The Performance of Asphalt Concrete Wearing Course Mix using De-oiled Bleaching Earth as Filler reviewed from Marshall Parameters

Muhammad Bagus Miftah
Department of Civil Engineering, State University of Malang, Indonesia
muhammad.bagus.1905216@students.um.ac.id

Boedi Rahardjo
Department of Civil Engineering, State University of Malang, Indonesia
boedi.rahardjo.ft@um.ac.id (corresponding author)

Pranoto
Department of Civil Engineering, State University of Malang, Indonesia
pranoto.ft@um.ac.id

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ABSTRACT

Road construction is essential to support connectivity, mobility, and economic growth. However, road construction can raise economic, social, and environmental issues. Many attempts have been made to develop the concept of sustainable road construction and to minimize environmental impacts by utilizing various materials. This work studies the incorporation of De-Oiled Bleaching Earth (DBE) as a filler into the Asphalt Concrete Wearing Course (AC-WC) mixture. The research objectives were first to analyze the characteristics of the ingredients that make up the AC-WC mixture and second to analyze the performance of AC-WC with DBE as a filler in terms of Marshall parameters. The results revealed that AC-WC with 10% DBE complied with the standard requirements. The highest stability was obtained with 10% DBE content, and the lowest was obtained with 90% DBE. The overall flow values of the specimens met the standards, except for the DBE content of 70% and 100%. The VIM values of the 0% and 10% DBE specimens were 4.76 and 4.87%, respectively, which met the specification standard of 3-5%. All samples exhibited VMA values ≥ 15% in accordance with the specifications. VFA values that met the specifications of ≥ 65% were obtained for DBE levels of 0, 10, 20, and 40%. MQ values that fulfilled the specification of ≥ 250 kg/mm were achieved for 0, 10, 20, 30, 40, 60, and 90% DBE. Thus, DBE can be used as a filler material in AC-WC mixtures for environmentally friendly road construction. The optimum content of DBE in the AC-WC mixtures was found to be 10%.

Keywords-asphalt pavement; DBE filler; AC-WC; Marshall parameters

I. INTRODUCTION

Extensive road development is essential to enhance connectivity and community mobility as well as to stimulate economic growth [1]. Various issues have developed in relation to road construction, including economic, social, and environmental factors [2]. Authors in [3] proposed a sustainable road construction project called the Green Road Solution. This project aims to minimize the environmental impact of road construction by utilizing recycled pavement materials, modified asphalt materials, and industrial waste in road construction. Authors in [4] modelled a road sustainability framework based on the triple bottom-line concept. The two assessment approaches identified were the Life Cycle Assessment (LCA) and sustainability rating systems (SRS). These studies contribute to raise individuals' understanding of road sustainability.

By using recyclable industrial waste or environmentally friendly components in asphalt concrete mixture modifications, experts have tried to create a number of innovations to add to the idea of sustainable road construction [5, 6]. Asphalt concrete mixtures are prepared by mixing asphalt, aggregates, additives, and fillers. Some additives used in asphalt concrete mixtures are fiberglass geogrids and carbon fibers [7, 8]. Fly ash, Portland cement, plastic waste, limestone, and other materials have been deployed to improve the performance of the mixtures [9]. The fillers utilized in asphalt concrete mixtures are selected based on specific characteristics, such as particle size, surface area, chemical properties, and physical properties, which influence the performance of the mixture [10]. The mixtures employed in the design of road buildings must adhere to specified regulations such as the specifications proposed by the American Association of State Highway and Transportation Officials (AASHTO) [11].

The Asphalt Concrete Wearing Course (AC-WC) layer is located at the uppermost part of the flexible pavement, specifically engineered to withstand various forms of load. However, poor AC-WC designs with narrow gradations result in several problems with AC-WC and the formation of puddles after rain. When rainwater is not drained effectively owing to poor drainage channels [12], the AC-WC structure experiences durability issues and rutting damage [13, 14].

This study investigates the use of De-Oiled Bleaching Earth (DBE) as a filler in AC-WC mixtures to enhance the performance and mitigate the environmental impact of DBE disposal. DBE is an industrial waste produced by Crude Palm Oil (CPO) refining. The abundance of CPO [15] is an opportunity to exploit DBE in road construction. DBE is a light brown fine powder that exhibits characteristics similar to fly ash and contains aluminum, silica (SiO_2), and iron oxide (Fe_2O_3) [16]. This substance is an essential binding factor for AC-WC to create a rigid and hard compound reaction [17]. According to the elemental analysis results, DBE can be utilized as a filler in AC-WC mixtures. In this study, the characteristics and performance of AC-WC were determined using DBE as the filler.

II. MATERIALS AND METHODS

A. Asphalt Properties

The asphalt material used in this study was sourced from Pertamina Manufacturing, with a penetration grade of 60/70. The evaluation results of the asphalt compared to the requirements are displayed in Table I.

TABLE I. ASPHALT REQUIREMENTS AND EVALUATION

Property	Test result	Technical requirement
Penetration (0.1 mm)	64.65	60 - 70
Ductility (cm)	150	≥ 100 cm
Softening Point (˚C)	49.5	48°C – 58 °C
Flash Point (˚C)	262	≥ 232 °C
Burn Point (˚C)	278	≥ 232 °C
Specific Gravity	1.125	≥ 1.00 gr/cm^3
Losing Weight (%)	0.25	≤ 0.8%

B. Aggregate and Filler Properties

The local stone utilized as aggregate and filler was evaluated to estimate the physical properties and their compliance with asphalt concrete grading, which is applied in Indonesia. The results of specific gravity and water absorption of coarse and fine aggregates are presented in Table II.

C. X-Ray Fluorescence (XRF) Analysis

Figure 1 shows the XRF spectrum of 5 g DBE. Significant amounts of Fe, Si, and Ca were observed. Table III lists the relative amounts of each element detected from the XRF measurements. Figure 2 illustrates that the DBE exhibits a brownish hue with fine grains, resembling fly ash and cement.

TABLE II. AGGREGATE PHYSICAL PROPERTIES

Property	Test result	Technical requirement
Los Angeles Abrasion Test Value (%)	14.60	Max 40%
Specific Gravity of Coarse Aggregate (gr/cm^3)		
Bulk Specific Gravity	2.56	Min 2.5 gr/cm^3
SSD Specific Gravity	2.63	
Apparent Specific Gravity	2.77	
Water Absorption of Coarse Aggregate (%)	2.96	Max 3%
Specific Gravity of fine Aggregate (gr/cm^3)		
Bulk Specific Gravity	2.57	Min 2.5 gr/cm^3
SSD Specific Gravity	2.63	
Apparent Specific Gravity	2.72	
Water Absorption of Fine Aggregate (%)	2.14	Max 3%
Specific Gravity Portland Cement (gr/cm^3)	3.13	Min 2.5
Specific Gravity De-Oiled Bleaching Earth (gr/cm^3)	2.00	

TABLE III. ELEMENTAL ANALYSIS OF DBE

Element	% Amount
Al	4.6
Si	28.6
P	6.37
K	3.65
Ca	14.9
Ti	2.52
V	0.21
Mn	0.45
Cr	0.1
Fe	37.1
Ni	0.07
Cu	0.23
Zn	0.11
Eu	0.3
Yb	0.1
Re	0.3
Pb	0.38

D. Selection of Mix Design

Mix planning is a quantitative procedure employed to calculate the required amounts of asphalt and aggregate for the mixture by analyzing their respective weights. Coarse aggregate was selected using sieve diameters ranging from No. ¾ (19 mm) to No. 4 (4.75 mm). The fine aggregate was passed from sieves No. 4 to No. 200 (0.075 mm). According to the 2018 Bina Marga Indonesia specification, the aggregate for AC-WC is predominantly fine in size [18]. The aggregate must be dry and free from dust and dirt. The aggregate gradation is presented in Table IV and Figure 3.

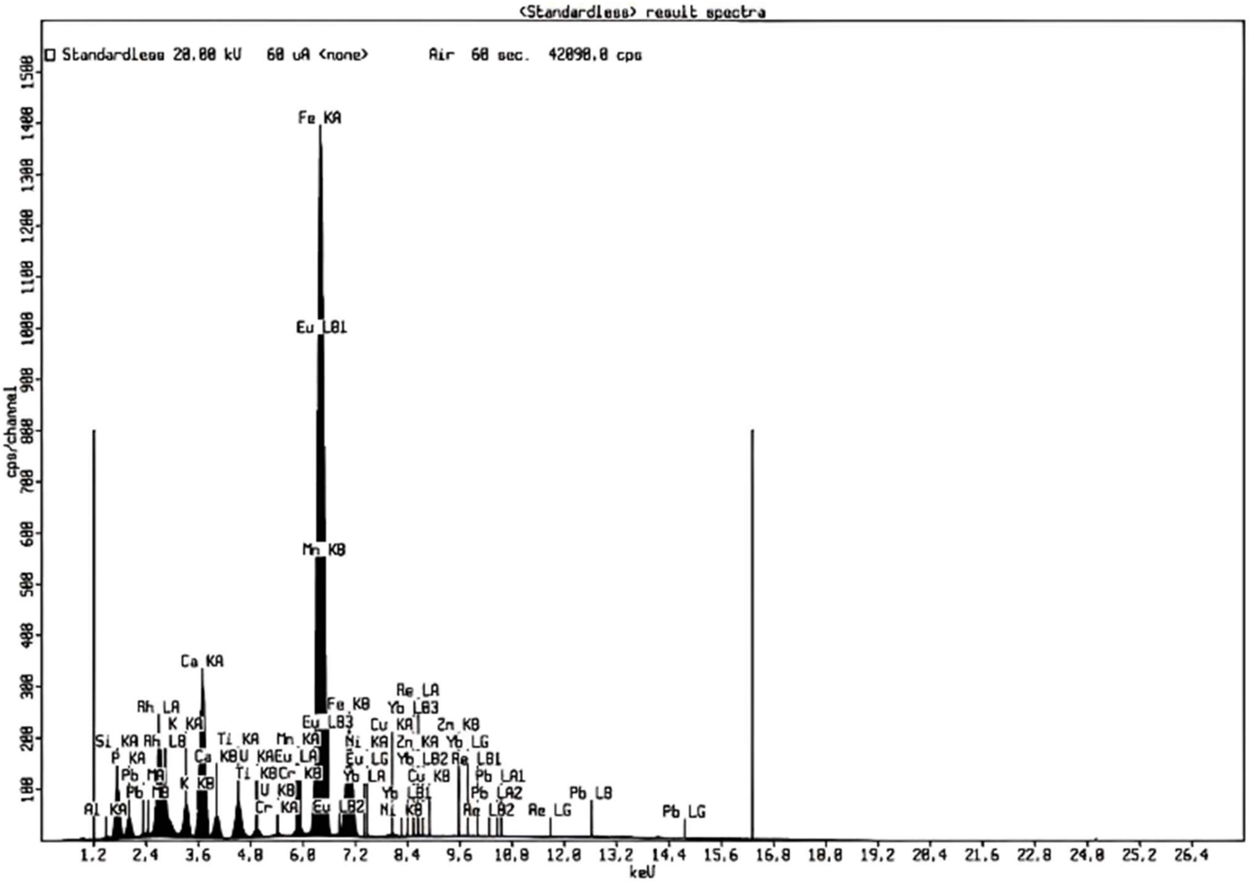

Fig. 1. XRF spectrum of DBE.

Fig. 2. Photograph of DBE.

TABLE IV. AGREGATE SIZE GRADATION [18]

ASTM sieve size (mm)	Specification limit (%)	%used in experiment	%retained	%Passing by weight (gram)
19	100	100	0	0
12.5	90-100	95	5	60
9.5	77-90	83.5	11.5	138
4.75	53-69	61	22.5	270
2.36	33-53	43	18	216
1.18	21-40	30.5	12.5	150
0.6	14-30	22	8.5	102
0.3	9-22	15.5	6.5	78
0.15	6-15	10.5	5	60
0.075	4-9	6.5	4	48
filler			6.5	78
Total				1200

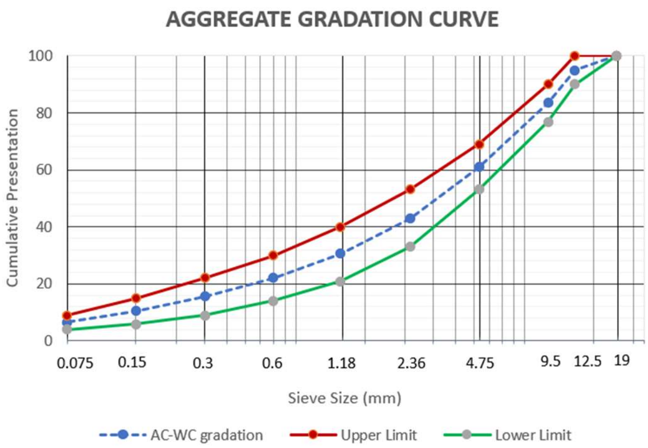

Fig. 3. Aggregate Gradation Curve for AC-WC.

E. *Calculation of Plan Asphalt Content*

Calculation of the plan asphalt content, Pb, was carried out to determine the Optimum Asphalt Content (OAC) using (1):

$$Pb = 0.035(\%CA) + 0.045(\%FA) + 0.18(FF) + K \quad (1)$$

Based on the weight graduation percentage of the mix gradation listed in Table IV, the %CA, %FA, and %FF values of the following mix were obtained:

$$\%CA = (0 + 5 + 11.5 + 22.5)\% = 39\% \quad (2)$$

$$\%FA = (18 + 12.5 + 8.5 + 6.5 + 5 + 4)\% = 54.5\% \quad (3)$$

$$\%FF = 6.5\% \quad (4)$$

In this study, K was set constant at 1.0. Thus, according to (1), the Pb is:

Pb = 0.035 (% CA) +0.045 (%FA) +0.18 (% FF) + K

Pb = 0.035 (39%) +0.045 (54.5%) +0.18 (6.5%) +1.0

Pb = 5.9875% ≈ 6%

F. Mix Design of AC-WC

This study adopted the Marshall methodology [19]. The independent variable was the filler DBE, and the dependent variable was the Marshall parameter. Pb was used to determine OAC percentages of 5%, 5.5%, 6%, 6.5%, and 7%. For each OAC percentage 3 samples were prepared, making a total of 15 test specimens. After identifying the OAC, the DBE filler content was varied from 0% to 100% at 10% intervals. Three specimens were prepared for each DBE amount, for a total of 33 specimens with varying DBE content. Ordinary Portland Cement (OPC) was deployed as the filler in the OAC specimens to determine the percentage ratio of DBE in them. OPC was selected due to its compliance with the specifications outlined in ASTM C150-12 standard [20], which qualifies it as an acceptable filler material. In addition, OPC exhibits consistent stability [21]. OPC has a smaller particle size than other fillers, such as fly ash, making it more convenient to be mixed with asphalt [6]. In addition, cement exhibits qualities similar to those of the aggregate and binder [22]. To prepare the test specimens, fillers were incorporated into the mixture using the dry method.

Fig. 4. Testing of DBE specimens using a Marshall Multiloader.

A total of 48 specimens with various amounts of OAC and DBE were prepared for the Marshall tests. The Marshall parameters evaluated were stability, flow, Marshall Quotient (MQ), and Voids In the Mix (VIM). The equipment used for the Marshall tests was MULTILOADER 34-V1182 (Figure 4), and the measurements were carried out following the ASTM D1559, D5581, and D6927 standards [23-25].

G. Specimen Preparation and Testing Procedure

Material preparation for the test specimens was carried out by separating the aggregates according to their fractions, washing them thoroughly with water, and drying them at a temperature of 105 ± 5 °C for 4 h to remove the water content. Each fraction was weighed according to the gradation to a total weight of 1200 g for each test specimen. The filler was then passed through a No. 200 sieve. The aggregates and fillers were heated to 120 °C in a pan. On the other hand, the asphalt was heated to melt at 160 °C and then weighed to reach OAC 6% or 72 grams of the total weight. Asphalt was added to the mixture at 155 °C and stirred until it was homogeneous. After the material was evenly mixed, the mixture was lifted and placed in a mold that had been greased with oil. While waiting for the temperature to drop to 145 °C, the mixture was pierced with 15 punctures at the edges and 10 punctures in the middle, so that no voids were formed. Subsequently, 2 × 75 impact compaction was carried out with an asphalt compactor. The test specimens were taken from the compactor to be labelled and allowed to stand for 3 h in an open room to reduce the temperature. After removal from the ejector, the specimens were allowed to stand for a day at room temperature (25 °C) before being soaked for 24 h in water. After the 24 h soaking, the specimens were placed in a water bath at 60 °C for 30 min. The test specimens were then ready for the Marshall tests.

III. RESULTS AND DISCUSSION

A. Optimum Asphalt Content

The results of the OAC test for the 15 specimens indicated that the asphalt content of 6% satisfied all the required parameter standards, as presented in Table V. The data show an agreement between the calculation of Pb ≈ 6% and the results of the OAC test specimens. Test specimens with varying amounts of DBE were prepared with an asphalt content of 6 %.

TABLE V. MARSHALL TEST RESULTS FOR ESTIMATING OAC

Marshall Parameters	% Asphalt Content					Specification	
	5	5.5	6	6.5	7	Min	Max
Stability (kg)	768.53	775.41	1006.69	778.28	863.44	800	
Flow (mm)	3.15	3.22	3.32	4.05	4.60	2	4
VIM (%)	10.63	7.35	4.75	3.98	3.20	3	5
VMA (%)	18.52	16.55	15.22	15.59	15.93	15	
VFA (%)	42.64	56.19	68.82	74.48	80.05	65	
MQ (kg/mm)	245.76	243.01	304.24	194.13	194.9	250	

B. Characteristics of DBE Filler in AC-WC Mixtures

When incorporated into the mix as a filler, DBE exhibited characteristic behavior and performance. First, from the material mixing process at 155 °C, it was found that it was difficult to reduce the viscosity of asphalt when the DBE content was high. However, the low DBE percentage levels did not require a long time for the material to be evenly mixed. Second, asphalt as a binding material between aggregate grains displays sticky and binding properties. However, as the percentage of DBE in the mixture increased, the binding properties of the asphalt were disturbed. Asphalt absorbs more DBE, which combines with fine aggregates to form lumps so that the mixture concentrates like granules. Third, the 3-5% oil content in DBE forms an adhesion reaction in the binder, which results in the aggregate not being completely coated with asphalt [26]. The texture of the mixture of the specimens tended to be oilier at high DBE levels.

C. Density

The use of DBE as a filler affected the unit mass of the compacted mixture. Figure 5 shows that density tended to decrease as DBE levels increased. An inspection of the aggregate revealed that it formed granules, which is a factor that influences the density. After soaking for 24 h, the DBE oil content was replaced with water that entered the pores of the test object. This was proven when the weight of the test object weighed by the Saturated, Surface Dry (SSD) increased, whereas the weight in the water decreased. Another identification was that After the process of compacting the test object with a high DBE content, there was an increasing number of oil spots on the research sample paper, as evidenced in Figures 6 and 7.

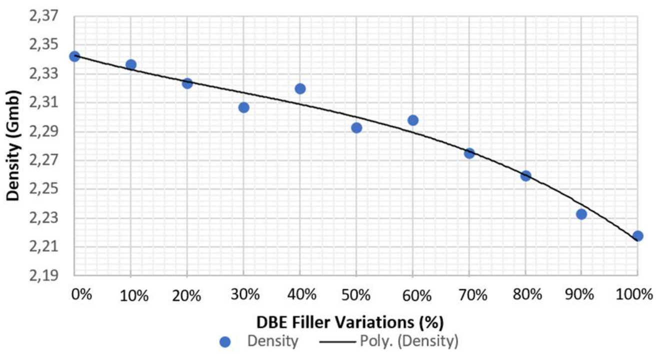

Fig. 5. Density of the mixture with increasing DBE content.

(a) (b)

Fig. 6. (a) Oil spots on 80% DBE, (b) oil spots on 100% DBE.

Fig. 7. A few oil spots were observed at 0 and 10% DBE.

D. Filler Specific Gravity

Many factors influence the results of this research test, including the calculation of the bulk, apparent, and effective specific gravity of the aggregates. Currently, there are no known specifications for DBE fillers in bulk or apparent specific gravity. The reader may refer to ASTM D-854-2006 for the procedure of testing the specific gravity of the DBE filler [27]. The results are listed in Table II, and the test results for the DBE variations are listed in Tables V and VI.

TABLE VI. CEMENT SPECIFIC GRAVITY

Property	Specific gravity		Bulk specific gravity	Apparent specific gravity	Effective specific gravity
	Bulk	Apparent	(Gsb)	(Gsa)	(Gse)
Coarse Aggregate	2.56	2.77	2.597	2.74	2.670
Fine Aggregate	2.57	2.72			
Portland Cement Filler	3.13				
DBE filler	2.00				

TABLE VII. DBE SPECIFIC GRAVITY

DBE Filler Content	Total Aggregate Composition				Bulk Specific Gravity	Apparent Specific Gravity	Effective Specific Gravity
%	%CA	%FA	%FF PC	%FF DBE	(Gsb)	(Gsa)	(Gse)
0	39	54.5	6.5	0	2.597	2.74	2.670
10	39	54.5	5.85	0.65	2.589	2.74	2.666
20	39	54.5	5.2	1.3	2.582	2.74	2.662
30	39	54.5	4.55	1.95	2.574	2.74	2.658
40	39	54.5	3.9	2.6	2.566	2.74	2.654
50	39	54.5	3.25	3.25	2.558	2.74	2.650
60	39	54.5	2.6	3.9	2.551	2.74	2.646
70	39	54.5	1.95	4.55	2.543	2.74	2.643
80	39	54.5	1.3	5.2	2.535	2.74	2.639
90	39	54.5	0.65	5.85	2.528	2.74	2.635
100	39	54.5	0	6.5	2.520	2.74	2.631

E. Stability

Figure 8 demonstrates that the addition of the DBE filler decreased the stability of the mixture. Several factors can influence stability, such as the aggregate gradation composition, mixing temperature, compaction temperature, and density of the test object. The filler material determines the adhesion properties between the aggregate and binder. Commercial materials, such as cement, have a chemical affinity that has been technically evaluated compared to DBE for asphalt; however, the stability of AC-WC with DBE filler is inconsistent. The decrease in stability is caused by the remaining oil content in the DBE, which softens the mixture, and the high percentage of Si compounds, which plays a role in reducing the interlocking ability between the aggregate and asphalt. Authors in [28] explained that the use of silica-based fillers causes poor adhesion between mixed elements. In [29], it was shown that adding used oil to an asphalt mixture can increase asphalt softening and reduce mixture cohesion.

Laboratory test findings disclosed an increase in stability when the filler was added after the aggregate was heated at a temperature of 100 °C, compared to the filler that was heated from the start of heating. Thus, the characteristics of the constituent materials in the form of DBE fillers play a role in determining the mechanical properties of the AC-WC mixture.

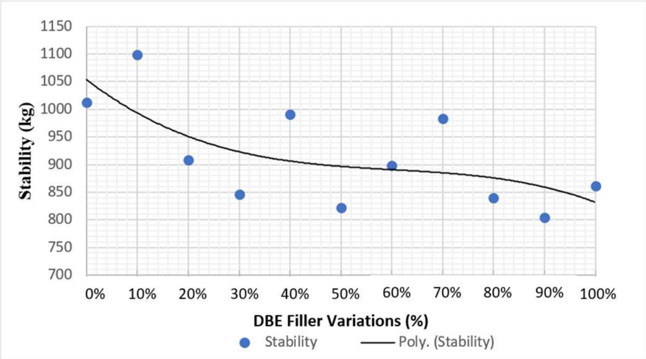

Fig. 8. Stability of the mixture with increasing DBE content.

F. Flow

A large percentage of the DBE in the mixture demonstrated an increase in the flow above the specification limit of 4 mm, as portrayed in Figure 10. The high flow was caused by an increase in the temperature during the material mixing process. The oil content in DBE prolongs the asphalt viscosity reduction process. Increasing the percentage of DBE in the mixture had no effect on the flow value, as long as the mixing temperature of the materials met the standard specifications.

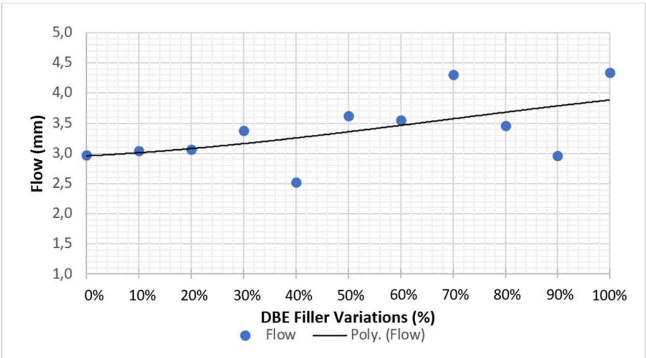

Fig. 9. Flow of the mixture with increasing DBE content.

G. Voids in Mix

The increase in VIM, as observed in Figure 10, is a result of the specific gravity of the DBE filler being lower than that of the cement. The formation of fine grains and filler absorption of water and asphalt play a role in determining the voids between the aggregate grains. The DBE filler is difficult to dissolve in water if it is not stirred, and it dissolves in water when it becomes a homogeneous component. Observations made during sieving revealed that DBE had a greater percentage of passing than cement through sieve No. 200. Thus, DBE contains finer particles than cement.

H. Voids in Mineral Aggegrate

Figure 11 shows that all the specimens met the requirements for >15% VMA. The VMA increased for DBE contents of over 60%.

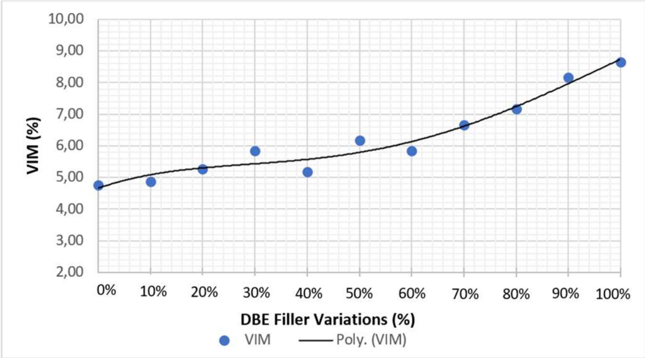

Fig. 10. VIM with increasing DBE content.

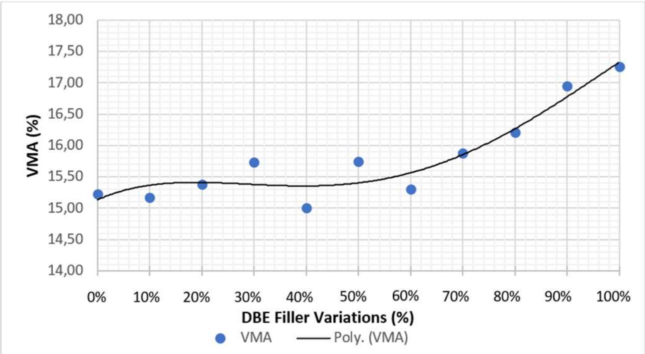

Fig. 11. VMA with increasing DBE content.

I. Voids Filled with Asphalt

Figure 12 illustrates the VFA evolution with DBE content. The specimens with 0, 10, 20, and 40% DBE contents exhibited VFA over the requirement of 65%.

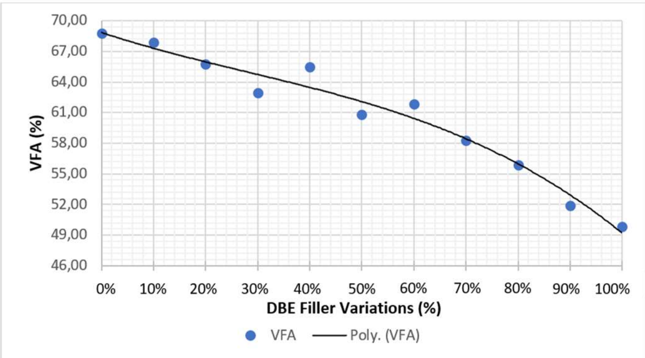

Fig. 12. VFA with increasing DBE content.

J. Marshall Quotient

Figure 13 presents the MQ values with increasing DBE content. The higher the MQ value is, the more resistant the mix is to wear, deformation, and cracking. DBE variations of 0%, 10%, 20%, 30%, 40%, 60%, and 90% met the requirement of ≥ 250 kg/mm.

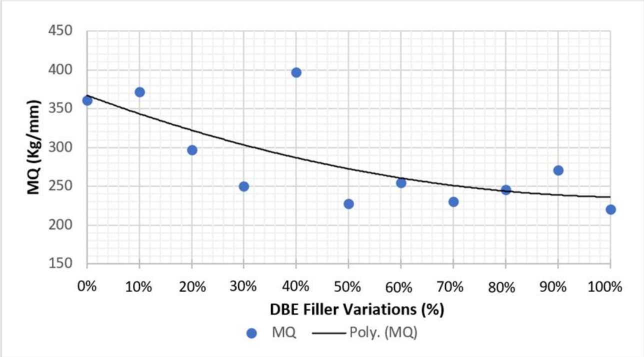

Fig. 13. MQ evolution with increasing DBE content.

IV. CONCLUSIONS

The analysis of the specimen test results revealed interesting conclusions. Specifically, the characteristics of the AC-WC mixture include aggregate, asphalt, and filler testing, all of which satisfy the specification requirements. The performance of AC-WC using DBE filler indicates that the overall stability value meets the specifications of ≥ 800 kg. The highest stability performance was obtained for a 10% DBE content of 1098.94 kg, and the lowest was obtained for a 90% DBE content of 803.89 kg. Furthermore, with an increase in DBE content, the flow increased, and all DBE variations met the requirements, except for 70% and 100% DBE content. The 0% and 10% DBE specimens exhibited VIM values of 4.76% and 4.87%, respectively, which were within the specification requirements. The specification of ≥ 15% VMA was met for all the specimens. VFA values over the specification of ≥ 65% were achieved for 0%, 10%, 20%, and 40% DBE. MQ values greater than ≥ 250 kg/mm of the specification were obtained at 0%, 10%, 20%, 30%, 40%, 60%, and 90% DBE contents.

The characteristic feature of mixing AC-WC with DBE filler is that it forms granules. The DBE oil content prolongs the process of reducing the asphalt viscosity but does not affect the flow value as long as the mixing temperature meets the standard specifications. The stability increased when the filler was added after the aggregate was heated at 100 °C. The AC-WC mixture with the optimum 10% DBE exhibited Marshall parameters that met the specifications. Thus, this study found that DBE can be used as a filler in AC-WC mixtures in response to sustainable road construction and efforts to reduce environmental impacts.

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