

Percentage Refusal Density (PRD) Performance of Hot Rolled Sheet-Wearing Course (HRS-WC) Mixture with Substitution of Palm Shell Ash as Filler

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Received 20 November 2025; Accepted 26 November 2025; Available online ;28 November 2025

Abstract

The increasing traffic volume and excessive loads on road pavements often cause permanent deformation in the wearing course layer. One potential solution is the utilization of industrial by-products, such as palm shell ash, as an alternative filler in Hot Rolled Sheet-Wearing Course (HRS-WC) mixtures. This study aims to evaluate the effect of palm shell ash substitution on the Optimum Asphalt Content (OAC) using the Marshall method and the Percentage Refusal Density (PRD) approach. The research was conducted through laboratory experiments with substitution variations of 0%, 25%, 50%, 75%, and 100%. The results indicate that the OAC determined by the Marshall method tends to increase with higher palm shell ash content, ranging from 7.46% to 8.30%. Meanwhile, the OAC values based on PRD range between 7.29% and 8.13%, with the 50% substitution producing the most optimal value at 7.29%. These findings suggest that palm shell ash has significant potential as an eco-friendly alternative filler to enhance the performance of HRS-WC mixtures while simultaneously promoting sustainable utilization of palm oil industry waste

Keywords: HRS-WC, Percentage Refusal Density, palm shell ash, filler, Optimum Asphalt Content

INTRODUCTION

A significant increase in traffic volume is a consequence of population growth, the development of the tourism sector, and the acceleration of infrastructure and transportation projects. This condition has resulted in excessive loading (overload) on road infrastructure [1]. The situation is further aggravated by Indonesia's tropical climate, where high temperatures cause expansion in pavement layers, leading to early damage such as rutting and bleeding [2][3]. The combination of excessive loads and high temperatures leads to various types of pavement damage. One of the functional failures, such as bleeding (the emergence of asphalt on the surface), causes the loss of surface texture as the asphalt film covers the coarse aggregates that provide friction. Therefore, it is necessary to optimize the asphalt content and pay close attention to the gradation of the asphalt mixture, particularly in the wearing course layer, which directly interacts with vehicle loads [4]

Hot Rolled Sheet-Wearing Course (HRS-WC) is one type of asphalt mixture widely used as the wearing course layer in road pavements in Indonesia. This mixture is designed to provide resistance to deformation, high stability, and a durable surface texture that ensures friction and driving safety [6].

Percentage Refusal Density (PRD) is a method used to describe the condition of asphalt mixtures under continued traffic loading. PRD serves as a parameter indicating the percentage of mixture density that resists

further compaction, reflecting the mixture's stability [7]. To ensure that asphalt mixtures can withstand heavy traffic loads without excessive deformation, an optimal PRD value is required. Therefore, the performance of HRS-WC using the Percentage Refusal Density (PRD) method needs to be improved by substituting some of its constituent materials—particularly the filler, which plays a crucial role in filling voids (the filler effect) [6].

According to data from the Indonesian Palm Oil Association [10], national production of Crude Palm Oil (CPO) exceeds 40 million tons per year, generating shell waste of approximately 6 to 8 million tons. Most of this waste has not been utilized optimally and is often discarded or burned, potentially causing negative environmental impacts. Therefore, utilizing this waste as filler in asphalt mixtures presents a promising solution from both technical and environmental perspectives [8][9].

Palm shell ash is a combustion residue derived from palm oil industry waste. This residue has an irregular granular shape that allows for particle interlocking, resulting in stronger adhesion between the ash and asphalt. Its high silica dioxide (SiO_2) content helps improve the compressive strength of asphalt mixtures by reducing shrinkage and enhancing resistance to permanent deformation. In addition to silica, the ash also contains alumina (Al_2O_3) and iron oxide (Fe_2O_3), which contribute to increased stability and density through their fine texture and strong binding properties with asphalt materials [9][8].

RESEARCH METHOD

This study is an experimental laboratory research conducted to determine the effect of palm shell ash substitution as filler on the Percentage Refusal Density (PRD) of HRS-WC mixtures. The research was carried out by preparing HRS-WC specimens with varying proportions of palm shell ash replacing part or all of the conventional filler, followed by testing the Marshall characteristics and PRD values. The overall experimental procedures followed the Indonesian National Standard (SNI) for asphalt mixture testing and the Ministry of Public Works specifications [4][12]. The Marshall test was conducted based on SNI 06-2489-1991, which determines stability, flow, and void characteristics of hot mix asphalt [11]. The PRD test was performed to evaluate the mixture's resistance to further compaction under continued traffic loading, following the method developed by the Transport Research Laboratory [13] and later adopted in local studies [7]. The HRS-WC gradation and composition used in this study refer to *Spesifikasi Umum Bina Marga Divisi 6 – Perkerasan Aspal* [4].

2.1 Materials and Equipment

The materials used include coarse and fine aggregates sourced from Lubuk Alung, fillers consisting of stone dust and palm shell ash obtained from PT. Incasi Raya Group, and 60/70 penetration grade asphalt produced by PT. Pertamina. The main equipment utilized comprises a complete set of Marshall testing apparatus, aggregate property testing instruments (Los Angeles Abrasion, Aggregate Impact Value, Aggregate Crushing Value), and asphalt property testing tools (penetration, ductility, softening point, flash and fire point, and viscosity).

2.2 Research Procedure

1. Testing of material properties includes determining the specific gravity and water absorption of aggregates, abrasion resistance, flakiness, elongation, weathering resistance, adhesion between aggregate and asphalt, as well as physical properties of the asphalt.
2. Marshall mix design was carried out with asphalt content variations of 6%, 6.5%, 7%, 7.5%, and 8%. The test specimens were molded into cylindrical shapes with dimensions of $\text{Ø } 10.16 \text{ cm} \times 7.5 \text{ cm}$, compacted with 75 blows per side, and tested to obtain values of stability, flow, Marshall Quotient, VIM (Voids in Mixture), VMA (Voids in Mineral Aggregate), and VFA (Voids Filled with Asphalt).
3. PRD testing was conducted using the optimum asphalt content obtained from the Marshall method (VIM $6\% \pm 0.5\%$), with 400 blows per side to simulate the effect of repeated traffic loading.

2.3 Number of Test Specimens

Determining the number of test specimens is essential to ensure the adequacy of samples for analysis. In this study, a total of 105 specimens were prepared, including those used for the Percentage Refusal Density (PRD) tests.

Table 1. Number of test specimens

Asphalt Percentage	Fly Ash Percentage				
	0%	25%	50%	75%	100%
6,5%	3	3	3	3	3
7%	3	3	3	3	3
7,5%	3	3	3	3	3
8%	3	3	3	3	3
8,5%	3	3	3	3	3
Total	105				

RESULTS AND DISCUSSION

3.1 Material Properties

The results of cement, aggregate, and fly ash testing are presented in **Tables 2-3**. All materials met SNI specifications, hence suitable for use in asphalt mixture.

Table 2 Testing of fine aggregates

Types of Testing	Test Method	Test Results	Standard Grades	Information
Specific gravity of bulk	SNI 1969:2016	2,477	2,5 – 2,7	Meet
Specific gravity of aparent	SNI 1969:2016	2,543	2,5 – 2,7	Meet
Specific gravity of Surface Saturated Dry	SNI 1969:2016	2,645	2,5 – 2,7	Meet
Absorption (%)	SNI 1969:2016	2,564	<3	Meet

(Source: Testing Data)

Table 3 Coarase aggregate testing

Types of Testing	Test Method	Test Results	Standard Grades	Information
Specific gravity of bulk	SNI 1970:2016	2,524	2,5 – 2,7	Meet
Specific gravity of aparent	SNI 1970:2016	2,560	2,5 – 2,7	Meet
Specific gravity of Surface Saturated Dry	SNI 1970:2016	2,620	2,5 – 2,7	Meet
Absorption (%)	SNI 1970:2016	2,115	<3	Meet
Abrasion (%)	SNI 2417:2008	27,7	≤40	Meet
Aggregat Crushingg Value (%)	SNI 03-4426-1997	23,319	≤30	Meet
Aggregat Impact Value	SNI 03-4426-1997	12,418	≤30	Meet
Flakinnes Index; (%)	SNI 8287:2016	4,98	Maks 10%	Meet
Elongation Index (%)	SNI 8287:2016	5,91	Maks 10%	Meet
SoudnesS ; (%)	SNI 3407:2008	2,915	Maks 10%	Meet
Affinity for Bitumen; (%)	SNI 2439:2011	98	Min 95%	Meet

Table 4 Filler test results

Types of Testing	Test Method	Test Results	Standard Grades	Information
Specific gravity	SNI-2531-1991	2,560	2,5- 2,6	Meet

3.2 Analysis of Percentage Refusal Density (PRD)

The absolute density test, which modifies the Marshall method by increasing compaction from 2×75 to 2×400 blows, simulates field conditions under heavy traffic loading [4]. This intensified compaction produces a denser mixture and smaller air voids, thereby representing the real pavement response more accurately under high load repetition. Based on the results, the Voids in Mix (VIM) under refusal conditions were consistently lower than those from the Marshall test at the same asphalt content (7,5%), indicating that maximum compaction reduces the remaining air voids within the mixture [7].

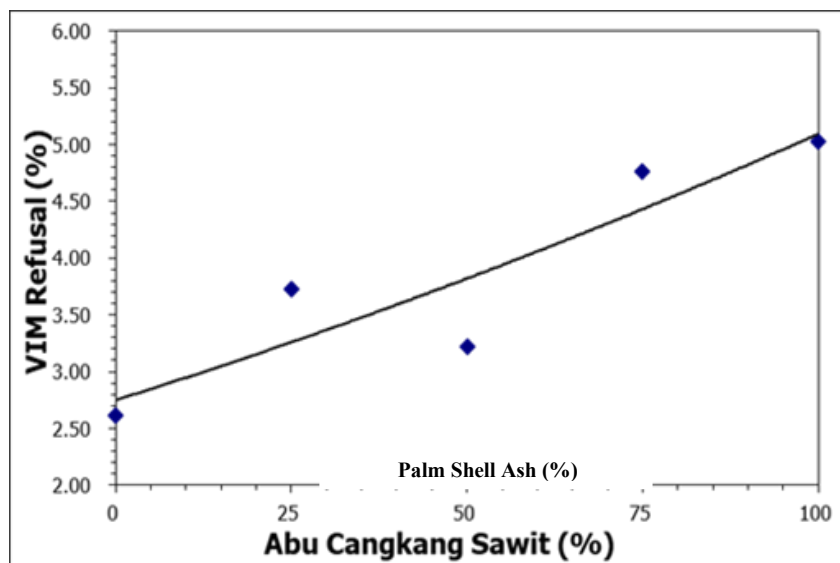


Fig. 1. Graph of VIM Refusal value on palm shell ash

Figure 1. Shows that the VIM Refusal value tends to increase with higher palm shell ash (PSA) content in the HRS-WC mixture. At 0% PSA, the VIM Refusal value is approximately 2.5%, while at 100% PSA substitution it reaches nearly 5.0%. This indicates that mixtures containing higher PSA percentages retain more air voids even after compaction under refusal conditions [4][[7]. The observed increase in VIM Refusal can be explained by the physical properties of palm shell ash particles, which are generally fine, angular, and irregular in shape [9]. These shapes enhance interlocking among particles, but the rough texture and irregular geometry also hinder complete densification under compaction, leaving small voids trapped within the mixture [8]. As the PSA content increases, the total surface area of the filler also increases, which requires more asphalt binder to fully coat the particles. When the binder is insufficient to coat all surfaces, micro-voids remain, leading to higher VIM values [6]. Chemically, PSA contains high levels of silica (SiO_2) and alumina (Al_2O_3), which contribute to improved adhesion with asphalt. However, the fine texture and absorptive nature of the ash increase the asphalt demand — that is, more binder is required to fill the surface pores and provide full coating [1]. Consequently, mixtures with higher PSA substitution show higher void contents unless the asphalt content is adjusted upward. This trend suggests that there exists an optimum PSA substitution level—around 25–50%—where the balance between filler interlocking and asphalt coating efficiency is maintained [8]. Beyond this range, excessive PSA results in increased voids and higher asphalt demand, reducing mixture workability and compaction efficiency.

Based on **Figure 2**, it can be observed that the VIM refusal values obtained are lower than the Marshall VIM values at the same asphalt content, which is 7.5%. This occurs because, under refusal conditions, the mixture has been compacted to its maximum limit, resulting in smaller air voids within the mixture.

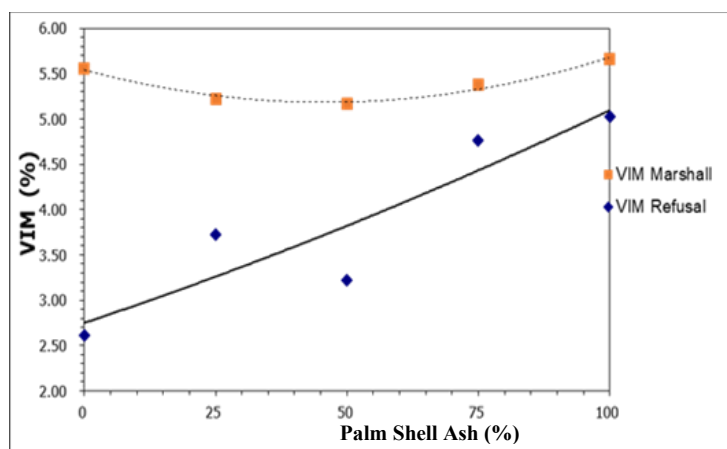


Fig. 2. Graph of Comparison of VIM Marshall and VIM Refusal

Figure 2. Compares the Voids in Mix (VIM) values obtained from the Marshall method and the Refusal Density (PRD) method for various percentages of palm shell ash (PSA) substitution. The graph shows that the VIM Refusal values (blue diamonds) are consistently lower than the VIM Marshall values (orange squares) at the same asphalt content (7.5%). This pattern indicates that under refusal compaction (2×400 blows), the mixture achieves higher density and lower air voids than under standard Marshall compaction (2×75 blows) [7]. The difference between VIM Marshall and VIM Refusal reflects the mixture's response to intense compaction and load repetition, simulating real pavement conditions under heavy traffic. The reduction in air voids under refusal conditions shows that the asphalt mixture can still densify beyond the standard laboratory compaction level, which is critical for assessing long-term field performance [4]. However, as the percentage of PSA increases, both VIM Marshall and VIM Refusal values exhibit an upward trend. This indicates that higher PSA content reduces the compactibility of the mixture due to its fine particle size, irregular shape, and high surface roughness, which create more interparticle friction and hinder close packing [9]. These physical characteristics result in a higher residual air void content even after refusal compaction.

Furthermore, palm shell ash contains significant amounts of silica (SiO_2) and alumina (Al_2O_3), which improve adhesion between the binder and aggregates but also increase binder demand. The porous and absorptive surface of PSA particles increases the required asphalt film to achieve full coating [1]. When asphalt content is constant, insufficient coating leads to microscopic voids within the mixture matrix, causing the VIM to rise. This aligns with previous findings showing that excessive fine or absorptive filler can increase the void ratio and reduce the effective binder content in hot mix asphalt [6]. The smaller difference between VIM Marshall and VIM Refusal at higher PSA contents suggests that the mixture becomes less responsive to additional compaction energy. This condition indicates a transition from a dense to a stiff and less workable mixture, where further compaction yields minimal density improvement due to high internal friction among particles [3].

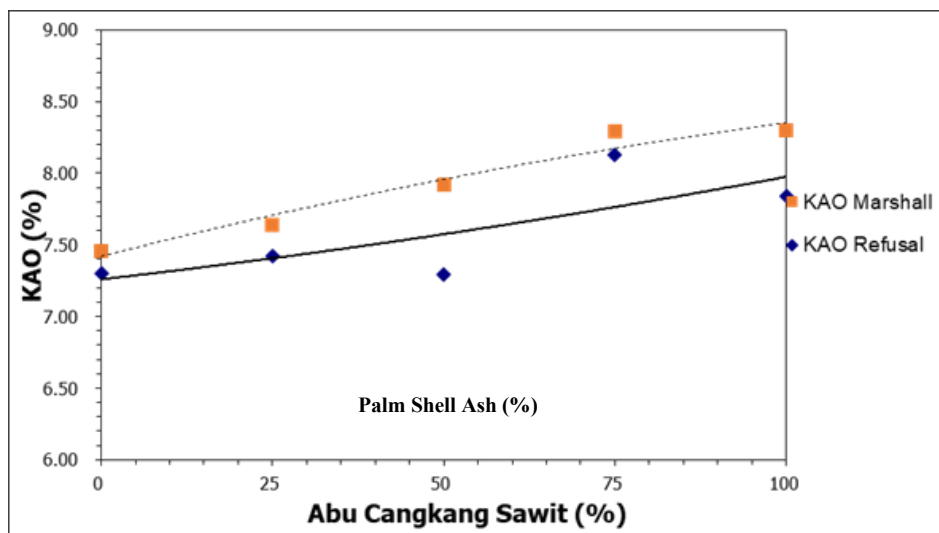


Fig. 3. Comparison of KAO Marshall and KAO Refusal values

Figure 3. Presents the relationship between the Optimum Asphalt Content (KAO) determined by the Marshall method and by the Refusal Density (PRD) method across different percentages of palm shell ash (PSA) substitution. Overall, both KAO Marshall and KAO Refusal values increase as the PSA content increases from 0% to 100%. However, the KAO Marshall values are consistently higher than the KAO Refusal values for each variation. This indicates that, under the refusal compaction condition, mixtures require slightly less asphalt to achieve maximum density compared to the Marshall condition [7]. The difference between KAO Marshall and KAO Refusal arises from the degree of compaction applied in each method. The refusal compaction (2×400 blows) represents a higher energy level that eliminates more air voids, thereby requiring less binder to fill the remaining voids in the mixture [4]. In contrast, the standard Marshall compaction (2×75 blows) results in higher air voids, necessitating more asphalt to achieve sufficient coating and cohesion among aggregates [3].

The increasing trend of KAO values with higher PSA substitution levels can be explained by the physical and chemical properties of palm shell ash. PSA particles are finer, more irregular, and more porous than conventional mineral fillers such as limestone dust (Siregar & Lubis, 2020). The fine texture and high surface area of PSA increase the binder absorption capacity, requiring more asphalt to coat all particles effectively (Kamaruddin & Nurdin, 2020). Moreover, the presence of silica (SiO_2) and alumina (Al_2O_3) within the ash enhances the interaction

between filler and asphalt, which strengthens the bonding but also raises the binder demand due to the higher surface energy of these compounds [1].

At lower substitution levels (0%–50%), the difference between KAO Marshall and KAO Refusal remains relatively small, indicating that the mixture compacts efficiently and maintains good stability. However, at 75% PSA, a notable increase occurs—where the KAO Refusal value reaches its highest point (approximately 8.1%). This behavior suggests that excessive PSA causes binder starvation, where much of the asphalt is absorbed by the filler, leaving less available for coating the coarse aggregates [6]. Consequently, the mixture requires a higher total asphalt content to achieve the desired density.

This observation aligns with findings from Kamaruddin and Nurdin (2020), who reported that high PSA levels (>50%) increase asphalt demand due to the filler's absorptive nature. Similarly, Siregar and Lubis (2020) noted that the micro-porous surface of palm shell ash enhances adhesion but limits workability if binder content is not properly adjusted.

CONCLUSION

The experimental results showed that the VIM Refusal values were consistently lower than the VIM Marshall values at the same asphalt content, confirming that the PRD (Percentage Refusal Density) method produces denser and more compact mixtures. However, both VIM values tended to increase with higher palm shell ash (PSA) substitution, indicating reduced compactibility at excessive filler levels due to the fine, irregular, and angular particle shape of PSA.

The analysis of Optimum Asphalt Content (KAO) revealed that both KAO Marshall and KAO Refusal values increased with greater PSA substitution. This trend reflects the higher asphalt demand caused by the porous and absorptive characteristics of PSA particles, which require more binder to achieve full coating. An optimum PSA substitution level was observed between 25% and 50%, where the mixture maintained a balance between density, stability, and binder demand. Beyond this range, particularly at 75%, the asphalt requirement increased significantly, indicating a decline in mixture workability and compaction efficiency.

Overall, the incorporation of palm shell ash as a partial filler replacement in HRS-WC asphalt mixtures demonstrates positive effects when used within the optimum range. It enhances the interlocking structure and binder-aggregate adhesion, contributing to higher stability and durability under heavy traffic conditions. From a practical standpoint, these findings imply that the PRD method can serve as a reliable approach for evaluating asphalt mixtures in tropical climates, where temperature and loading conditions are severe. Environmentally, the utilization of palm shell ash offers a sustainable and eco-friendly alternative to conventional mineral fillers, reducing palm oil industry waste while supporting green and resilient road infrastructure development in Indonesia.

ACKNOWLEDGEMENT

This research was funded by the 2025 DIPA budget of Politeknik Negeri Padang. We extend our gratitude to Politeknik Negeri Padang for facilitating this research and to all other parties who have contributed to this study.

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