International Journal of GEOMATE, Nov., 2023 Vol.25, Issue 111, pp.41-48
ISSN: 2186-2982 (P), 2186-2990 (O), Japan, DOI: https://doi.org/10.21660/2023.111.3936
Geotechnique, Construction Materials and Environment

# EFFECT OF SEVERAL LIME MATERIALS ON SPLIT MASTIC ASPHALT PROPERTIES

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**ABSTRACT:** Split Mastic Asphalt (SMA) is an open-graded mixture with a high filler content. There have been many types of additives used in an effort to improve the performance of mixtures. Limestone is one of the filler options for asphalt pavements and is a mineral resource that has a large amount in Indonesia, estimated at 2,160 billion tons [1]. There were three types of lime used in this study, abundantly available in west Sumatra, i.e. Palupuh (PL), Kamang Mudiak (KM) and Padang Panjang (PP) lime. The significance of this study is to determine the effect of each replacement filler on the characteristics of the split mastic asphalt 0/11 (SMA 0/11) mixture based on the Marshall test. PP lime with a lime content of 7% and an asphalt content of 6.7% to 7% produced the highest stability value of 1,020.0 kg. Thus, it can be concluded that PP lime is the most suitable as a filler for SMA pavement and PP lime content of 7% has a high stability value and other Marshall parameters has followed to the standards required.

*Keywords: Lime, Split Mastic Asphalt, Marshall Stability, Pavement*

## 1. INTRODUCTION

Split Mastic Asphalt (SMA) is one of the hot mix asphalt layer constructions capable of handling heavy traffic. This mixture is suitable for new road construction, road improvement and maintenance. This type of construction has properties that are resistant to high temperatures, resistant to deformation, sufficiently flexible, and homogeneous. SMA is an open-graded mixture with a high filler content. Many types of additives have been used to improve the performance of pavement mixtures derived from certain chemicals and even from wasted goods, such as plastic waste [1]. The plastic is typically shredded or melted and mixed with the asphalt binder or aggregates. This technique not only helps in reducing plastic waste but can also improve the properties of the pavement, such as increased strength and resistance to moisture damage [2,3].

In addition, efforts to improve performance can also be made by changing the type of filler. Materials used as fillers include lime, rock ash, portland cement (PC) and other non-plastic materials. Filler is a fine-grained material that functions as filler grains in manufacturing asphalt mixtures. The filler material added can be limestone dust, quenched lime ash, magnesium lime ash, or dolomite, according to AASHTO M303-89-2014, or cement or fly ash, whose source is approved by the work supervisor. The filler added for cement must be 1% to 2% of the total weight of aggregate. For other fillers, it must be 1% to 3% of the total aggregate weight except for SMA because the pavement for this SMA cannot use cement as per Directorate General of Highways, 2020.

Generally, the filler used for asphalt pavements is rock ash. In reality, in the field or areas where there is often a scarcity of stone ash filler, Portland Cement is a standard filler for road pavements.

Filler in the Stone Mastic Asphalt (SMA) pavement can be modified by limestone, that may have several advantages such as:

- Cost-effective: Limestone is often less expensive compared to other filler materials commonly used in SMA pavement, such as hydrated lime or mineral fillers. Using limestone as a filler can help reduce construction costs, making it a cost-effective option.
- Improved durability: Limestone is a durable material that can enhance the overall durability and longevity of the SMA pavement. It helps in reducing rutting and cracking by providing stability and strength to the asphalt mix.
- Increased skid resistance: Skid resistance is an essential property of pavement to ensure safe driving conditions. Limestone filler can enhance the skid resistance of SMA pavement due to its rough surface texture, providing better traction and grip for vehicles.
- Better moisture resistance: Limestone has inherent moisture-resistant properties. Incorporating limestone as a filler in SMA pavement can help improve its resistance to moisture damage, reducing the risk of deterioration caused by water infiltration and subsequent freeze-thaw cycles.

- Improved workability: Limestone fillers typically have a finer particle size distribution, which enhances the workability of the asphalt mix. It improves the cohesiveness and compact ability of the mix during construction, leading to a smoother and more uniform pavement surface.
- Environmental benefits: Limestone is a natural and abundant resource. Utilizing limestone as a filler in SMA pavement can reduce the need for extracting and processing other materials, minimizing the environmental impact associated with their production [4–9].

Recently, there has been a lot of research on fillers from local materials that are widely used and environmentally friendly to modify the properties of asphalt in asphalt concrete mixtures. Limestone is one of the filler options for asphalt pavements and is a mineral resource that has a large amount in Indonesia, estimated at 2,160 billion tons, such as the availability of limestone in the Bukit Tui hill area Padang Panjang, West Sumatra [10].

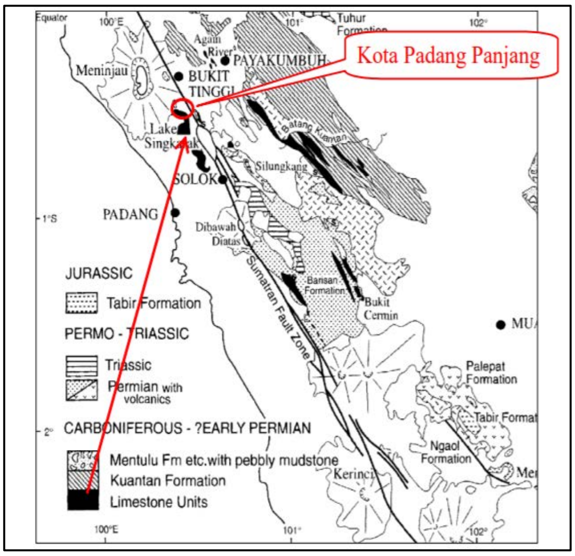


Fig.1 Distribution of Limestone in West Sumatra and Padang Panjang City [10]

As seen on Fig. 1, based on the calculation of limestone reserves at the Bukit Tui mining site in an area of ±17 hectares, it is known that the volume and amount of limestone reserves that have prospects for mining is 5,344,434 $m^3$ with a predicted net limestone tonnage of 12,826,641.6 MT. This is an excellent potential for the limestone processing industry in the City of Padang Panjang, supported by the Decree of the Minister of ESD 1095.K/30/MEM/2014. In addition, lime produced from Padang Panjang mining has gone through a combustion process.

Meanwhile, the lime from Kanagarian Kamang Mudik, Kamang Magek District, Agam Regency, West Sumatra, has long been processed and used by the community. It is found in deposits in the form of limestone that form hills, usually broken down or mined in the form of lumps. These lumps are then processed through a size reduction process (crushing, grinding and milling) to obtain a product in the form of flour with a particle size above 60 mesh. The area of Agam Regency is covered by extrusive igneous rock types with intermediate reaction (andesite from Mount Merapi, Mount Singgalang, Mount Tandikek, Lake Maninjau, and Mount Talamau) covering an area of 68,555.10 ha (32.43%), extrusive igneous rock with an acid reaction (pumice tuff) covering an area of 55,867.90 ha (26.43%), a sedimentary rock with limestone type covering an area of 80,011.80 ha (3.79%), alluvium deposits reaching an area of 48,189 ha (22.79%). Lime mining products originating from Agam Regency are pure lime without processing.

This can be seen from the abundant production of limestone, the use of limestone on the pavement is expected to increase the strength of the pavement due to its pozzolanic nature in addition to utilizing abundant material.

In this study, the three types of limestone were used for SMA pavements, so that it can be known which type of limestone is more suitable for SMA pavements, namely those with high stability and adequate void content.

## 2. RESEARCH SIGNIFICANCE

The significance of this study is to determine the effect of each replacement filler on the characteristics of the split mastic asphalt 0/11 (SMA 0/11) mixture based on the Marshall test. Determine the optimum lime filler content to produce the maximum SMA pavement stability value so that it can provide input on the technical specifications of Highway Specification 1987 and also an input for local governments regarding the potential use of limestone from mining as a pavement mixing material.

## 3. MATERIALS AND METHODS

### 3.1 The Origin of the Aggregate

The materials used in this study obtained from the quarry or supplier in local area. The filler used in this research is cement. Three types of lime used in this investigation are originated from Padang Panjang (PP), Palupuh (PL) and Kamang Mudiak/ Kamang Magek (KM). This limestone can be used as a filler in whole or in part by first grinding it until it passes the sieve no. 200 in order to be used as a filler as required by Highways Specification 2020 [8].

The gradation of aggregate in pavement is a critical step in pavement design and construction to ensure the longevity, safety, and performance of the road infrastructure.

The aggregate gradation must be compatible with the type and grade of asphalt binder used in the mix. Improper gradation can result in poor adhesion between the aggregates and the binder, leading to premature pavement failure

The independent variables used were asphalt content variation and lime filler content variation. The type of pavement mixture used is SMA 0/11 gradation as shown in Fig.2. This gradation is used to see the properties of the mixture using several different types of lime filler.

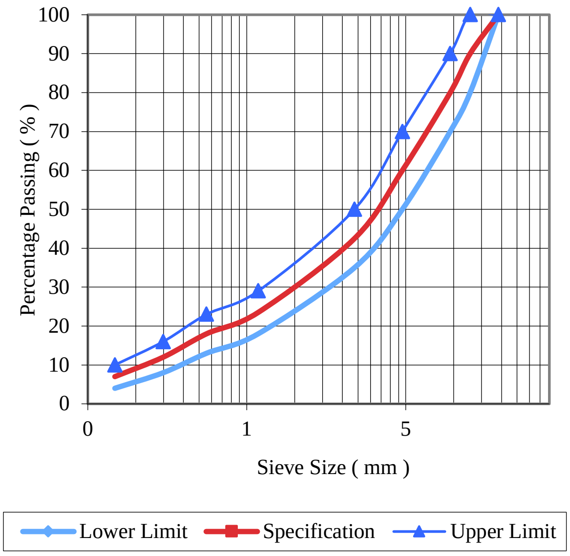


Fig.2 SMA 0/11 gradation used in the investigation

Properly graded aggregates ensure that the particles interlock well, leading to better packing and increased pavement density, resulted in a more stable and durable pavement structure.

In addition, the proper graded aggregate mix improves resistance to deformation under traffic loads, can enhance skid resistance, improving safety for vehicles, especially during wet or slippery conditions [8].

### 3.2 Bitumen Properties

To ensure its quality and suitability for specific purposes, various properties of bitumen need to be tested. These properties testing helps in evaluating its performance, durability, and behavior under different conditions.

Test results on asphalt Pen. 60/70 Pertamina, which was also tested at the Technical Laboratory of the West Sumatra National Road Implementation Center, has obtained results from each test, both penetration examination, softening point, flash point, ductility, weight loss, solubility in CCL4, penetration after weight loss and specific gravity carried out following that in the specifications used. The results obtained from the asphalt inspection according to the specifications of Highways Specification (2020) [8] are shown in the table 1.

Table 1 Bitumen properties used in this investigation

| No. | Parameters | Specification*) | Results |
|---|---|---|---|
| 1 | Penetration 25° C (0.1 mm) | 60 – 79 | 62.8 |
| 2 | Softening Point (°C) | 48 – 58 | 48.25 |
| 3 | Flash Point (°C) | min. 200 | 337 |
| 4 | Ductility 25° C | min. 100 | > 100 |
| 5 | Thin Film Oven Test (TFOT) (%) | maks. 0.8 | 0.0156 |
| 6 | Solubility in $CCL_4$ (%) | min. 99 | 99.524 |
| 7 | Penetration after TFOT (%) | min. 54 | 82.80 |
| 8 | Specific gravity (gr/cc) | min. 1 | 1.029 |

As can be seen from table 1, the result of the testing of the asphalt inspection carried out complies with the specifications of Highways (2020). Meaning that, this asphalt can be used as a binder for road pavement in general and especially in this study which will be used to form SMA pavement mixture.

### 3.3 Lime Properties

For expansive soils, the addition of lime can provide an abundance of calcium and magnesium ions. This results in ion exchange i.e. these ions tend to displace other common cations such as sodium Na+ and potassium K+. Calcium ions displace sodium and potassium ions which significantly reduces the plasticity index of the clay. Thereby reducing the expansively of the soil. The reduction in plasticity is usually accompanied by a reduction in the swelling potential [9]. In addition, the use of lime can also reduce the settlement [10].

Table 2 Technical Properties of lime used

| No | Parameter | Unit | Kamang Magek lime | Padang Panjang Lime | Palupuh Lime | Standards |
|---|---|---|---|---|---|---|
| 1 | Specific Gravity | g/mL | 2.83 | 2.76 | 2.96 | ASTM C 188-95 |
| 2 | Passing sieve # 200 | % | 68.06 | 34.75 | 51.37 | SNI 02-2804-2005 (6.6) |
| 3 | CaO | % | 49.34 | 55.46 | 33.94 | SNI 02-2804-2005 (6.2) |
| 4 | $CaCO_3$ | % | 88.1 | 99.03 | 60.61 | SNI 02-2804-2005 (6.2) |
| 5 | $P_2O_5$ | % | 0.01 | 0.04 | 0.03 | SNI 7763:2018 (6.7) |
| 6 | Water Content | % | 0.77 | 0.01 | 0.13 | SNI 02-2804-2005 (6.4) |
| 7 | $Al_2O_3+Fe_2O_3$ | % | 1.15 | 2.73 | 2.39 | SNI 02-2804-2005 (6.3) |
| 8 | $Fe_2O_3$ | % | 0.51 | 0.67 | 1.27 | SNI 2049:2015 (7.1.3.4) |
| 9 | MgO | % | 0.72 | 1.48 | 14.67 | SNI 02-2804-2005 (6.1) |
| 10 | $SiO_2$ | % | 4.64 | 9.62 | 4.63 | SNI 02-2804-2005 (6.5) |

There are three types of lime used as a filler replacement material, namely Palupuh Lime (PL lime) and Kamang Magek (KM lime), which are natural lime and Padang Panjang (PP lime), which is slaked lime. The types of lime used are extinguished lime that is Padang Panjang lime and natural lime that are Palupuh and Kamang Mudiak lime).

Extinguished lime, also known as hydrated lime or slaked lime, is a chemical compound with the formula $Ca(OH)_2$. It is obtained by adding water to quicklime (calcium oxide, CaO) in a controlled process called hydration. Extinguished lime is called so because it was traditionally used to "extinguish" or quench fires by producing steam upon contact with water.

When quicklime reacts with water, it undergoes a chemical reaction, producing heat and converting into hydrated lime. The reaction can be represented as follows: $CaO + H_2O \rightarrow Ca(OH)_2$. Table 2 shows that the results of testing in the laboratory for fine aggregate inspection have met the requirements set out in the Highways specifications (2020) [8].

## 4. RESULTS AND DISCUSSION

The main objective of this research was to evaluate the effect of lime added to the mixture on the properties of the SMA pavement. In this section, all the performance-based testing conducted on the Porous Asphalt pavement mixture are presented and discussed.

### 4.1 Marshall Properties of the Lime

To investigate the effect of the fillers on the rheological properties of the SMA pavement, the results from the Marshall properties, such as Stability, Flow, Void in the Mineral Aggregate (VMA) and Void in the mixture, are presented.

Table 3 The required value of Marshall Parameters

| No. | Parameters | Bina Marga, Institute of Road Engineering 1998 |
|---|---|---|
| 1 | Stability | ≥ 800 kg |
| 2 | Flow | ≥ 2 mm |
| 3 | Marshall Quotient | 200 – 500 kg/mm |
| 4 | Void in Mineral Aggregate | ≥ 16 % |
| 5 | Void Filled with Asphalt | ≥ 65 % |

The required value of Marshall parameters to determine the optimum lime content (OBC) are presented in table 3. Moreover, three Marshall parameters are essential: Stability, Flow, and Air Void Content [11]. The Air Void consist of Void in Mineral Aggregate, Void in Mixture and Void

Filled with Asphalt.

Stability refers to the ability of the asphalt mix to resist deformation and remain structurally stable under traffic loads and environmental stresses. An optimum bitumen content ensures adequate cohesion and bonding between the aggregates, resulting in a mix that can bear the weight of traffic without excessive deformation or rutting.

Meanwhile the Flow Number value measures the deformation of the asphalt mix specimen at a specified temperature and load. The range value of flow is 3 mm to 5 mm. It indicates the ability of the mix to deform and accommodate stress under traffic loads. As the flow number is increasing the higher the deformation of the pavement is.

An appropriate bitumen content is crucial to achieve a desired flow value, as excessive bitumen can lead to excessive flow and instability, while insufficient bitumen can cause brittleness and cracking.

Moreover, the Air Void content refers to the volume percentage of Air Voids (pores) within the compacted asphalt mix. Adequate Air Voids are necessary to accommodate thermal expansion and prevent moisture damage within the mix. An optimal bitumen content ensures that the mix is well-coated and properly compacted, reducing the potential for excessive Air Voids, which can lead to moisture infiltration and subsequent pavement distress.

*4.1.1 Marshall Stability*

Stability evaluates the ability of the asphalt mixture to withstand applied loads [12].

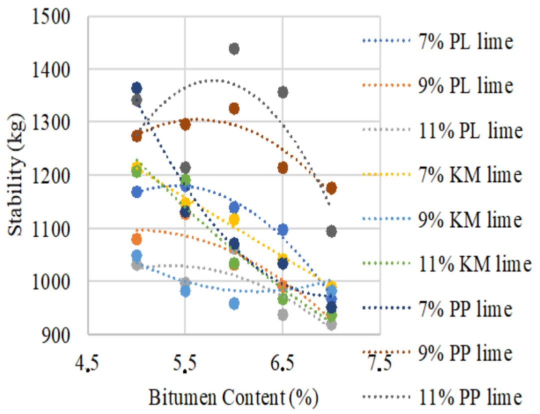


Fig.3 Stability vs various types of lime proportion

Fig. 3 shows how the inclusion of lime in the mixture influences the OBC of the mixture. The OBC of the control mixture was 5% (the peak of the orange curve); however, the modified mixture reached the highest Stability value at 6% bitumen content, giving an OBC of 6% if the Marshall test was only conducted on the control mixture and the same OBC is used for all the other mixtures.

For a mixture of SMA with PL lime, the stability value is above 600 kg, showing that for each variation in the content of the lime hammer filler, the stability value for the addition of bitumen content produces the same pattern. The optimal stability value is obtained by using asphalt content of 5.5% - 6%.

*4.1.2 Marshall Flow*

The Flow Number (FN) indicates the potential of the mixture to resist rutting [13,14]. The Marshall Quotient (MQ) indicates the mixture’s resistance to deformation [15] and is calculated by dividing the Marshall Stability by the Marshall Flow Number [16].

Prior to testing, the samples were immersed in water at 60°C for 30 minutes. Marshall stability is the peak load resistance obtained during a constant deformation load rate, and Marshall flow is the deformation of the asphalt mixture obtained during the stability test.

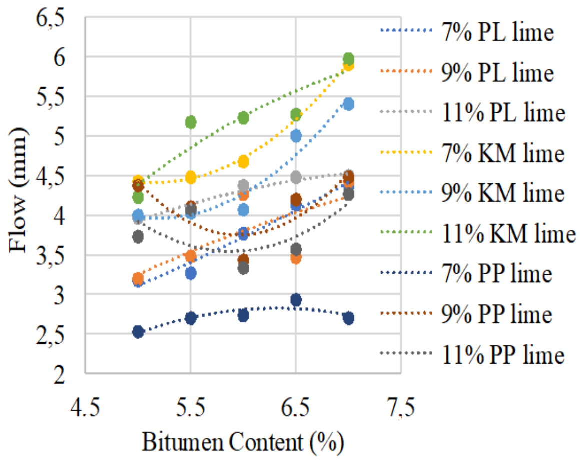


Fig.4 Flow vs various types of lime proportion

As shown in Fig. 4, PL lime for bitumen content range of 5% - 7% produces a flow that meets the SMA mix flow value requirement. Each mixture with different filler content shows a pattern of increasing flow values by adding the same asphalt content. The smallest value of Flow Number is for the 7% PP lime. It means the lesser the FN, the stronger the pavement mixture is. That indicates the resistance of the asphalt mixture to permanent deformation and the rutting value.

Therefore, in this research, Flow Number, as parameters showing rutting susceptibility of mixture especially for PL lime as well as KM lime that having the higher value of FN.

*4.1.3 Marshall Void in Mineral Aggregate*

The Air Void content is the main parameter in to optimize the asphalt mixture and pavement design [16]. The Air Void content also helps predict the performance of the mix over its service life [17]. Air Void is also strongly correlated with Flow [18]. A minimum Void in mineral aggregate (VMA) is recommended to satisfy the required mixture durability. The binder can fill VMA; the thicker the binder's film, the higher the durability of the mixture. It is accepted that a higher Tensile Strength Ratio (TSR) is obtained at lower Air Void (AV) contents. Therefore, decreasing the AV content increases the mixture's durability [17], and the increased binder content allows the mixture to resist better cracking. However, it should be noted that the lower Air Void may result in bitumen bleeding by producing more plastic Flow [8].

The void space between aggregate particles of a compacted mix is referred to as VMA and is used to indicate the available space for bitumen to adequately coat each aggregate particle [19].

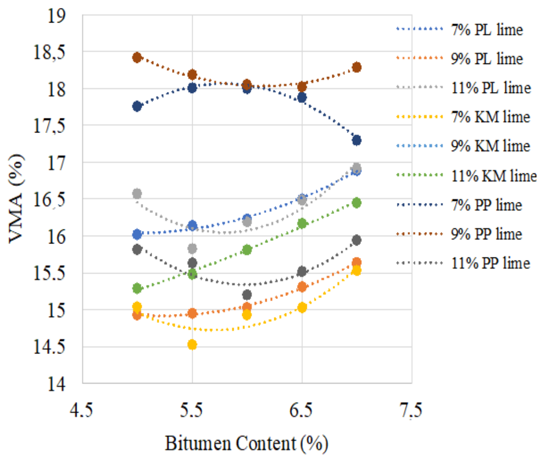


Fig.5 VMA vs various types of lime proportion

As shown in Fig. 5, with a filler content of 11% PL lime, the VMA value decreased as the bitumen content increased from 5% to 6%. Furthermore, there was an increase in the VMA value along with the addition of bitumen content by up to 7%. Overall the VMA value generated on each test object has not reached the specification VMA value requirements.

The higher the VMA value means, the more voids in the mixture that can be filled with asphalt so that the impermeability of the mixture to water and air is higher. However, a VMA value that is too high can result in a higher potential for bleeding when receiving loads at high temperatures.

From the results of this experiment, the VMA value has increased, this is in accordance with the tendency for the VMA value to increase with an increase in the percentage of bitumen content. The increase in VMA value is due to the asphalt film covering the aggregate getting thicker as the asphalt content increases so that the distance between voids becomes larger. Based on the specifications of Directorate General of Highways 2020, the requirement for a minimum VMA score of 18%, from the results of the study it was found that the VMA value of 7% PP lime and 9% PP lime met the requirements starting from asphalt content of 5.5% to 6.5%.

*4.1.4 Marshall Void in Mixture*

Voids in Mixture (VIM), namely the percentage between Air Voids and the total volume of the mixture after compaction. The volume of void in the mixture is high and low asphalt content will cause faster fatigue.

VIM (Void in Mix) expresses the percentage of voids in the total mix. The VIM value can indicate the level of impermeability of a mixture. Shows a pattern of decreasing VIM values with increasing bitumen content. This suggests that the voids between the aggregate grains are large enough so that at each addition of asphalt content, the asphalt is still quick enough to enter into the cavity of the mixture, which can make the mixture denser and the VIM value smaller.

Based on the test results, using a higher filler content impacts a smaller VIM value because the mixture tends to be denser. Almost all variations in asphalt content in the SMA mixture with a filler content of 9% and 11% obtained VIM values that met specifications.

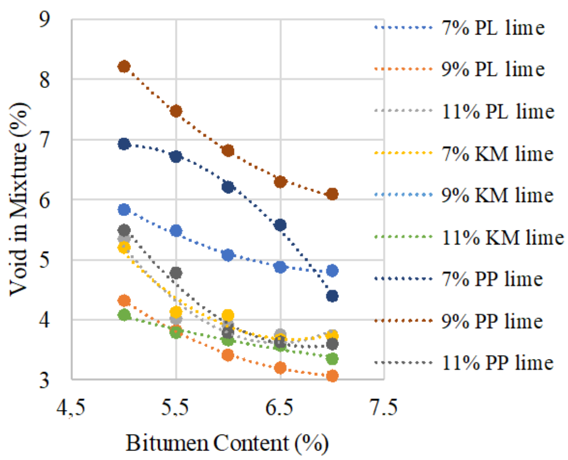


Fig.6 VIM vs various types of lime proportion

Figure 6 shows the pattern of decreasing VIM values with increasing asphalt content. This indicates that the voids between the aggregate grains are large enough so that at each addition of asphalt content, the asphalt is still quick enough to enter into the cavity of the mixture, which can make the mixture denser and the VIM value smaller.

Based on the test results, using a higher filler content impacts a smaller VIM value because the mixture tends to be denser. Almost all variations in asphalt content in the SMA mixture with a filler content of 9% and 11% obtained VIM values that met specifications.

### 4.2 Optimum Binder Content Determination

To determine the optimum binder content (OBC), three essential Marshall parameters are determined: Stability, Flow, and Air Void [8].

The Marshall mix design method involves testing various combinations of aggregate gradations and bitumen contents to find the optimum bitumen content that meets the specified criteria for stability, flow, and Air Void content.

By determining the optimum bitumen content, engineers can design asphalt mixes that provide a balance between strength, durability, and resistance to distress, ensuring long-lasting and reliable pavements. It's important to note that other mix design methods, such as the Superpave system, also consider these parameters along with additional performance-related tests for designing asphalt mixes.

The OBC highly depends on the characterization of the binder, aggregate, and additives, to enhance specific properties, like improved rut resistance, reduced temperature susceptibility, or increased workability. The presence of additives may alter the binder-aggregate interaction and influence the optimum bitumen content required to achieve the desired performance characteristics.

Different binder contents were considered for a specific aggregate, and the Marshall test was conducted on the prepared samples. The sample with the highest stability (minimum of 8000N), Flow between 2 and 4 mm, and an Air Void between 3% and 5% were deemed to be the optimum sample; its binder content could then be called the "optimum binder content (OBC)", as seen on Fig. 7.

Figure 7 is the range of bitumen content in the SMA mixture that meets specification. To determine the OBC, is the bitumen content that fulfil the specification requirement [20-21]. Thus, the bitumen content in the range of 6.7% until 7% is the optimum bitumen content that can be used in the SMA mixture that containing 7% PP lime filler.

## 5. CONCLUSIONS

SMA pavement using several types of lime was tested with a Marshall apparatus, resulting that PP lime had good results compared to KM lime and PL lime.

PP lime with a lime content of 7% and an asphalt content of 6.7% to 7% produced the highest stability value of 1,020.0 kg. The results obtained from testing for PP lime (slaked lime) meet the Bina Marga specifications. The highest stability of PL lime is 1,096.6 kg with an asphalt content of 5%, while the KM lime has the highest stability of 1,155.3 kg with asphalt content 5%.

It can be seen from other Marshall supporting parameters such as VIM, VMA, Flow values, for the three types of lime, the PP lime was chosen with a lime content of 7% to be the best lime because it has a high stability value and other parameters according to the standards required.

Thus, PP lime is the most suitable as a filler for SMA pavement and PP lime content of 7% has a high stability value and other parameters has followed to the standards required [8].

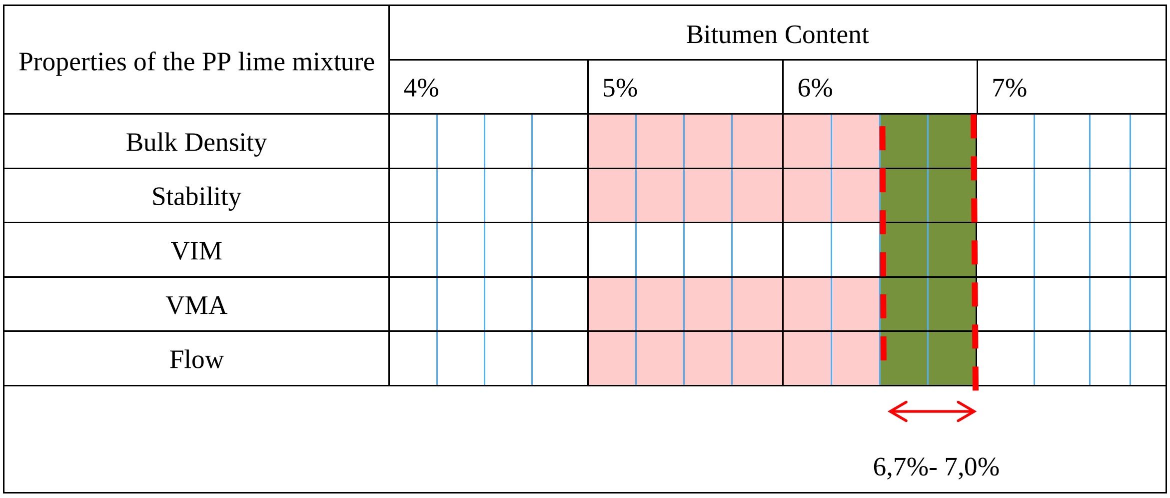


Fig. 7 Range of Bitumen Content for SMA with 7% PP Lime Filler

## 6. ACKNOWLEDGMENTS

The authors gratefully acknowledge the support provided by Universitas Andalas.

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