

Analysis of Volumetric Characteristics of Cold Emulsion Asphalt Mixtures on Closed and Open Gradation with Cement and Lime Filler Variations

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Abstract: Cold Emulsion Asphalt Mixture (CAED) uses unheated emulsified asphalt, thus reducing gas emissions and health risks for workers. Volumetric characteristics and aggregate gradation are very important to assess the quality of CAED. Therefore, the purpose of this study is to examine the volumetric characteristics of CAED, namely Void in Mix (VIM), Void in Mineral Aggregate (VMA), and Void Filled with Bitumen (VFB), with variations in filler (cement, lime) and aggregate gradation (dense, open). The study used a laboratory experimental method, including material preparation, sample preparation with five variations of filler, testing VIM, VMA, and VFB values, and data analysis. This study shows that the volumetric characteristics of CAED with closed and open gradations meet the VMA and VFB specifications, but the VIM value is only met in the closed gradation of CAED with a variation of 50% cement:50%. Better aggregate interlocking in closed gradations results in smaller air voids. Closed gradations are recommended for heavy traffic, while open gradations are suitable for well-drained roads and light traffic.

Keywords: Aggregate gradation; CAED; Cement filler; Lime filler; Volumetric characteristics

Introduction

Cold Emulsion Asphalt Mixture (CAED) is an innovation in road pavement technology that can be used without a heating process. In the manufacture of hot asphalt mixtures, high temperatures are needed to melt the asphalt to make it easier to mix it with aggregate (Wulandari et al., 2023b). CAED uses emulsion asphalt as a binder in asphalt mixtures. Emulsion asphalt is made by mixing asphalt with water, and to unite water with asphalt is added with an emulsifier. Because this emulsion asphalt is in the form of a liquid colloid at room temperature, it allows mixing to be carried out without heating. Cold asphalt mixtures therefore provide several advantages over hot mixtures, especially in terms of energy efficiency and environmental impact (Karyawan et al., 2023). CAED

does not require additional energy for heating, so it is more energy-efficient and environmentally friendly, in line with the need for more sustainable technology in the construction sector (Lawalata, 2020).

Technically, emulsion asphalt in CAED is a stable liquid made from asphalt, water, and emulsifying materials. This emulsifier material keeps the asphalt dispersed in water at room temperature, so that CAED can be mixed and applied without heating (Purnomo et al., 2010). It differs from conventional asphalt which requires high temperatures to achieve ideal viscosity. With room temperature as the process condition, CAED not only reduces greenhouse gas emissions from fuel combustion but also lowers health risks for workers exposed to overheating or harmful fumes when mixing and applying asphalt mixtures (Winoko & Santoso, 2020).

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Volumetric characteristics such as Void in Mix (VIM), Void In Mineral Aggregate (VMA), and Void Filled With Asphalt (VFB) are important factors in the quality assessment of CAED. VIM refers to the volume of air void within a mixture, VMA is the volume of void in unfilled mineral aggregates, whereas VFB is the percentage of volume of void filled with asphalt. These three characteristics play a significant role in determining the stability, durability, and resistance of the mixture to traffic loads (Hamzah et al., 2016). Mixtures that have the right VIM, VMA, and VFB values will be better able to survive in the long term and provide better stability against deformation or damage (Karyawan et al., 2021). For example, a VIM value that is too low can result in cracking due to the lack of expansion space will cause bleeding and the mixture is susceptible to plastic grooves. (rutting), while a VIM value that is too high can reduce load resistance (Kurniawan et al., 2021).

One of the main factors affecting the volumetric characteristics of CAED is aggregate gradation, which is the distribution of aggregate grain sizes within the mixture. The aggregate gradation determines the size and distribution of the void between the aggregate grains, which directly affects the VIM, VMA, and VFB values (Winardi et al., 2022). Tight gradations, which have a more uniform grain size distribution, tend to produce denser mixtures with lower VIM values and strong interlocking between grains, which contributes to the stability of the mixture. On the other hand, open gradations have an uneven distribution of grains, resulting in mixtures with larger void and higher VIM values (Ayun & Prastyanto, 2021).

This study aims to analyze the volumetric characteristics of CAED through the variation of cement and lime fillers, and to examine the performance of two types of aggregate gradations: tight gradation and open gradation. The special purpose of this study is to understand the influence of filler composition

variations and aggregate gradation types on VIM, VMA, and VFB values. This analysis is expected to provide in-depth insights into the optimal CAED design for road pavement applications, both in terms of long-term stability and effective use of resources (Hartanto et al., 2016). Thus, this research can help direct the selection of CAED designs that are efficient, sustainable, and meet the technical requirements required in road pavement.

This study offers new insights into the optimal design of Cold Emulsion Asphalt Mixtures (CAED) emphasizing quality and resource efficiency criteria. The topic highlights the relationship between filler variations (cement, lime) and aggregate gradation types (dense, open) in influencing the volumetric characteristics of CAED, which has not been widely explored.

Method

This study uses a laboratory experimental approach to analyze the volumetric characteristics of a mixture of cold emulsion asphalt with variations of cement filler and lime on two types of aggregate gradations (Oruc et al., 2007). The experimental approach is considered the most appropriate in assessing the performance of asphalt mixtures because it can facilitate controlled testing on specific material variations (Susanto & Suaryana, 2019). The stages of this laboratory research include material preparation, sample making, testing, and data analysis which are carried out systematically.

Material Preparation

The initial stage of the research involves the preparation of the main materials in the form of aggregate, cement, lime, and emulsion asphalt used as materials in the manufacture of cold asphalt concrete mixtures (see Figure 1).

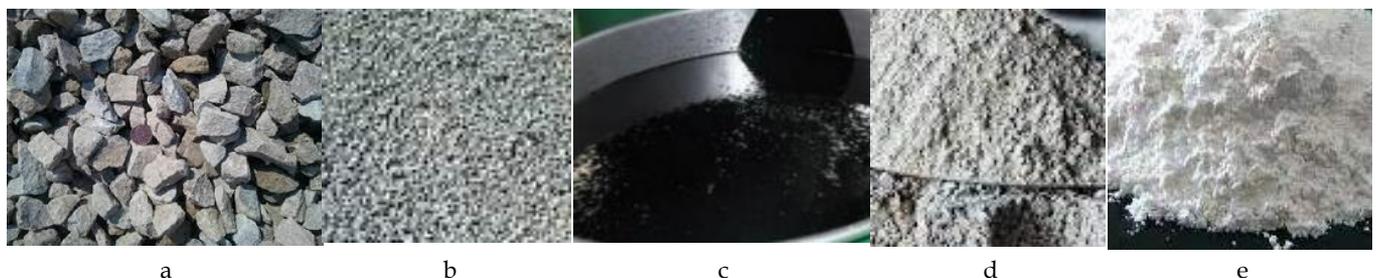


Figure 1. CAED material: (a) Coarse aggregate, (b) Fine aggregate, (c) Emulsion asphalt, (d) Cement filler, (e) Lime filler

Preparation of aggregates that are suitable for gradation is very important (Setiawan et al., 2016) because the size and distribution of aggregate particles

will affect the volumetric characteristics of the mixture, such as VIM (Void In Mix), VMA (Void In Mineral Aggregate), and VFB (Void Filled With Asphalt) (One et

al., 2020; Shah & Abdullah, 2010). The aggregate gradation used consists of a closed gradation and an open gradient, as shown in Figure 2. Cement and lime are used as fillers, each of which has a different function in improving the cohesion and stability of the mixture

(Padallingan et al., 2024; Sarsam & Samor, 2020). Emulsified asphalt acts as a binder for aggregates and fillers in mixtures at room temperature without the need for heating (Wulandari & Tjandra, 2023).

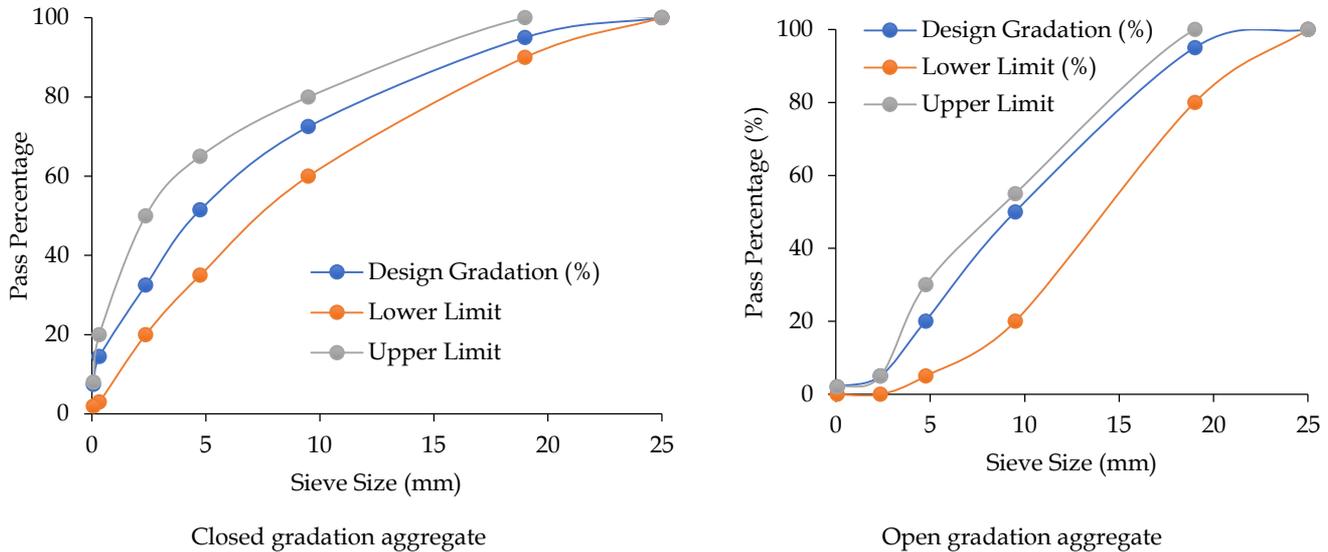


Figure 2. Aggregate grading specification

Mixed Sample Making

The next stage is the creation of cold asphalt concrete samples with five variations in the composition of cement and lime filler. The composition was divided into five variations to observe the influence of the proportions of cement and lime on the volumetric characteristics of the mixture. These variations are: The variations are: Variation 1: 0% cement: 100% lime; Variation 2: 25% cement: 75% lime; Variation 3: 50% cement: 50% lime; Variation 4: 75% cement: 25% lime; Variation 5: 100% cement: 0% lime.

Previously, volumetric characteristics (VMA, VIM, VFB) and mechanical (stability, flow, Marshall Quotient) tests were carried out to obtain KARO (optimum residual asphalt content). Each sample was made in 3 pieces to be tested for volumetric characteristics. The mixing process is carried out at room temperature in a uniform manner to avoid variations in mixing techniques that can affect the final result.

Sample Testing

After manufacturing, each sample is tested for VIM, VMA, and VFB scores. VIM, VMA, and VFB measurements are important in determining the quality of asphalt mixtures because they relate to the stability and durability of the mixture against deformation and

damage due to traffic loads (Nageim et al., 2012; Hidayatulloh et al., 2021; One et al., 2020). This test is carried out using a method that refers to pre-established standards, ensuring that the results can be consistently compared between filler variations.

Data Analysis

The test result data was then analyzed to evaluate the performance of each filler variation and aggregate gradation type. This analysis aims to identify filler variations that produce the most optimal volumetric characteristics, both in tight and open gradations. The analysis in this experiment can help in identifying significant differences between the variations and determining the most suitable filler composition to improve the quality of the cold asphalt mixture. Careful analysis is expected to provide an in-depth understanding of the effect of cement filler and lime proportions on the performance of cold emulsion asphalt mixtures.

Result and Discussion

The aggregate used in this study consists of coarse aggregate and fine aggregate. The aggregate test results are shown in Table 1 and Table 2.

Table 1. Coarse aggregate test results

Types of Testing	Terms*	Method	Results
Apparent Specific Gravity (Gsa)	> 2.5	SNI 1969-2008	2.89
Dry Specific Gravity (Gsb)	> 2.5	SNI 1969-2009	2.75
Surface Dry Saturated Specific Gravity (Gss)	> 2.5	SNI 1969-2010	2.80
Effective Specific Gravity (Gse)	> 2.5	SNI 1969-2011	2.82
Water Absorption (Gsw)	< 3%	SNI 1969-2012	1.80

(*) Source: Spesifikasi Umum Bina Marga 2018 Revisi 2 (2020)

Table 2. Fine aggregate test results

Types of Testing	Terms*	Method	Results
Apparent Specific Gravity (Gsa)	> 2.5	SNI 1970-2008	2.61
Dry Specific Gravity (Gsb)	> 2.5	SNI 1970-2008	2.54
Surface Dry Saturated Specific Gravity (Gss)	> 2.5	SNI 1970-2008	2.64
Effective Specific Gravity (Gse)	> 2.5	SNI 1970-2008	2.57
Water Absorption (Gsw)	< 3%	SNI 1970-2008	1.18

(*) Source: Spesifikasi Umum Bina Marga 2018 Revisi 2 (2020)

Emulsion Asphalt Test Results

The test of emulsion asphalt was obtained from PT Asphalt Karya Nusantara's test data, except for the specific gravity of emulsion asphalt. The emulsion asphalt used is CSS-1h type emulsion asphalt. Cationic emulsion asphalt is divided into four categories based on the setting speed, namely CSS (Cationic Slow Setting), CMS (Cationic Medium Setting), CRS (Cationic Rapid Setting), and CQS (Cationic Quick Setting).

Viscosity and penetration significantly affect the stability and porosity of the specimen (Irianto et al., 2021). Stability and porosity increase as viscosity and penetration decrease. CSS-1h was chosen because it has low viscosity and penetration compared to CMS-2 and CRS-2 (One et al., 2020; Wulandari et al., 2023a; Wulandari et al., 2023b). The results of the CSS-1h emulsion asphalt test are shown in Table 3.

Table 3. Results of CSS1h emulsion asphalt test

Types of Testing	Unit	Method	Results*)	Specification**)
Residue Level	%	SNI 2488:2011	68.70	Min. 57
Electric Particle Charge	-	SNI 03-3644-1994	Positive	Positive
Sedimentation Per 24 Hours	%	SNI 6828:2001	0.81	Max. 1
Viscosity	second	SNI 06-6721-2002	85.00	20-100
Sieve Analysis	%	SNI 3643:2012	0.00	Max. 0.1
Solubility in Trichloroethylene	%	SNI 2438:2015	1.022	≥1.0

Source: *) PT. Asphalt Karya Nusantara; **) Spesifikasi Umum Bina Marga 2018 Revisi 2 (2020)

Results of Asphalt Specific Gravity Test

The optimum residual asphalt content that will be used for the next sample is 7.5% of the total mixture. the emulsion obtained through testing with the SNI 2441:2011 method was 1.012. The results show that the emulsion asphalt has met the requirements of the 2018 Bina Marga General Specification Revision 2 (2020) where the specific gravity of asphalt is ≥ 1.0. Therefore, it can be concluded that emulsion asphalt can be used for further testing in this study as a mixture of cold emulsion asphalt (CAED).

specific gravity which will later be used for marshal volumetric calculations. The filler test is presented in Table 4.

Table 4. Filler test results

Testing	Results
Specific Gravity of Fly ash	2.167
Cement Specific Gravity	2.742
Lime Specific Gravity	2.620

Test Results of Optimum Residual Asphalt Content (KARO)

The determination of the optimum residual asphalt content in this study uses Marshall's characteristic values, namely Stability, Fatigue (flow), VMA, VIM,

Results of Filler Test

The test of filler materials includes screening materials that pass the filter no.200 (0.075 mm) and

VFB, MQ (Marshall Quotient). The test results for the optimum residual asphalt content can be seen in Figure

1. The optimum residual asphalt content that will be used for the next sample is 7.5% of the total mixture.

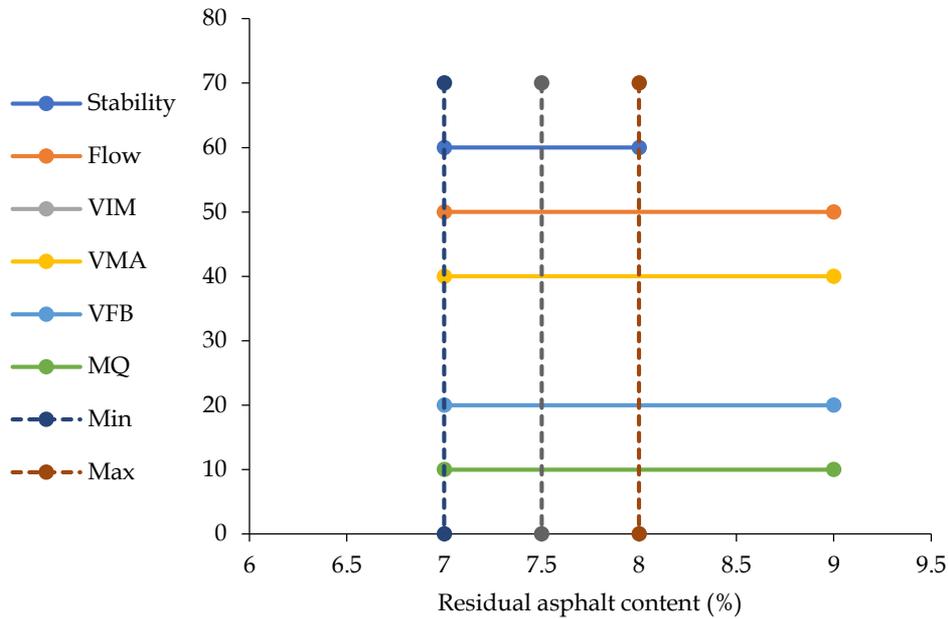
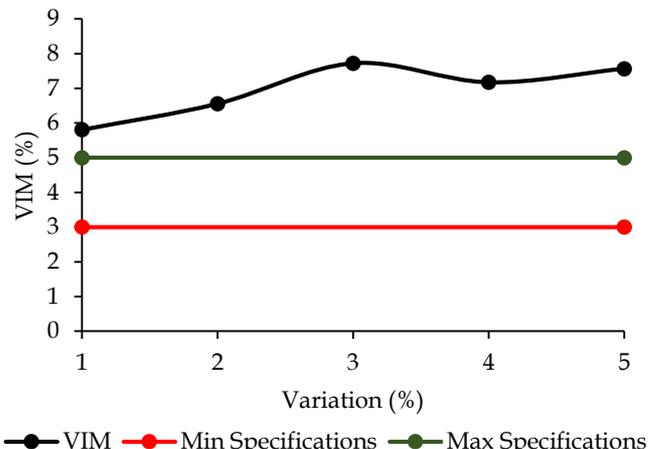
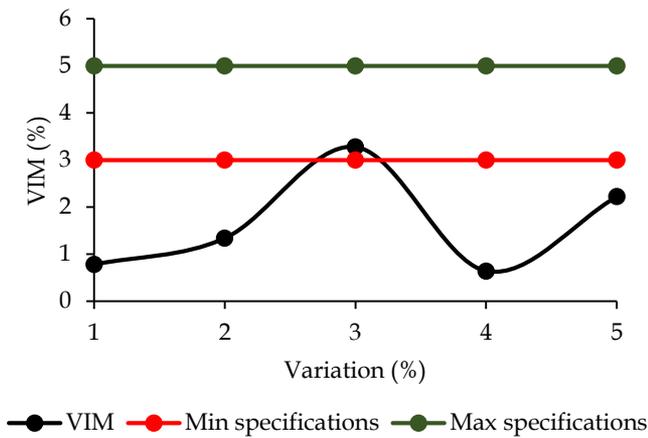


Figure 3. Determination of Optimum Residual Asphalt Rate (KARO's)

Analysis of cavity characteristics in the mixture (VIM) of CAED mixtures

In Figure 2, it is shown that the VIM value in the closed gradation is only Variation 3 (50% Cement: 50% Lime) that meets the VIM specification in the range of 3-

5%. The VIM value on the open gradation has no variation that meets the specification because all variations are above the upper limit of the specification. This is due to the larger inter-aggregate void.



Closed gradation aggregate

Open graded aggregate

Figure 4. Relationship of variation with VIM values for closed and open gradations

VIM analysis on emulsion asphalt mixtures for closed and open gradations, shown in Figure 3. In closed gradations, only variation 3 meets the VIM standard, while the other variations do not, because the VIM value obtained is lower than the minimum

specification. On the other hand, open gradation results in a VIM value that exceeds the upper limit of the specification on all variations. A low VIM at a closed gradation indicates a higher material density, while an open gradation, with a VIM above the specification,

reflects a discontinuous distribution of aggregate grains, resulting in a larger air cavity.

The density of the mixture has a direct effect on structural strength (Wijaksono et al., 2023). Only variation 3 on closed gradations meets VIM specifications, so it has a higher potential in terms of resistance to deformation and heavy traffic loads. Other variations may have a risk of deterioration in performance due to their less than optimal density.

Excessive air void at open gradations can increase the risk of water infiltration, which in turn accelerates damage from freeze-thaw or other degradation processes (Mohi et al., 2020). A high VIM at open gradation indicates a susceptibility to this damage, which has the potential to shorten the life of the road if not managed properly (Syahairony & Naibaho, 2024; Anas et al., 2020).

Closed gradation is suitable for use on high-traffic roads because better density can withstand the load

more effectively (Setiawan et al., 2017). Meanwhile, open gradations, which have high porosity, are recommended for surfaces that require high drainage, although they are only ideal for roads with light traffic (Kusharto, 2017). This interpretation highlights the importance of selecting gradations according to specifications, considering environmental conditions and traffic loads to improve road durability and longevity (Thanaya et al., 2022).

Characteristic Analysis of CAED Void in Mineral Aggregate (VMA)

In Figure 2, it is shown that the VMA values in the closed and open gradations of all variations are above the minimum limit of 14%, indicating good results (Hmoud, 2011). Similar to VMA, the VFB value shows the entire gradation with 5 variations meeting the requirements (minimum 65), as shown in Figure 3.

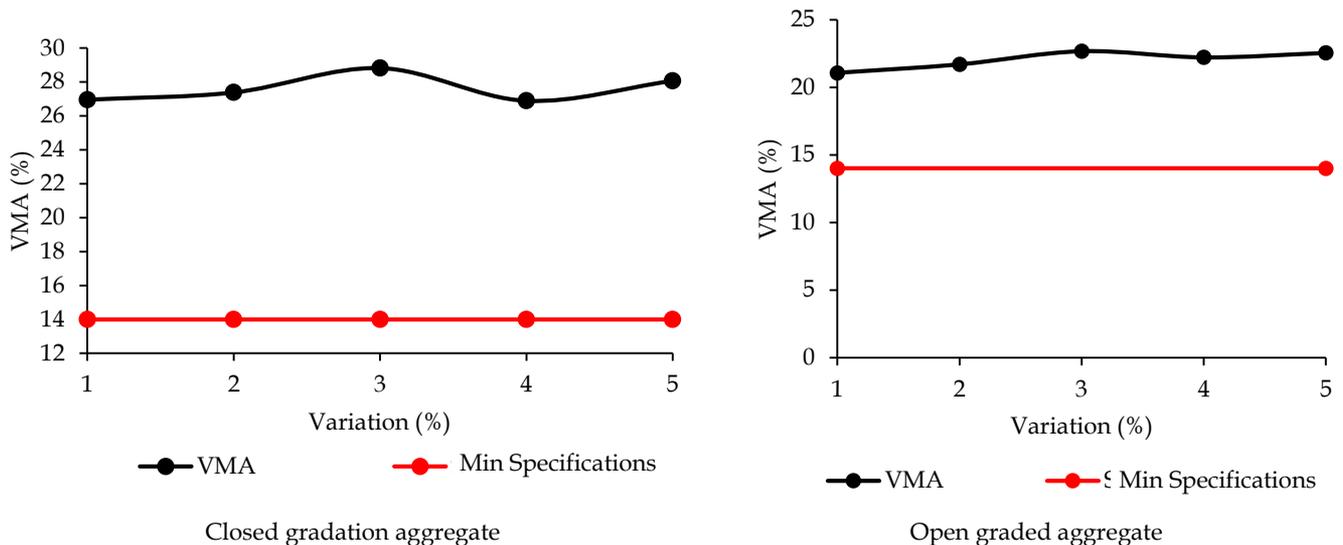


Figure 5. Relationship of variation with VMA values for closed and open gradations

Figure 5 shows the results of Void in Mineral Aggregate (VMA) analysis on emulsion asphalt mixtures with closed and open gradations. Demonstrated compliance with VMA requirements on all filler variations in both gradation types, with higher yields at closed gradations. In both types of gradations, all filler variations met the VMA requirement above 14%, while closed gradients showed higher VMA values than open gradients. A higher VMA value at the closed gradation indicates that the tight grain distribution favors interlocking between aggregate particles (Yuniarti, 2015). This reduces the cavity between the grains and results in better mixture density.

An adequate VMA is essential to ensure the stability of the asphalt mixture (Gusty, 2024). With a VMA above 14%, the mix has enough space to hold the

necessary asphalt, providing good stability. Closed gradations, which have higher VMA values, show greater stability potential, especially in withstanding deformation due to heavy traffic loads. The tight distribution of grains in closed gradations improves interlocking, i.e. bonds between grains that help increase structural strength and resistance to deformation (Alzara et al., 2024). This reduces the void between the particles resulting in a mixture that is more resistant to external pressure (Ramlan, 2016).

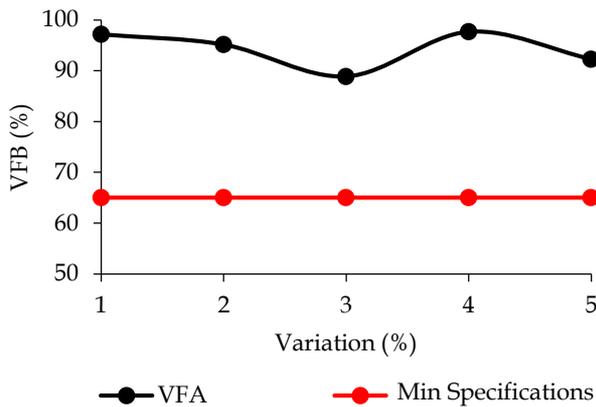
Closed gradations with high VMA values are suitable for road surfaces that require high structural strength and durability, for example on heavy traffic roads. Open gradations, while meeting VMA standards, are more ideal for roads with high drainage

requirements because lower interlocking results in greater porosity (Haryati et al., 2019).

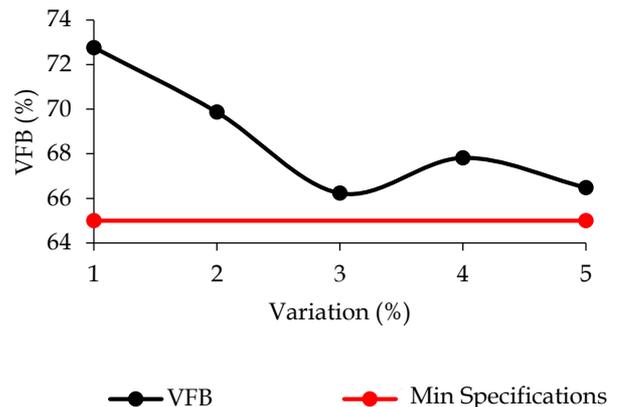
This explanation highlights the importance of selecting gradations according to the purpose of use and environmental conditions, where closed gradations are more suitable for long-term stability and durability, while open gradations are suitable for better drainage on light roads.

Analysis of the Characteristics of Void Filled with Bitumen (VFB) of CAED Mixtures

Results of Void Filled with Bitumen (VFB) analysis on emulsion asphalt mixture with closed and open



Closed gradation aggregate



Open graded aggregate

Figure 6. Relationship of variation with VFB values for closed and open gradations

Results of VFB analysis on emulsion asphalt mixture with closed and open gradations. It shows that the VFB values on both gradation types meet the standard above 65%, with variations in the interlocking rate and VFB values between closed and open gradients. Both gradations have VFB values above 65% for all filler variations, but open gradients tend to have lower VFB values than closed gradients. Open gradations result in lower VFB values due to less strong interlocking between grains than closed gradations (Tumpu & Irianto, 2022), which have a tight grain distribution resulting in increased interlocking and higher VFB. VFB is an important indicator in determining asphalt's resistance to deformation (Shahnewaz et al., 2024), because void filled asphalt can increase resistance to traffic loads (Putri et al., 2019). Higher VFB values at closed gradations signify better levels of mix density and higher resistance to deformation (Putri et al., 2019).

Strong interlocking on closed gradations creates a more even distribution of pressure within the mixture, resulting in better resistance to deformation. At open gradations, lower interlocking leads to lower VFB, so the

gradations. It shows that the VFB values on both gradation types meet the standard above 65%, with variations in the interlocking rate and VFB values between closed and open gradients. Both gradations have VFB values above 65% for all filler variations, but open gradients tend to have lower VFB values than closed gradients. Figure 6 shows that the open gradation results in a lower VFB value due to the less strong interlocking between the grains than the closed gradation, which has a tight grain distribution that increases the interlocking and results in a higher VFB.

mixture is more susceptible to wear and deformation if used on high-traffic roads (Shahnewaz et al., 2024).

Closed gradation is suitable for road surface coatings with heavy traffic loads because the high VFB and strong interlocking increase the bearing capacity and road life (Shahnewaz et al., 2024). In contrast, open gradations, while VFB eligible, are better suited for well-drained roads, where the traffic load is lighter because the grain structure allows water to flow out more quickly. This interpretation shows that closed gradations are preferred for heavy traffic conditions due to higher VFB and interlocking values, while open gradients are suitable for high-drainage roads that serve for light loads (Syahairony & Naibaho, 2024; Pangestika et al., 2023).

Conclusion

This study shows that the volumetric characteristics of cold emulsion asphalt mixture with closed and open gradations meet the specifications of VMA and VFB, but the VIM value is only met at closed gradation with Variation 3 (50% Cement: 50% Lime). This is because

closed gradations result in better interlocking between aggregates, so that the formed air void are smaller, as opposed to open gradations.

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Author Contributions

Conceptualization, writing—review and editing, I.D.M.A.K., R.Y., D.W., and F.F.S.; methodology, I.D.M.A.K. and R.Y.; validation, I.D.M.A.K., D.W., and F.F.S.; collection of experimental data, visualization, analysis, I.D.M.A.K., R.Y., D.W., F.F.S., B.S.S.F., and B.A.L.S.; writing—original draft preparation, I.D.M.A.K., F.F.S., B.S.S.F., and B.A.L.S. All authors have read and approved the published version of the manuscript.

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Conflicts of Interest

All author declare that there is no conflict of interest.

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