectively in construction applications that require aggregates with high durability. Lower wear means that the aggregate is more resistant to mechanical damage, which is important to ensure the stability and durability of roads and buildings. Conversely, aggregates with higher wear may show the potential for faster degradation when exposed to heavy loads and environmental conditions, so they may be less suitable for applications that require higher durability. Based on the test results, it can be concluded that the laterite stone tested showed a wear value of 27.2% which indicates good resistance to abrasion and impact in accordance with the standards applied. This confirms that laterite stone can be a suitable material for use in construction, especially in applications that require materials with good resistance to mechanical erosion.

Specific Gravity and Water Absorption Test of Coarse Aggregate on Laterite Stone Sni 03-1969-1990

Table 8. Results of specific gravity and water absorption tests of coarse aggregate

Description	**Weight (Gram)**
Oven Dry Test Object Weight	4.021,2
Saturated Surface Dry Test Specimen Weight	4.182,4
Weight of Test Object in Water	2.369,8

Discussion of Standard Marshall Test Results on Asphalt Mixtures with Variations of 50% Laterite – 50% Crushed Stone

Table 9. Standard Marshall test results 50% laterite-50% crushed stone

Marshall Standard Test 50% Laterite – 50% Crushed Stone

Variable	Asphalt Content	Value	KAO
Density	6,5%	2,163	6,15%
VMA	7%	18,38	
VIM	5%	6,12	
VFWA	7%	79,36	
MQ	6%	428,65	
Flow	7%	5	
Stability	6%	1.472,9	

Based on the Marshall Standard test results with a mixture of 50% laterite and 50% crushed stone, the optimum asphalt content (OAC) obtained was 6.15%. At this asphalt content, the mixture showed characteristics that support good road pavement performance, although there were some differences from the 100% laterite mixture. The density of the mixture was recorded at 2.163 gr/cc at an asphalt content of 6.5%. This density is higher than the 100% laterite mixture, indicating that the combination of laterite and crushed stone produces a denser mixture and has the potential to have better structural strength, which is important for increasing resistance to deformation and traffic loads. Void In Mix (VIM) at an asphalt content of 5% was 6.12%, slightly higher than the 100% laterite mixture. A higher VIM indicates a larger void space in the mixture, which can affect the stability of the mixture. However, this value is still within the acceptable range, so that the mixture still has the flexibility needed to absorb variations in load and temperature without being damaged. Void in Mineral Aggregate (VMA) at 7% asphalt content was recorded at 18.38%, higher than the 100% laterite mixture. A higher VMA indicates that the mixture has more void spaces in the mineral aggregate, allowing for the addition of more asphalt to fill these voids. However, a high VMA must also be balanced with adequate VFWA to keep the mixture stable. Void Filled with Asphalt (VFWA), which reached 79.36% at 7% asphalt content, indicates that most of the void spaces in the aggregate have been filled by asphalt, although the percentage is lower than the 100% laterite mixture. This could indicate that this mixture has slightly lower resistance to water and air infiltration, which could affect the longevity of the road pavement. The Marshall Quotient (MQ) at 6% asphalt content was 428.65 kg/mm, indicating a lower stiffness of the mixture compared to the 100% laterite mixture. Lower MQ values may indicate that the mixture is more flexible, but may also be more susceptible to plastic deformation under heavy loads. Flow at 7% asphalt content was recorded at 5 mm, lower than the 100% laterite mixture. The lower Flow value indicates that the mixture experiences less plastic deformation when loaded, meaning that it is more stable and tends to retain its shape better. The stability of the mixture at 6% asphalt content was recorded at 1,472.9 kg, which is lower than the 100% laterite mixture. This lower stability indicates that the 50% laterite and 50% crushed stone mixture may be less able to withstand very high traffic loads, but is still adequate for use on moderately trafficked roads. Overall, it can be concluded that the mixture with 6.15% KAO consisting of 50% laterite and 50% crushed stone performed quite well, although there were some compromises compared to the 100% laterite mixture. This combination resulted in a denser mixture but with slightly lower stability and stiffness. Nevertheless, this mixture still meets the criteria for use in road pavements, especially in areas where laterite and crushed stone are available and material costs are a consideration.

Discussion of Standard Marshall Test Results on Asphalt Mixtures with 100% Crushed Stone Variations

Table 10. Standard Marshall test results of 100% crushed stone

Marshall Standard Testing 100% Broken Stone			
Variable	**Asphalt Content**	**Value**	**KAO**
Density	7%	2,232	6,2%
VMA	7%	19,04	

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VIM	5%	5,91
VFWA	7%	78,72
MQ	5%	366,78
Flow	7%	5
Stability	6%	1.329,8

Based on the Marshall Standard test results using 100% crushed stone as aggregate, the optimum asphalt content (OAC) obtained was 6.2%. At this asphalt content, the mixture showed significant characteristics for application in road pavement. Density at 7% asphalt content was recorded at 2.232 gr/cc. This density value is the highest compared to mixtures using laterite, either fully or partially. This high density indicates that the crushed stone mixture has a very dense structure, which provides superior structural strength and good resistance to deformation. Void In Mix (VIM) at 5% asphalt content was recorded at 5.91%. This VIM value is slightly lower than that of the mixture containing laterite, indicating that the crushed stone mixture has less void space. This means that this mixture tends to be more stable because fewer pores reduce the possibility of water infiltration, which can cause long-term damage. Void in Mineral Aggregate (VMA) at 7% asphalt content was 19.04%. This value indicates that the crushed stone aggregate has quite a large void space before the addition of asphalt. High VMA allows for better asphalt absorption, but also requires sufficient asphalt to fill the voids, so that the mixture does not become too brittle. Void Filled with Asphalt (VFWA) at 7% asphalt content was recorded at 78.72%, slightly lower than the other mixtures. This indicates that although the crushed stone mixture has a high VMA, the filling of voids by asphalt is slightly lower, which can reduce the resistance of the mixture to deformation due to traffic loads. The Marshall Quotient (MQ) at 5% asphalt content was recorded at 366.78 kg/mm, which is the lowest value compared to the other mixtures. The lower MQ indicates that the crushed stone mixture has lower stiffness, which can make it more susceptible to deformation when loaded. However, this value also indicates that the crushed stone mixture may have slightly more flexibility. Flow at 7% asphalt content was 5 mm, indicating the level of plastic deformation that occurs when loads are applied to the mixture. This moderate Flow value indicates that the mixture has a good balance between stiffness and flexibility, able to withstand deformation without becoming too stiff or too soft. The stability of the mixture at 6% asphalt content was recorded at 1,329.8 kg, which is the lowest value compared to other mixtures. This lower stability value indicates that the crushed stone mixture may be less able to withstand very high traffic loads, but is still adequate for roads with moderate to high traffic.

Overall, the mixture with 6.2% OAC using 100% crushed stone as aggregate showed different characteristics compared to the mixture using laterite. The high density and large VMA highlight the structural strength and good asphalt absorption ability, but the lower stability and stiffness indicate a compromise in terms of resistance to deformation under traffic loads. This mixture is still suitable for road pavement applications, especially in areas where crushed stone is abundant and a high-density mixture is required.

From this comparison, it can be concluded that the 100% laterite mixture showed superior performance in terms of stiffness, stability, and asphalt filling, making it very suitable for road pavements that require high resistance to loads. However, the 100% crushed stone mixture showed a higher density, which may be more resistant to wear. Meanwhile, a mixture of 50% laterite - 50% crushed stone offers a balance between the two with moderate characteristics, which can be an option if material availability or cost considerations are the main factors.

Discussion of Refusal Density Test Results

Table 11. Refusal density test results for Marshall HRA 100% laterite, 50% laterite-50% crushed stone

Marshall Refusal Density Testing HRA100% Laterite							
Density	**VMA**	**VIM**	**VFWA**	**MQ**	**Flow**	**Stability**	**KAO**

2,112	17,12	5,71	83,53	477,7	6,5	2.223,5	5,9

Refusal Density Test Marshall HRA 50% Laterite-50% Crushed Stone							
Density	**VMA**	**VIM**	**VFWA**	**MQ**	**Flow**	**Stability**	**KAO**
2,112	17,12	5,71	83,53	477,7	6,5	2.223,5	6,15

Refusal Density Testing Marshall HRA 100% Crushed Stone							
Density	**VMA**	**VIM**	**VFWA**	**MQ**	**Flow**	**Stability**	**KAO**
2,112	17,12	5,71	83,53	477,7	6,5	2.223,5	6,2

Based on the results of the Refusal Density Marshall test on three types of mixtures of 100% laterite, 50% laterite - 50% crushed stone, and 100% crushed stone, it can be seen that the three mixtures show very similar results in several important parameters, such as density, VMA, VIM, VFWA, MQ, Flow, and Stability. The three mixtures have the same density value, which is 2.112 gr / cc. This shows that the mixtures have the same density, regardless of the aggregate composition used. This consistent density shows that the three mixtures can produce a stable and dense structure, with equal ability to withstand traffic loads. The VMA value for all mixtures is 17.12%, indicating that the amount of empty space in the mineral aggregate before the addition of asphalt is also consistent among the three mixtures. This means that the aggregate structure in all mixtures has the same ability to absorb and retain asphalt, which is important to ensure the durability of the mixture. The VIM value is also the same for all three mixtures, which is 5.71%. This shows that the pore volume in the mixture, which reflects the void space not filled by asphalt, is consistent across all types of mixtures. A uniform VIM indicates that all mixtures have similar permeability, which is important to maintain structural stability and prevent excessive water infiltration. The VFWA value of 83.53% for all mixtures indicates that the percentage of void space filled by asphalt is the same. This indicates that the level of void filling by asphalt in all mixtures is the same, which has an impact on the ability of the mixture to withstand deformation and damage due to traffic loads. The MQ value of 477.7 kg/mm across all mixtures indicates that the stiffness or resistance of the mixture to plastic deformation is similar. With the same MQ value, the three mixtures are expected to have equivalent levels of strength and flexibility, which are important for long-term performance. In addition, the Flow value of 6.5 mm indicates that the level of plastic deformation when the load is applied is also the same among the three mixtures. This value indicates that all mixtures have balanced deformability, which allows them to absorb energy without experiencing significant structural damage. The stability value of 2,223.5 kg indicates that the ability of the three mixtures to withstand traffic loads is also similar. This equally high stability indicates that the mixtures have strong resistance to loading, which is an important factor in road pavement applications.

The main difference between the three mixtures lies in the OAC value, with 100% laterite having an OAC of 5.9%, a mixture of 50% laterite - 50% crushed stone having an OAC of 6.15%, and 100% crushed stone having an OAC of 6.2%. Although the OAC values are different, this difference does not significantly affect other parameters, indicating that small variations in asphalt content do not have a major impact on the physical characteristics of the mixtures in this test.

Thus, it can be concluded that the results of this test indicate that despite the variation in aggregate composition (laterite and crushed stone), the main characteristics such as density, VMA, VIM, VFWA, MQ, Flow, and stability remain consistent. This indicates that all types of mixtures have balanced and similar performance under the given test conditions, with different OACs providing flexibility in material selection based on material availability and specific project needs.

Discussion of Abrasion Test Results Using the Los Angeles Machine for Laterite Stone

Table 12. Abrasion test results on laterite stone

Gradation A	Testing

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Pass sieve		I	II
Pass	**Retained**	**Weight (a)**	**Weight (a)**
76,2 (3")	63,5 (2 ½")		
63,5 (2 ½")	50,8 (2")		
50,8 (2")	36,1 (1 ½")		
36,1 (1 ½")	25,4 (1")	1.252,9	
25,4 (1")	19,1 ($^3/_4$")	1.252,8	
19,1 ($^3/_4$")	12,7 (½")	1.255,5	
12,7 (½")	9,52 ($^3/_8$")	1.252,1	
9,52 ($^3/_8$")	6,35 (¼")		
6.35 (¼")	4,75 (No 4)		
4,75 (No 4)	2,36 (No. 8)		
Total Weight (a)		**5.013,3**	
Weight retained on sieve No. 12 After experiment (b)		**3.652,0**	

Abrasion testing using the Los Angeles machine is a standard method for measuring the resistance of aggregates to wear and impact, which is very important for determining the quality of aggregates to be used in road and building construction. In this test, laterite stone is selected as the test material to assess its resistance to abrasion. Based on SNI 03-2417-1991, laterite stone with A gradation is used to measure the level of wear. The testing process involves placing aggregates of a certain size with steel balls in a Los Angeles machine, which are then rotated for a certain period of time. This test is carried out twice to ensure consistency of results. The sieve sizes used vary from large sieves (76.2 mm or 3 inches) to small sieves (2.36 mm or No. 8). The initial weight of the aggregate before the test is recorded as the initial weight (5,013.3 grams) and the weight of the aggregate retained on sieve No. 12 after the test is recorded as the final weight (3,652.0 grams). The test results show that the wear of the laterite stone is 27.2%. This means that 27.2% of the initial weight of the aggregate was damaged or broken during the testing process. According to the SNI 03-2417-1991 standard, the wear value of 27.2% is within the acceptable limit for the use of aggregates in construction, especially roads and other building structures which generally require a maximum wear limit of around 30-40%. This wear value indicates that laterite stone has fairly good resistance to abrasion and impact, making it suitable for use in construction applications that require materials with high resistance to mechanical erosion.

The wear value of 27.2% indicates that laterite stone has good potential resistance to wear, which means that this material can maintain its shape and structure well even though it is exposed to abrasion or impact in field use. Aggregates with good abrasion resistance will provide stability and longer service life in road and building construction. In other words, the laterite stone tested shows characteristics that are suitable for use in environments that require high durability, such as on highway surfaces that must withstand heavy traffic loads and extreme weather conditions.

Overall, this test confirms that laterite stone with a wear value of 27.2% has adequate resistance to abrasion and impact, in accordance with the applicable standards. This indicates that laterite stone can be the right choice for construction materials that require aggregates with good resistance to mechanical erosion, providing assurance that structures built using this aggregate will have good stability and durability in the long term.

Discussion of Abrasion Test Results Using the Los Angeles Machine for ½ Crushed Stone

Table 13. Abrasion test results on ½ crushed stone

Gradation A		Testing	
Pass sieve		**I**	**II**
Pass s	**Retained**	**Weight (a)**	**Weight (a)**
76,2 (3")	63,5 (2 ½")		
63,5 (2 ½")	50,8 (2")		
50,8 (2")	36,1 (1 ½")		
36,1 (1 ½")	25,4 (1")	1.052,0	

25,4 (1”)	19,1 ($^3/_4$”)	1.450,0
19,1 ($^3/_4$”)	12,7 (½”)	1.456,3
12,7 (½”)	9,52 ($^3/_8$”)	1.042,6
9,52 ($^3/_8$”)	6,35 (¼”)	
6,35 (¼”)	4,75 (No 4)	
4,75 (No 4)	2,36 (No. 8)	
Total Weight (a)		**5.000,9**
Weight retained on sieve No. 12 After experiment (b)		**3.456,0**

The results of the wear test of 1/2 crushed stone aggregate showed a wear value of 30.9%. This wear indicates the level of aggregate mass loss after undergoing abrasion and impact testing with the Los Angeles machine according to the SNI 03-2417-1991 standard. The wear value is at the upper limit of the acceptable range for the use of aggregates in road construction.

Aggregates with high wear like this generally indicate that this material has fairly good abrasion resistance. However, aggregates that experience high wear tend to be more brittle and susceptible to degradation, especially in harsh environmental conditions such as heavy traffic loads or extreme weather changes such as freeze-thaw cycles or rapid temperature changes.

In road construction applications, aggregates with high wear like this are usually more suitable for layers that are not directly exposed to vehicle loads, or require additional maintenance to maintain the quality of the road surface. This is important to consider in the planning and maintenance of road infrastructure in order to achieve optimal long-term performance.

Overall, the 1/2 crushed stone aggregate with wear of 30.9% shows that this material can still be used in road construction with the note of selecting the right design and the necessary maintenance to maintain the quality and longevity of the road being built.

CONCLUSION

Based on the results of the analysis and further discussion, it can be concluded as follows: 1) Marshall Characteristics testing on various mixtures shows different results. For 100% laterite, it has good density with moderate VMA and VIM, and stability and MQ indicate a fairly strong mixture, although high flow indicates moderate elasticity. In a mixture of 50% laterite-50% crushed stone, the results are similar to 100% laterite, with increased stability and decreased elasticity in some sets. For 100% crushed stone, the mixture has a solid density, increased VMA, decreased VIM, and increased VFWA. Its stability is high, with varying flow and MQ decreasing with increasing KAO, indicating a more stable mixture but with increased elasticity, 2) the results of the refusal density test show that the average density is 2.194 gr / cc with low VMA and VIM and high VFWA, indicating good pore filling efficiency. The RB1-RB3 set has higher density, slightly increased VMA and VIM, but lower VFWA and decreased stability and MQ. The RC1-RC3 set shows the same density as RB1-RB3, but higher VMA and VIM, with low VFWA, lowest stability, and MQ, indicating less than optimal mechanical performance, 3) the abrasion test results with the Los Angeles machine showed that the laterite stone experienced 27.2% wear, indicating good resistance to abrasion and impact, and is suitable for road and building construction. In contrast, the ½ crushed stone showed 30.9% wear, which is at the upper limit of the SNI 03-2417-1991 standard for road construction aggregates, which is 30-40%. Although it meets the standard, this higher wear indicates that the aggregate may be more susceptible to degradation, especially under heavy traffic loads or extreme weather conditions.

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