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Performance of Percentage Refusal Density (PRD) in Asphalt Concrete – Wearing Course (AC-WC) Mixtures with Silica Sand Substitution as Fine Aggregate

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Abstract

Indonesia is experiencing significant traffic load growth; however, this is often not matched by the development of adequate road infrastructure. This phenomenon occurs because traffic load growth is faster than the development of road infrastructure. Excessive traffic load can cause damage to the roads. Aggregates, especially fine aggregates, play an important role in flexible pavement layers, particularly in the AC-WC layer. The AC-WC layer aims to provide smoothness, safety, and comfort for road users while protecting the underlying layers from damage caused by traffic loads, such as subsidence, ruts, and asphalt deformation. The use of silica sand has become one alternative to improve the quality of the AC-WC layer. This study aims to obtain the Optimal Asphalt Content (KAO) value and the Refusal Optimal Asphalt Content (KAO) value. The KAO value using the Marshall method in the AC-WC mixture is 5.99% for 0% silica sand variation, 5.88% for 25% silica sand variation, 5.845% for 50% silica sand variation, 5.835% for 75% silica sand variation, and 5.810% for 100% silica sand variation. The Refusal KAO value is 5.920% for 0% silica sand variation, 5.83% for 25% silica sand variation, 5.785% for 50% silica sand variation, 5.750% for 75% silica sand variation, and 5.775% for 100% silica sand variation. Thus, the greater the percentage of silica sand added as a substitute for fine aggregates in the AC-WC mixture, the lower the Marshall KAO and Refusal KAO values obtained. The KAO value obtained using the percentage refusal density method in the AC-WC mixture is 5.920% at 0% silica sand variation, 5.83% at 25% silica sand variation, 5.785% at 50% silica sand variation, 5.750% at 75% silica sand variation, and 5.775% at 100% silica sand variation. Thus, the higher the percentage of silica sand added as a fine aggregate substitute in the AC-WC mixture, the lower the resulting refusal KAO value.

Keywords: *Asphalt, AC-WC, Silica Sand, KAO, Refusal*

INTRODUCTION

Flexible pavement is one of the essential components in road infrastructure designed to withstand traffic loads and provide a safe and comfortable surface for road users. Aggregates are one of the main components of flexible road pavements, and fine aggregates play a crucial role in achieving good pavement quality. However, there is one layer in flexible road pavements that often experiences damage: the wearing course (AC-WC). The AC-WC layer aims to provide smoothness, safety, and comfort for road users while protecting the underlying layers from damage due to traffic loads. Common damages occurring in the AC-WC layer due to repeated traffic loads include the formation of deformations such as subsidence, ruts (rutting), and bleeding. To avoid rutting damage in asphalt mixtures, heavier compaction equipment can be used with a longer compaction time to achieve maximum density. Generally, this condition is necessary when the Marshall asphalt content is relatively close to the lower limit or the planned asphalt content is designed with maximum density. In such efforts, it is necessary to avoid applying asphalt content that apprKAOhes the upper limit. Maximum density is intended as the highest (maximum) density achieved, so the mixture can practically not become denser. Maximum density is an approximation of field conditions after the asphalt mixture has been secondary compacted by traffic over several years of its planned lifespan [2].

One province in Indonesia with abundant natural resources, both organic and inorganic, is West Sumatra. One abundant natural resource in this province is silica sand. The silica sand in West Sumatra accounts for 82.5% of Indonesia's silica sand reserves but has not been optimally utilized [3] Additionally, particularly for PT Semen Padang, there is a significant amount of silica sand waste from its industrial processes. Therefore, the author is interested in utilizing silica sand waste from PT Semen Padang's processing to help reduce environmental pollution. If silica sand waste is not managed and is directly disposed of into the environment, it poses a significant danger to the surrounding environment. Physically, silica sand typically has a coarse texture with uneven grain shapes, featuring many protrusions and depressions that can interlock. This results in a stronger bond between the silica sand and asphalt, forming a more stable AC-WC layer that is resistant to aggregate ravelling. Thus, it is hoped that silica sand can be used as fine aggregate in the AC-WC mixture to achieve maximum density, making the mixture practically unable to be compacted further. Therefore, if a mixture cannot be compacted further or has reached maximum density, the AC-WC mixture will withstand repeated traffic loads

RESEARCH METHODS

This research uses the Marshall method and maximum density. Maximum density is a modified Marshall test in which the number of blows during compaction is increased from the usual 2 x 75 blows to 2 x 400 blows, with the aim of simulating the condition of the pavement layer that will be subjected to heavy traffic loads and whether it will achieve a density level that may easily undergo shape changes. In this study, mixtures were made with variations of silica sand substitution percentages of 0%, 25%, 50%, 75%, and 100%. This research was conducted in the laboratory of the State Polytechnic of Padang. This study also conducted property tests on coarse aggregates, fine aggregates, fillers, silica sand, and asphalt. Subsequently, Marshall tests were performed to obtain the Optimal Asphalt Content (KAO) using the Marshall method. The property tests aimed to determine whether the materials used to create the mixture met the general specifications of 2018 [2].

The test specimens with maximum density were made with two specimens for each asphalt content: -0.5% (VIM 6%), VIM 6%, and +0.5% (VIM 6%) for eac h variation of silica sand. The total number of test specimens used in this study can be seen in the table 1 and Table 2.

Table 1. Number of *Marshall Test Pieces*

Asphalt Rate	AC-WC + Silica Sand (%)				
	0	25	50	75	100
5	3	3	3	3	3
5,5	3	3	3	3	3
6	3	3	3	3	3
6,5	3	3	3	3	3
7	3	3	3	3	3
Total Samples KAO			75		

Table 2. Number of PRD Test Pieces

Mixed Types	AC-WC + Silica Sand (%)				
	25	25	50	75	100
PRD	6	6	6	6	6
Total Samples PRD			30		

RESULTS AND DISCUSSION.

1. Results of Material Quality Testing

Based on the material property tests conducted in the laboratory, the results obtained meet the general specifications of 2018, Division 6, as well as the related SNI standards.

Table 3. Coarse Aggregate Test Results

No	Testing	Condition	Result
1	Specific Gravity (Gs)		
	a. Gs Bulk	2,5-2,7	2,52
	b.Gs SSD	2,5-2,7	2,605
	c. Gs Semu	2,5-2,7	2,753
	d. Absorption (%)	≤ 3%	3,361
2	Agregat Impact Value (AIV) (%)	Max 30%	9,202
3	Agregat Crushing Value (ACV) (%)	Max 30%	23,209
4	Abrasi (%)	Max 40%	16
5	Flakines Index (%)	Max 10%	11,94
6	Elongated Index (%)	Max 10%	5,91
7	Aggregate Weathering (%)	Max 10%	4,15
8	Adhesion of Aggregate to Asphalt	Min 95%	95

Table 4. Fine aggregate test results

No	Testing	Condition	Result
	Specific Gravity:		
	a. Gs Bulk	2,5-2,7	2,492
1	b. Gs SSD	2,5-2,7	2,562
	c. GS Semu	2,5-2,7	2,68
	d. Absorption (%)	≤ 3%	2,817

Table 5. Slica Sand Test Result

No	Testing	Condition	Result
1	Specific Gravity (Gs)		
	a. Gs Bulk	2,5-2,7	2,59
	b.Gs SSD	2,5-2,7	2,66
	c. Gs Semu	2,5-2,7	2,79
	d. Absorption (%)	≤ 3%	2,58
2	Abrasi (%)	Max 30%	40,2
3	Aggregate Weathering (%)	Max 10%	0,75

Table 6. Asphalt Test Results

No	Testing	Condition	Result
1	Specific Gravity	Min. 1%	1,032
2	Penetration (mm)	60-70	70
3	Duckiness (cm)	Min. 100	150
4	Soft Point (°C)	Min 48	48

5	Flash Point and Burn Point (°C)	Min 232	344 & 354
6	Weight Loss TFOT (%)	≤ 0,8%	0,3106
7	Viscosity (°C)	≤ 300	160 150

2. Marshall Testing

Density

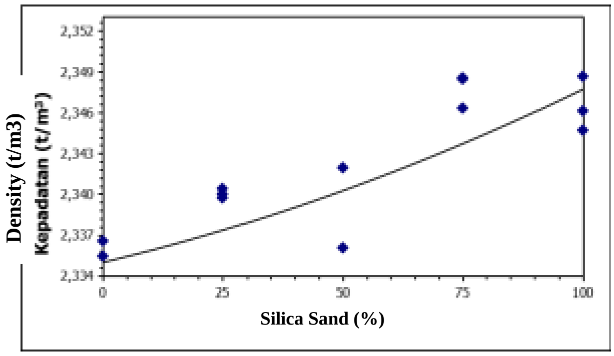

Fig 1. Density comparison to silica sand

From Fig 1, it can be seen that the higher the percentage of silica sand added as fine aggregate in the AC-WC mixture, the higher the density value of the mixture. This is because silica sand has a high specific gravity, resulting in low volume, small voids, and low porosity, which increases the density value of the mixture.

Void In Mix (VIM)

From Fig 2. It can be seen that the greater the addition of the percentage of silica sand as a fine aggregate, the lower the VIM value will be produced. This is due to the high specific gravity of silica sand, so the porosity is low, so the ability of silica sand to absorb asphalt is low. Cavities formed in the mixture (VIM) then the cavity is absorbed by the asphalt, so that the cavity that is not filled with asphalt is getting fewer, resulting in the mixture becoming solid.

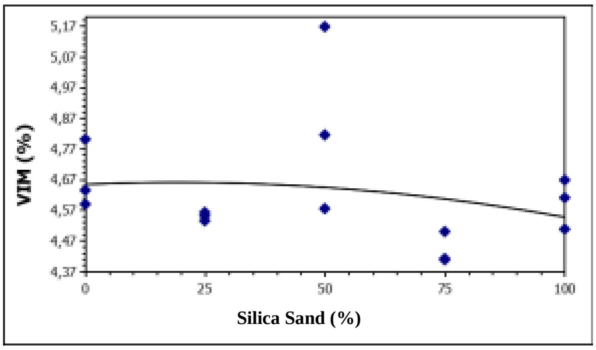

Fig 2. Comparison of VIM to silica sand

Void In Mineral Aggregate (VMA)

From Fig 3. It can be seen that the greater the addition of the percentage of silica sand as a fine aggregate, the lower the VMA value will be produced. This is because the texture on the surface of silica sand is finer than the fine aggregate of broken stone which makes the asphalt cover the surface of the aggregate to be more and the absorption of water in the silica sand is smaller compared to the fine aggregate of broken stone so that the amount of asphalt absorbed by the aggregate becomes less which makes the cavity between the aggregates smaller so that the mixture becomes tighter.

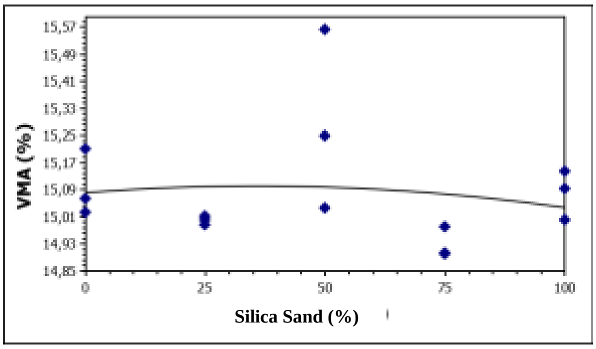

Fig 3. VMA comparison against silica sand

Void Filled With Asphalt (VFA)

From Fig 4. It can be seen that the greater the addition of the percentage of silica sand as a fine aggregate, the higher the VFA value will be produced. This is because the AC-WC mixture with the addition of silica sand makes the percentage value of the cavity covered by asphalt even larger, this is influenced by the VIM and VMA values where the smaller the VIM and VMA values of the mixture, the greater the percentage value of the cavity covered by asphalt (VFA).

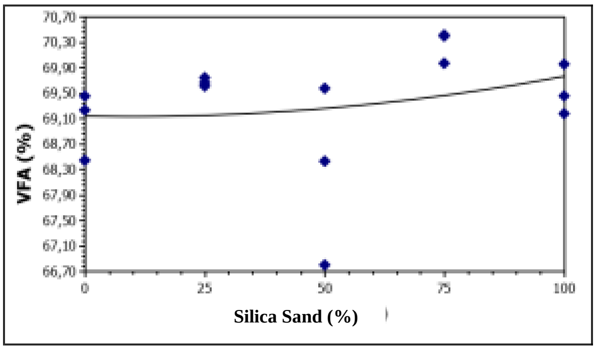

Fig 4. Comparison of VFA to silica sand

Stability

From Fig 5, it can be seen that the greater the addition of the percentage of silica sand as a fine aggregate, the higher the stability value will be. This is because the addition of silica sand to the AC-WC mixture makes the *interlocking* in the mixture increase and closes the gaps between the existing aggregates so as to strengthen the *interlocking* properties in the mixture. The stability value is also affected by the penetration value obtained. The larger the percentage of silica sand used, the lower the penetration produced. Low penetration value results in high stability value. However, high stability can make pavements stiff and prone to cracking due to traffic loads.

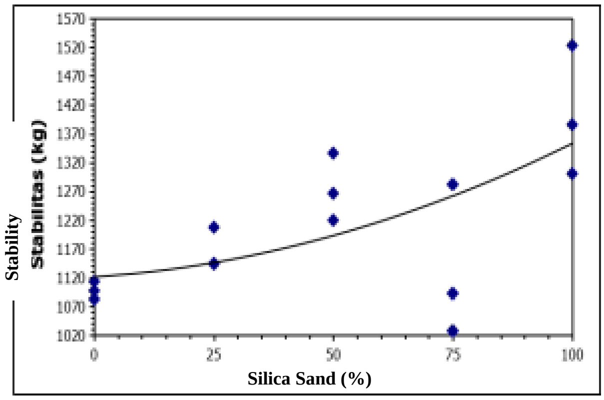

Fig 5. Stability comparison against silica sand

Flow

From Fig 6, it can be seen that the higher the addition of the percentage of silica sand as a fine aggregate, the higher the resulting fatigue value will be and will decrease after reaching the maximum value along with the addition of the percentage of silica sand in the AC-WC mixture. This is because the AC-WC mixture with the addition of silica sand makes the asphalt mixture thicken, making the AC-WC mixture plastic and easily deformed. The greater the deformation due to the traffic load, the more the *flow value* in the asphalt mixture with the addition of silica sand.

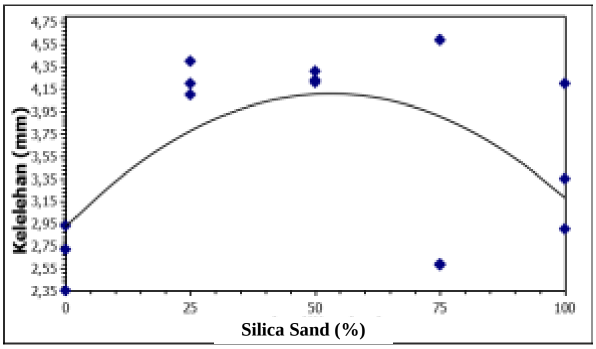

Fig 6. **Comparison of fatigue to silica sand**

Marshall Quotient (MQ)

From Fig 7, it can be seen that the higher the addition of the percentage of silica sand as a fine aggregate, the lower the MQ value and will increase after reaching the minimum value produced along with the addition of the percentage of silica sand in the AC-WC mixture. This is due to its high stability value and high *flow* value so that the mixture tends to be less stable and flexible. So that the mixture becomes more plastic, if it receives a load, it will undergo a greater deformation, and the application of sufficient asphalt content will increase the bond between the aggregates so that the mixture becomes more rigid.

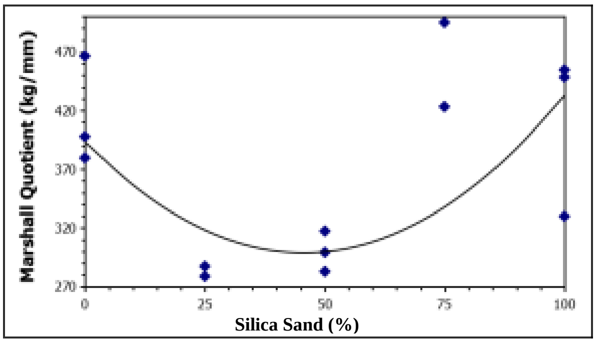

Fig 7. Comparison of MQ to silica sand

3. Marshall KAO Analysis

Based on laboratory testing results for silica sand substitution as fine aggregate in the AC-WC mixture, the Optimal Asphalt Content (KAO) at 0% silica sand is 5.99%, at 25% silica sand is 5.88%, at 50% silica sand is 5.845%, at 75% silica sand is 5.835%, and at 100% silica sand is 5.810%. The comparison of Marshall KAO values for the five variations of silica sand addition in the AC-WC mixture can be seen in Figure 8. Based on Figure 8, it can be observed that the higher the percentage of silica sand added as fine aggregate, the lower the resulting KAO value. This is because silica sand has a high specific gravity, resulting in low volume, and thus requires less asphalt to cover all the aggregate surfaces in the AC-WC mixture. Due to its low porosity, asphalt is not well absorbed.

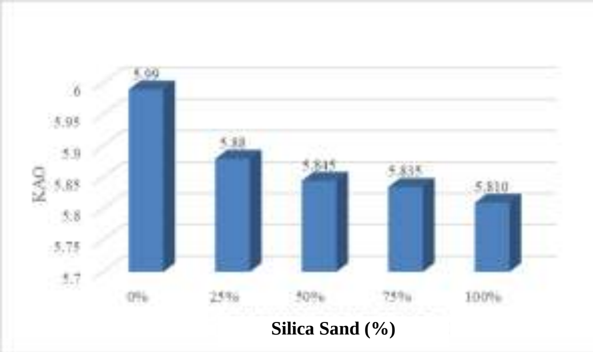

Fig 8 . Comparison of KAO marshall value to silica sand

3.2 Refusal KAO Analysis

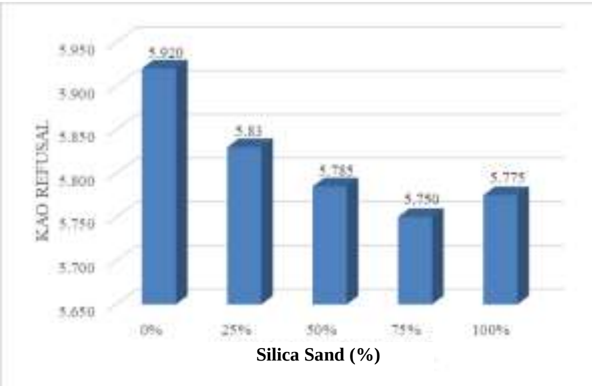

Fig 9. Comparison of KAO refusal values to silica sand

Based on Figure 9, it can be observed that the refusal KAO value decreases as more silica sand is added to the AC-WC mixture. This is because the silica sand added to the AC-WC mixture has a high specific gravity, which reduces the mixture's volume, resulting in a smaller surface area covered by asphalt. Therefore, the more silica sand added to the AC-WC mixture, the lower the optimum refusal asphalt content produced, and the refusal KAO value corresponds with the Marshall KAO.

3.3 Comparison Analysis of Marshall KAO and Refusal KAO

Based on Figure 10, it can be observed that both Marshall KAO and refusal KAO values decrease as more silica sand is added to the AC-WC mixture, with the refusal KAO value being lower than the Marshall KAO. This is due to the different number of blows and achieving maximum density that can no longer be compacted, resulting in smaller remaining voids in the mixture with the refusal method, thus requiring less refusal KAO compared to Marshall KAO. At 100% silica sand addition, the Marshall and refusal KAO values are nearly the same, averaging at 5.793%.

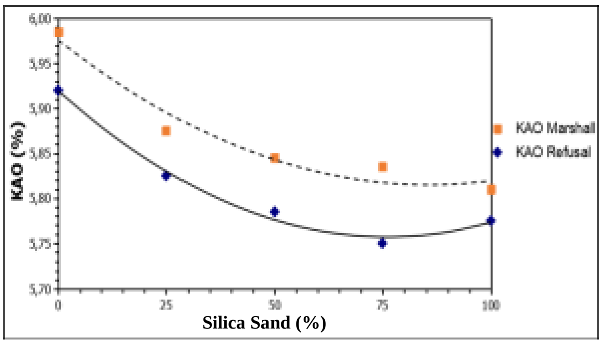

Fig 10. Comparison of Marshall KAO and refusal KAO values for silica sand

CONCLUSIONS.

The KAO value obtained using the Marshall method in the AC-WC mixture is 5.99% at 0% silica sand variation, 5.88% at 25% silica sand variation, 5.845% at 50% silica sand variation, 5.835% at 75% silica sand variation, and 5.810% at 100% silica sand variation. Thus, the higher the percentage of silica sand added as a fine aggregate substitute in the AC-WC mixture, the lower the resulting KAO value.

The KAO value obtained using the percentage refusal density method in the AC-WC mixture is 5.920% at 0% silica sand variation, 5.83% at 25% silica sand variation, 5.785% at 50% silica sand variation, 5.750% at 75% silica sand variation, and 5.775% at 100% silica sand variation. Thus, the higher the percentage of silica sand added as a fine aggregate substitute in the AC-WC mixture, the lower the resulting refusal KAO value.

Among the five variations of silica sand addition percentages in the AC-WC mixture, the best percentage for the AC-WC mixture is 100% silica sand. This is because at 100% silica sand, a high stability value can be achieved. If the stability value is high, it can make the mixture more stable

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