Indonesian Journal of Maritime Technology (ISMATECH)
Vol. 04, Issue 01, June 2026
eISSN: 3025-518X
DOI: https://doi.org/10.35718/ismatech.v4i1.8482100

Utilization of Egg Shell Powder as a Filler in Asphalt AC-WC (Asphalt Concrete-Wearing Course) Mixture on Air Flow and Absorption Characteristics

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KEYWORDS
AC-WC;
Filler;
Marshall;
Water absorption;
Eggshell powder

ABSTRACT – Asphalt Concrete-Wearing Course (AC-WC) is the surface layer of flexible pavement that directly receives traffic loads and protects the underlying layers from the effects of water and weather. The performance of AC-WC is strongly influenced by stability, Marshall flow, air voids, density, and resistance to water absorption. This study utilizes eggshell powder (ESP) as an alternative filler due to its high calcium carbonate content and its potential to fill voids between aggregate particles. The objectives of this study are to determine the optimum asphalt content, determine the optimum ESP content, and evaluate the effect of ESP variations on Marshall flow characteristics and water absorption of AC-WC mixtures. This research was conducted experimentally in the laboratory using ESP variations of 2%, 6%, and 10%. The tests included material characterization, aggregate gradation design, Marshall testing, determination of optimum asphalt content, and water absorption testing. The results show that the optimum asphalt content was 5.24%. The mixture with 6% ESP produced the most balanced performance, with a stability value of 2373.09 kg, Marshall flow of 3.53 mm, VIM of 4.51%, VMA of 20.20%, VFA of 77.67%, density of 2.36 g/cm³, MQ of 673.75 kg/mm, and the lowest water absorption of 0.495%. In terms of flow behavior, the 6% ESP mixture remained within the required specification range, indicating adequate flexibility without excessive deformation. In terms of water absorption, the 6% ESP mixture showed the best resistance to water ingress compared with the 2% and 10% ESP mixtures. The 2% ESP content was insufficient to produce a void structure that met the specifications, while the 10% ESP content tended to increase mixture stiffness and water absorption. Therefore, the use of 6% ESP has the potential to serve as an environmentally friendly alternative filler in AC-WC mixtures, particularly in improving the balance between Marshall flow characteristics and water absorption resistance.

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INTRODUCTION

Road infrastructure is an important component in supporting community mobility, goods distribution, and regional economic growth. In flexible pavement structures, Asphalt Concrete-Wearing Course (AC-WC) functions as a surface layer that directly receives traffic loads and interacts with temperature changes and rainwater. Therefore, AC-WC mixtures must have good stability, flexibility, density, and water resistance in order to provide an optimal service life [1,2].

The performance of asphalt mixtures is strongly influenced by aggregate composition, asphalt content, and filler material. Filler functions to fill the voids between aggregates, increase mixture density, improve asphalt-aggregate bonding, and affect Marshall parameters such as stability, flow, VIM, VMA, VFA, density, and Marshall Quotient (MQ) [2,3]. The use of insufficient filler can cause the mixture to become less stable, while excessive filler can make the mixture too stiff and more susceptible to cracking [4].

In recent years, the utilization of waste materials as alternative materials in asphalt mixtures has been increasingly developed. This approach not only aims to improve the technical performance of the mixture but also supports the principles of sustainable construction by reducing waste and improving the efficiency of natural material use [5,6]. One type of waste that has the potential to be used as an alternative filler is eggshell powder. Eggshells contain a high amount of calcium carbonate ($CaCO_3$), which gives them characteristics similar to lime and makes them potentially capable of improving the bond between asphalt and aggregate [7,8].

Several previous studies have shown that eggshell powder can be used as a filler or modifying material in asphalt mixtures. Rumbyarso and Ulum [9] stated that the use of duck eggshell as a filler in asphalt concrete mixtures was able to produce stability values that met the specifications. Erfen and Yunus [10] also showed that eggshell is suitable for use as a filler in hot mix asphalt at certain contents. Masued [11] found that the use of 6% eggshell powder was able to provide good mixture performance based on Marshall parameters. Another study by Razzaq et al. [12] showed that the addition of eggshell powder could affect the physical and mechanical properties of hot mix asphalt.

Nevertheless, most previous studies have mainly focused on Marshall stability, VIM, VMA, VFA, and MQ. Studies that specifically examine the effect of eggshell powder on flow characteristics and water absorption in AC-WC mixtures are still limited. In fact, flow indicates the ability of the mixture to undergo plastic deformation when receiving loads, while water absorption is directly related to the potential for moisture-induced damage, such as stripping and the loss of bonding between asphalt and aggregate [2,13].

Based on the explanation above, this study was conducted to analyze the utilization of eggshell powder as a filler in AC-WC mixtures in relation to Marshall flow characteristics and water absorption. The eggshell powder variations used in this study were 2%, 6%, and 10%. This research is expected to contribute to the development of road pavement materials that are environmentally friendly, economical, and sustainable.

METHODS

This study employed a laboratory experimental method. The materials used consisted of coarse aggregate, fine aggregate, conventional filler, 60/70 penetration asphalt, and eggshell powder as an alternative filler. Material testing was conducted to ensure that all materials met the applicable testing standards. Coarse aggregate testing included sieve analysis, specific gravity, water absorption, and abrasion tests, referring to SNI ASTM C136:2012, SNI 1969:2016, and SNI 2417:2008 [14–16]. Fine aggregate testing was carried out based on SNI ASTM C136:2012 and SNI 1970:2016 [14,17].

The 60/70 penetration asphalt was tested through penetration, softening point, flash point and fire point, specific gravity, and ductility tests in accordance with the relevant SNI standards [18–22]. Meanwhile, the eggshell powder filler was tested through sieve analysis and specific gravity testing to determine its suitability as a filler material in asphalt mixtures [14,23].

The AC-WC mixture design was carried out based on the 2018 General Specifications of Bina Marga Revision 2 [1]. The optimum asphalt content was determined through Marshall testing on the baseline mixture. After the optimum asphalt content was obtained, specimens with eggshell powder variations of 2%, 6%, and 10% were prepared. Marshall testing was conducted to obtain the values of stability, flow, density, VIM, VMA, VFA, and MQ. Water absorption testing was also carried out to determine the ability of the mixture to absorb water after the immersion process.

The research stages began with a literature review on Asphalt Concrete-Wearing Course (AC-WC) mixtures, the use of alternative fillers, the utilization of eggshell powder, the Marshall method, flow characteristics, and water absorption in asphalt mixtures. After that, material collection was conducted, consisting of coarse aggregate, fine aggregate, filler, 60/70 penetration asphalt, and eggshell waste. The eggshell waste was then processed through several stages, namely washing to remove impurities, drying to reduce moisture content, grinding into powder, and sieving until it passed the No. 200 sieve in order to meet the characteristics required for filler material.

The next stage was the physical property testing of the materials to ensure that all materials used met the applicable specifications. After the materials were declared suitable, the combined aggregate proportions were designed according to the AC-WC gradation. Then, the estimated asphalt content and optimum asphalt content were determined as the basis for specimen preparation. Marshall specimens were prepared for two types of mixtures, namely the baseline mixture without eggshell powder and the variation mixtures containing eggshell powder (ESP) as an alternative filler. In this study, ESP was not used as a substitute for asphalt or aggregate, but was introduced as a filler variation in the AC-WC mixture at contents of 2%, 6%, and 10%.

Marshall testing was conducted to obtain the values of stability, flow, density, VIM, VMA, VFA, and Marshall Quotient (MQ). In addition, water absorption testing was also conducted on the eggshell powder variation mixtures to determine the ability of the mixture to resist water ingress. All test results were then analyzed to determine the effect of eggshell powder variations on the characteristics of the AC-WC mixture and to identify the optimum eggshell powder content.

The materials used in the AC-WC mixture in this study consisted of coarse aggregate, fine aggregate, conventional filler, 60/70 penetration asphalt, and eggshell powder as an alternative filler.

Figure 1. Constituent materials of the AC-WC mixture consisting of eggshell powder, coarse aggregate, fine aggregate, and 60/70 penetration asphalt.

The ESP variations used in this study were 2%, 6%, and 10%. The 2% variation represented a low filler content, the 6% variation represented an intermediate content that was expected to be the optimum content, while the 10% variation was used to evaluate the effect of higher filler content on the performance of the mixture.

Table 1. ESP variation in the AC-WC mixture

Mixture	ESP Content	Description
Baseline	0%	AC-WC mixture without ESP variation
Variation 1	2%	Low ESP content
Variation 2	6%	Intermediate ESP content
Variation 3	10%	High ESP content

Figure 2. Marshall test specimens of the AC-WC mixture with ESP variations.

The parameters analyzed in this study included density, VIM, VMA, VFA, stability, flow, Marshall Quotient (MQ), and water absorption. Density was used to determine the compactness level of the asphalt mixture after the compaction process. VIM was analyzed to determine the percentage of air voids within the mixture, while VMA was used to determine the amount of voids in the mineral aggregate of the asphalt mixture. In addition, VFA was analyzed to determine the percentage of voids in the aggregate structure that were filled with asphalt.

Stability was used to determine the ability of the mixture to withstand loads without experiencing permanent deformation. Flow was analyzed to determine the flow characteristics or the amount of plastic deformation of the mixture when subjected to loading. In addition to the Marshall parameters, this study also analyzed water absorption to determine the ability of the mixture to resist water ingress into the mixture voids. All of these parameters were used to evaluate the performance of the AC-WC mixture with eggshell powder (ESP) as a filler variation.

RESULTS AND DISCUSSION

Results and Discussion of Material Testing

The parameters analyzed in this study include density, VIM, VMA, VFA, stability, flow, Marshall Quotient (MQ), and water absorption. Density was used to determine the compactness level of the asphalt mixture after the compaction process. VIM was analyzed to determine the percentage of air voids within the mixture, while VMA was used to determine the amount of voids in the mineral aggregate of the asphalt mixture.

Stability was used to determine the ability of the mixture to withstand loads without experiencing permanent deformation. Flow was analyzed to determine the flow characteristics or the amount of plastic deformation of the mixture when subjected to loading. In addition to the Marshall parameters, this study also analyzed water absorption to determine the ability of the mixture to resist water ingress into the mixture voids. All of these parameters were used to evaluate the performance of the AC-WC mixture with eggshell powder as a filler variation.

Determination of the Optimum Asphalt Content

The design of aggregate proportions was conducted based on the specified AC-WC gradation. The calculation of the estimated asphalt content produced a pKAO value of 5.24%. Marshall tests were then performed on several asphalt content variations to determine the optimum asphalt content for the AC-WC mixture.

Table 2. Summary of Marshall Test Results for the Baseline Mixture

Asphalt Content (%) (%)	VMA (%)	VIM (%)	VFA (%)	Stability (kg)	Density (gr/cm³)	Flow (mm)	MQ (kg/mm)
4,24	13,39	3,95	70,48	1498,45	2,39	3,60	417,22
4,74	15,84	5,50	65,26	1447,01	2,34	2,33	625,51
5,24	14,95	3,34	77,68	1865,03	2,38	5,01	379,03
5,74	14,77	1,94	86,88	1607,78	2,39	3,45	483,30
6,24	14,76	0,50	96,59	1331,24	2,41	3,81	422,20
Specification	≥15	3–5	≥65	≥800	-	2–4	≥250

Based on the baseline test results, the optimum asphalt content was determined to be 5.24%. This value was then used as the fixed asphalt content for the ESP variation mixtures. In general, an increase in asphalt content affects the volumetric and mechanical parameters of the mixture. The highest stability value in the baseline mixture was obtained at an asphalt content of 5.24%, with a stability of 1865.03 kg. This indicates that, at this asphalt content, the mixture had the best load-bearing capacity compared to the other asphalt content variations.

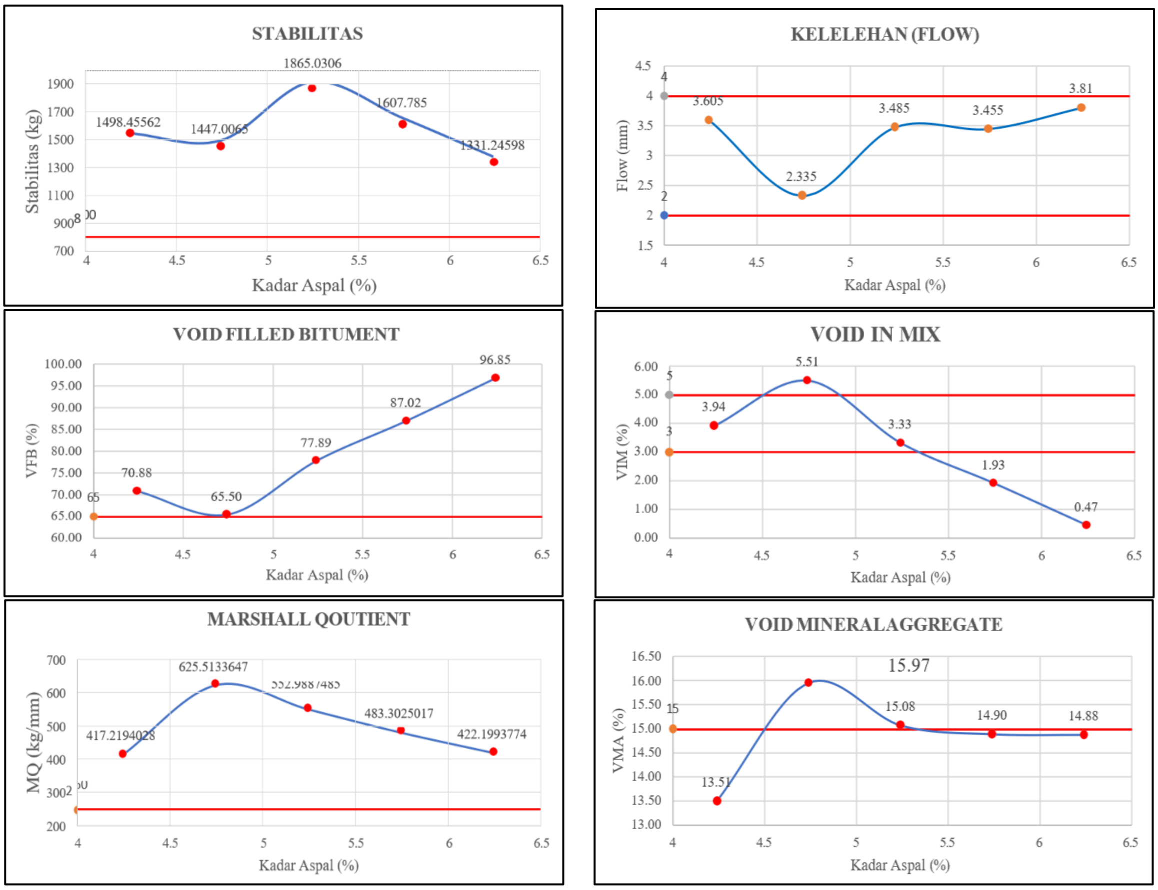


Figure 3. Relationship Between Asphalt Content and Stability, Flow, MQ, VIM, VMA, and VFB of the Baseline Mixture.

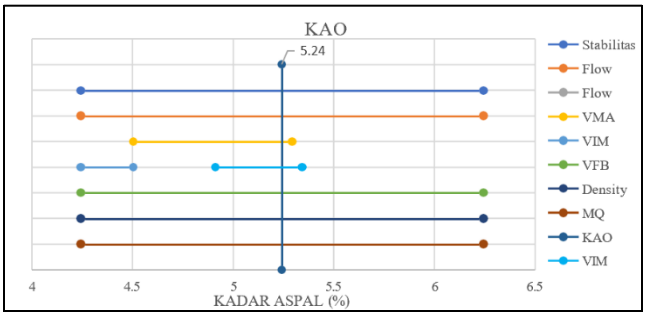


Figure 4. Optimum Asphalt Content (OAC) Graph

However, not all parameters of the baseline mixture were in ideal condition. The flow value at 5.24% asphalt content was recorded at 5.01 mm, which exceeded the specification range of 2–4 mm. This condition indicates that the baseline mixture at this asphalt content had relatively high plastic deformation. Therefore, the addition of ESP as an alternative filler was evaluated to determine whether the mixture could achieve a more balanced performance, particularly in terms of flow and water absorption.

Marshall Test Results for Mixtures with ESP Variations

After the optimum asphalt content was obtained, the AC-WC mixtures were prepared using ESP filler variations of 2%, 6%, and 10%. The Marshall test results of the ESP variation mixtures are presented in the following table:

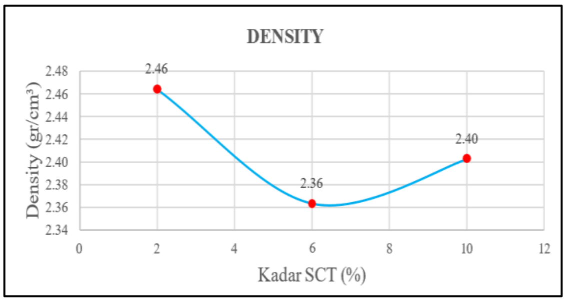
Table 3. Summary of Marshall test results for mixtures with ESP variations

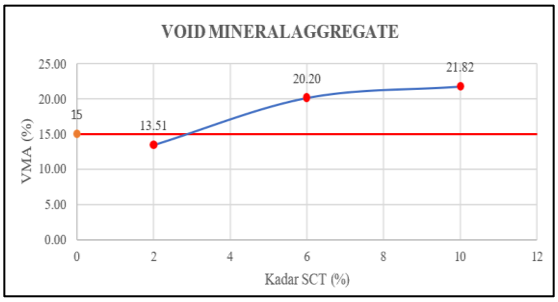
%OAC	ESP %	VMA	VIM %Pori	VFB	Stability kg	Density kg/cm³	Flow mm	MQ kg/mm
5,24	2	13,51	1,14	91,59	1774,99	2,46	2,44	727,25
5,24	6	20,20	4,51	77,67	2373,09	2,36	3,53	673,75
5,24	10	21,82	2,24	89,72	2328,07	2,40	2,67	873,10
Specification		≥15	3-5	≥65	≥1000	-	2-4	≥250

Based on Table 1.3, the 6% ESP content was the variation that provided the most balanced performance. This can be seen from its highest stability value of 2373.09 kg and a flow value of 3.53 mm, which remained within the specification limits. In addition, the VIM value of 4.51% also met the specification range of 3–5%, indicating that the air voids in the mixture were in an ideal condition.

At 2% ESP content, the stability value of 1774.99 kg still met the minimum specification. However, the VMA value of 13.51% and the VIM value of 1.14% did not meet the required specifications. The excessively low VIM value indicates that the air voids in the mixture were too small. This condition may reduce the available space for asphalt expansion when temperature increases, potentially leading to bleeding or deformation.

At 10% ESP content, the stability value remained high at 2328.07 kg. However, the VIM value of 2.24% did not meet the specification. In addition, the MQ value of 873.10 kg/mm indicates that the mixture tended to be stiffer. A mixture that is too stiff may increase the risk of cracking when subjected to repeated loading or temperature changes.





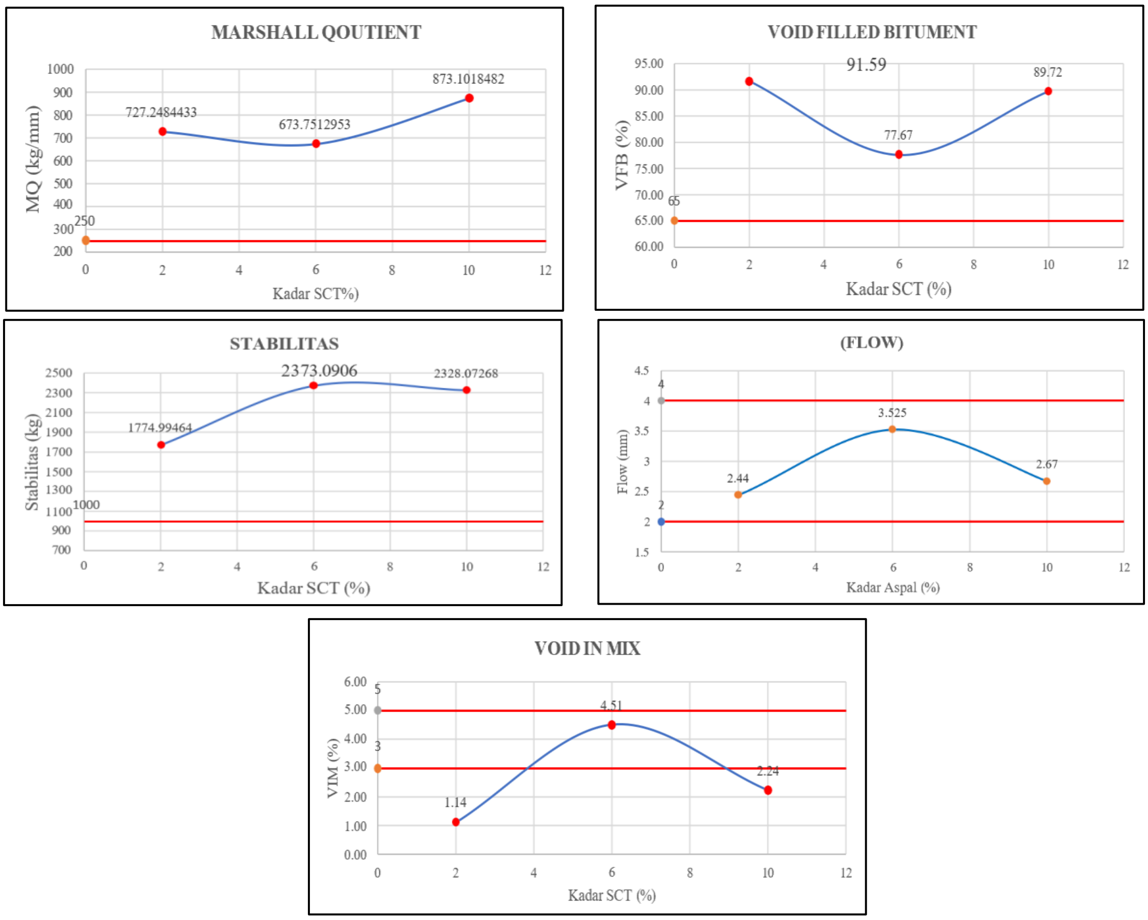


Figure 5. Relationship between ESP content and density, VMA, stability, flow, MQ, VIM, and VFB.

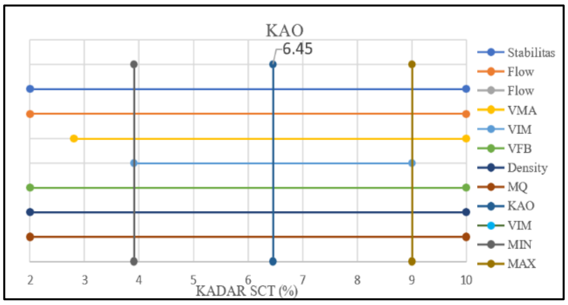


Figure 6. Optimum Asphalt Content (OAC) Graph

Stability Analysis

Stability is a key parameter that indicates the ability of the mixture to withstand loads without experiencing permanent deformation. The test results showed that all ESP variations met the minimum stability specification, which is greater than 1000 kg. The stability value at 2% ESP content was 1774.99 kg, increased to 2373.09 kg at 6% ESP content, and then slightly decreased to 2328.07 kg at 10% ESP content.

The increase in stability at 6% ESP content indicates that eggshell powder was able to function effectively as a filler. The fine ESP particles filled the voids between aggregates, resulting in a denser and stronger mixture structure. In addition, the $CaCO_3$ content in ESP is believed to help improve the adhesion between asphalt and aggregate.

The decrease in stability at 10% ESP content, although not significant, indicates that excessive filler addition does not always improve mixture performance. A filler content that is too high may cause the mixture to become stiffer, disrupt asphalt distribution, and reduce workability during compaction. Therefore, 6% ESP can be considered the optimum content in terms of stability.

Analysis of Flow Characteristics in the AC-WC Mixture

Flow indicates the ability of the mixture to undergo plastic deformation when subjected to loading. A flow value that meets the specification indicates that the mixture still has sufficient flexibility. In this study, all ESP variations had flow values within the specification range of 2–4 mm.

The flow value at 2% ESP content was 2.44 mm, increased to 3.53 mm at 6% ESP content, and reached 2.67 mm at 10% ESP content. The 6% ESP content provided the most balanced flow value because it was neither too low nor exceeded the maximum specification limit. This indicates that the mixture with 6% ESP had good deformation capacity without losing its stability.

At 2% ESP content, the relatively low flow value indicates that the mixture tended to be stiffer. This condition may occur because the amount of filler was not sufficient to form a stable mixture distribution. At 10% ESP content, although the flow value still met the specification, the mixture showed a tendency to become stiffer due to the increased MQ value. This indicates that excessive filler content may increase the stiffness of the mixture.

Therefore, in terms of flow characteristics, the 6% ESP content is the most appropriate composition because it produced a flow value within the specification limits and was supported by the highest stability value.

Analysis of VIM, VMA, and VFA

Volumetric parameters are very important in determining the durability of asphalt mixtures. VIM represents the air voids within the mixture, VMA represents the voids in the mineral aggregate, and VFA represents the percentage of voids filled with asphalt. At 2% ESP content, the VIM value of 1.14% and the VMA value of 13.51% did not meet the required specifications. This indicates that the mixture was too dense and did not provide sufficient air voids. An excessively low VIM value may cause the mixture to become less stable under temperature changes.

At 6% ESP content, the VIM value was 4.51%, the VMA value was 20.20%, and the VFA value was 77.67%. These three parameters met the required specifications. This condition indicates that the mixture had a good balance between air voids, voids in the mineral aggregate, and voids filled with asphalt. This balance is important for maintaining the stability and durability of the mixture.At 10% ESP content, the VMA value of 21.82% and the VFA value of 89.72% met the specifications, but the VIM value was only 2.24%, which did not meet the required range of 3–5%. The low VIM value indicates that the air voids in the mixture were too small. In addition, a high filler content may cause the mixture to become too stiff and less flexible. Based on the volumetric parameters, the 6% ESP content was the best variation because all the main parameters met the required specifications.

Marshall Quotient Analysis

Marshall Quotient is the ratio between stability and flow. The MQ value indicates the stiffness level of the mixture. The higher the MQ value, the stiffer the mixture. The results showed that all ESP variations met the minimum MQ specification of 250 kg/mm. The MQ value at 2% ESP content was 727.25 kg/mm, at 6% ESP content was 673.75 kg/mm, and at 10% ESP content was 873.10 kg/mm. The highest MQ value occurred at 10% ESP content, indicating that this mixture had the highest stiffness. However, excessive stiffness should be considered carefully because it may increase the risk of cracking.

The 6% ESP content produced a more balanced MQ value because it remained high but did not indicate excessive stiffness. This finding confirms that the 6% ESP content is more suitable for producing a stable, sufficiently flexible, and deformation-resistant mixture.

Water Absorption Analysis

Water absorption was used to evaluate the ability of the mixture to resist water ingress into its pore structure. The higher the water absorption value, the greater the possibility of moisture-induced damage, such as stripping or the loss of bonding between asphalt and aggregate.

Table 4. Water absorption test results of mixtures with ESP variations

Content ESP	Dry Weight (gr)	SSD Weight (gr)	Water Absorption (%)
2%	1207,9	1214,8	0,571
6%	1251,9	1258,1	0,495
10%	1301,2	1313,2	0,922

The test results showed that the 6% ESP content produced the lowest water absorption value, which was 0.495%. This value was lower than that of the 2% ESP content, which was 0.571%, and the 10% ESP content, which was 0.922%. The low water absorption at 6% ESP content indicates that the ESP filler was able to effectively fill the voids between aggregates, thereby reducing the pathways for water to enter the mixture.

At 2% ESP content, the amount of filler was not sufficient to optimally fill the voids, leaving open pores that allowed water to enter the mixture. Meanwhile, at 10% ESP content, the water absorption value increased significantly. This may occur because excessive filler disrupts the workability of the mixture, results in less ideal compaction, and potentially forms new micropores.

Relationship between Flow Characteristics and Water Absorption

The relationship between flow and water absorption shows that the 6% ESP content provided the best balance between flexibility and water resistance. At this content, the flow value of 3.53 mm still met the specification, while the water absorption reached the lowest value of 0.495%. This indicates that the mixture was neither too stiff nor too plastic and had a relatively dense internal structure.

At 2% ESP content, the flow value met the specification; however, the VIM and VMA values did not meet the required standards, indicating that the mixture structure was not yet ideal. At 10% ESP content, the flow value also met the specification, but the water absorption increased. This condition shows that the flow value alone is not sufficient to determine the quality of the mixture. The analysis must also consider the volumetric parameters and water absorption. Therefore, the optimum ESP content is not only determined by the highest stability value, but also by the balance among flow, VIM, VMA, VFA, MQ, density, and water absorption.

Determination of Optimum Eggshell Powder (ESP) Content

Based on all testing parameters, the eggshell powder (ESP) content of 6% was identified as the optimum variation in the AC-WC mixture. This is indicated by the highest stability value of 2373.09 kg, which shows that the mixture had the best ability to withstand loads. In addition, the flow value of 3.53 mm was still within the specification range, indicating that the mixture maintained good plastic deformation capacity and was not excessively stiff.

From the volumetric aspect, the 6% ESP content also showed results that met the required specifications. The VIM value of 4.51% was within the specification range of 3–5%, indicating that the air voids in the mixture were in an ideal condition. The VMA value of 20.20% met the minimum requirement of 15%, while the VFA value of 77.67% also met the minimum requirement of 65%. This condition indicates that the mixture had a good balance between air voids, voids in the mineral aggregate, and voids filled with asphalt.

Furthermore, the Marshall Quotient (MQ) value at 6% ESP content was 673.75 kg/mm, which met the minimum specification of 250 kg/mm. This indicates that the mixture had sufficient stiffness without losing its flexibility. The 6% ESP content also produced the lowest water absorption value of 0.495%, indicating that the mixture had better resistance to water ingress. Therefore, the 6% ESP content can be considered the optimum content because it produced a good balance among stability, flow, volumetric parameters, stiffness, and resistance to water absorption.

These results indicate that the use of waste material as an alternative material should be applied at an appropriate content. The 6% ESP content provided the best performance, whereas the 10% ESP content was not the optimum variation because it tended to increase mixture stiffness and resulted in higher water absorption. This phenomenon is in line with the findings of Hijriah et al. [19], which showed that the excessive use of waste materials can cause an imbalance in particle distribution, form additional voids, and reduce the internal density of the material.

The 2% ESP content was not optimum because the VIM and VMA values did not meet the required specifications. The 10% ESP content was also not the best option because, although its stability value remained high, the water absorption increased and the mixture tended to become stiffer. Therefore, the 6% ESP content was selected as the most balanced optimum content.

CONCLUSION

Based on the research results, the optimum asphalt content for the AC-WC mixture was obtained at 5.24%. Eggshell powder was proven to be applicable as an alternative filler because it affected the mixture performance, particularly in terms of stability, flow, volumetric parameters, Marshall Quotient (MQ), and water absorption. Among all variations tested, the 6% eggshell powder content was the optimum variation, producing the highest stability value of 2373.09 kg, a flow value of 3.53 mm, VIM of 4.51%, VMA of 20.20%, VFA of 77.67%, MQ of 673.75 kg/mm, and the lowest water absorption value of 0.495%. The 2% ESP variation did not show optimum performance because the VIM and VMA values did not meet the required specifications. Meanwhile, the 10% ESP variation was also not the best variation because it tended to increase the stiffness of the mixture and produced the highest water absorption value of 0.922%. Therefore, the use of 6% ESP was able to produce an AC-WC mixture that was more stable, sufficiently flexible based on Marshall flow, met the volumetric parameter requirements, and had better resistance to water absorption.

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