Available online at www.CivileJournal.org

Civil Engineering Journal

(E-ISSN: 2476-3055; ISSN: 2676-6957)

Vol. 8, No. 08, August, 2022

Effects of HDPE Utilization and Addition of Wetfix-Be to Asphalt Pavement in Tropical Climates

Daud Nawir [1*], Achmad Zultan Mansur [1]

[1] *Civil Engineering Department, University Borneo Tarakan, Amal lama, Tarakan 77123, Indonesia.*

Received 10 June 2022; Revised 24 July 2022; Accepted 29 July 2022; Published 01 August 2022

Abstract

Plastic Waste (PW) is one of the primary sources of pollution, leading to drainage system blockages, thereby causing floods and road pavement damage. One of the major ways to reduce pollution due to plastic waste and excessive exploitation of natural resources is through the development of HDPE. It is also important to reduce damage to road pavement structures by improving the quality of the asphalt used during construction. Therefore, this research aims to analyze the effects of using HDPE shale, an ecologically friendly material, and the addition of Wetfix-Be to asphalt pavements in tropical climates. The study results showed that 5.75% of the OAC asphalt using plastic waste raises the stability value and meets the specification requirements. Specimens of AC-WC concrete asphalt mixture were also tested by immersing them in fresh and seawater for 0.5, 24, 72, and 96 hours. In conclusion, using HDPE plastic waste and Wetfix-Be keeps the AC-WC concrete asphalt mixture stable.

Keywords: HDPE; Wetfix-Be; Soaked; AC-WC; Pavement.

1. Introduction

Due to its location on the equator, Indonesia is one of the countries with a tropical climate in Southeast Asia. According to preliminary studies, Indonesia's location in the pacific ring of fire makes it highly vulnerable to natural disasters [1]. The inability to balance high rainfall with adequate infrastructure will undoubtedly impact community problems, such as road pavement damage. This destruction, known as a puddle, is generally caused when the amount of rain and water catchment to the ground is greater than the recusing power of the soil [1]. Jakarta, Indonesia's capital and the center of economic growth, often experiences problems with high rainfall. This capital city experiences floods each time there is prolonged rainfall, with the inundation of some road points [2]. Flooding of roadways caused by significant weather events is a widespread issue in practically every region worldwide. It frequently causes temporary or long-term deterioration of pavement layers, as evident on the unbound layers beneath the bound surface, constructed with hot-mix asphalt (HMA) [3]. Flooding can significantly raise the moisture content of materials in pavements to saturation, which is known to degrade the mechanical qualities of most paving materials. Therefore, without stabilization, the stiffness of unbound materials, such as subgrade soils, aggregate base, subbase, and full depth recovered materials, decreases with an increase in susceptibility [4]. Asphalt mix stiffness is also known to diminish as moisture content increases, causing more significant damage than in dry conditions. Water can also impair the link between pavement layers, causing its structure to deteriorate significantly [5, 6].

Wetfix Be, a liquid anti-stripping additive produced by Azko Nobel Surface Chemistry for hot and warm mixed asphalt, is usually used in the construction of roads in Indonesia. This product is easily found in the marketplace. Adding

* Corresponding author: daudnawir@gmail.com

http://dx.doi.org/10.28991/CEJ-2022-08-08-010

this addictive substance, which is easily found in the marketplace, increases the durability of the flexural pavement [7]. Waste management is another big problem associated with standing water on road surfaces because it lowers the stability value of road pavement. Muis et al. [7], and Khairini [8], stated that the use of Wetfix-Be can withstand standing water on roads. Several countries, especially in Southeast Asia, still find it difficult to control and manage waste [9]. Plastic materials are widely used to simplify the lives of humans, however, in most cases, it is indiscriminately disposed. According to research on the flow of plastic waste dumped into the sea, Indonesia is the second-largest contributor worldwide after China stated that plastic, which was initially manufactured to provide significant benefits, has become a severe threat to the biosphere [10, 11]. A strategy is needed to prevent the continuous increase in plastic waste to maintain environmental stability and health in Indonesia [12, 13].

The adequate management of plastic waste through recycling, reusing, and reducing on asphalt road pavement can produce environmentally friendly materials resistant to water soaking [14, 15]. Hasan et al. [16] stated that plastic wastes as modifiers in asphalt mixtures help mitigate the associated environmental threat caused by its indiscriminate disposal. According to Suksiripattanapong et al. [17], several million tons of asphalt are used for road pavement yearly. Therefore, there is a need to demonstrate the benefits of plastic waste as an added value to asphalt. Peng et al. [18] reported that plastic waste can benefit the market. Therefore, this study investigated the use of this product in road construction to make the environment safer and more habitable through the recycling process. This study used an Asphalt Concrete Wearing Course (AC-WC) mixture, a wear layer in the uppermost surface layer of roads, which experiences direct contact with vehicles because it is waterproof with high stability. The use of plastic waste mixed with asphalt and strengthened using Wetfix-Be liquid, which is very suitable for road pavement conditions often flooded, is rare. Preliminary studies only addressed the function of Wetfix-Be performance and the impact of plastic waste on road pavements [7, 11, 17]. However, this study aims to maintain the environmental balance of plastic waste by using it on road pavement and increasing the durability of asphalt with the addictive Wetfix-Be. Flood conditions analyzed in this study are the soaking of concrete asphalt specimens with fresh and sea waters to determine their resistance to extreme weather.

2. Materials and Methods

2.1. Physical Properties of Aggregate

Tables 1 to 3 show the laboratory test results of the characteristics of fine and coarse aggregates and their fillers. According to General Specification of Indonesia Requirement [19], the road materials specification must be in accordance with the standard coarse aggregate, stone ash, and Filler.

Table 1. Physical Properties of Coarse Aggregate

No.	Properties	Results	Specification		Unit
			Min	Max	
1	Water Absorption				
	Coarse aggregate 5–10 mm	2.09	-	3.0	
	Coarse aggregate 1–2 cm	2.12	-	3.0	%
2	Density				
	Coarse aggregate 0.5–1 cm				
	Apparent Specific Gravity	2.81	2.5		
	SSD Specific Gravity	2.72	2.5		
	Bulk Specific Gravity	2.74	2.5		
	Coarse aggregate 1–2 cm				
	Specific Gravity	2.79	2.5		
	SSD Specific Gravity	2.73	2.5		
	Bulk Specific Gravity	2.74	2.5		
3	***Artificial Flake Index***				
	Coarse aggregate 0.5–1 cm	21.12	-	25	%
	Coarse aggregate 1–2 cm	10.14	-	25	%
	Abrasion				
	Coarse aggregate 0.5–1 cm	26.72	-	40	%
	Coarse aggregate 1–2 cm	25.43	-	40	%

Table 2. Physical properties of stone ash

No.	Properties	Results	Specification		Unit
			Min	Max	
1	Water Absorption	2.86	-	3.0	%
2	Bulk Specific Gravity	2.54	2.5		
	SSD Specific Gravity	2.57	2.5		
	Apparent Specific Gravity	2.62	2.5		
3	Sand Equivalent	91.23	50		

Table 3. Physical properties of Filler

No.	Properties	Results	Specification		Unit
			Min	Max	
1	Water Absorption	2.34	-	3.0	%
2	Bulk Specific Gravity	2.68	2.5		
	SSD Specific Gravity	2.72	2.5		
	Apparent Specific Gravity	2.82	2.5		
3	Sand Equivalent	70.23	50		

2.2. Characteristics of Asbuton Modification

Asphalt Buton (Asbuton) is one of Indonesia's local materials used in the construction of roads and bridges, which is the first step towards the use of national resources for self-sufficiency after independence [20]. Hot mixtures with grain or modified asphalt Asbuton and bitumen should be used for roads that experience heavy traffic loads above 10 million ESA or LHR greater than 2000 vehicles and more than 15% trucks [21]. Road segments with a maximum field temperature above 60ºC need to be constructed with asphalt extracted from Buton's granular and added with petroleum bitumen. Table 4 shows the physical properties of asbuton modified characteristics by the 2018 General Specifications of Bina Marga.

Table 1. Physical Properties of Asbuton Modification

No.	Properties	Results	Specification		Unit
			Min	Max	
1	Penetration before weight loss	75.3	60	79	mm
2	Penetration after weight loss	85	54	-	mm
3	Weight loss	0.34	-	-	%
4	Specific gravity	1.14	1	-	
5	Ductility at 25 ◦C, 5 cm/min	117	100	-	Cm
6	Flashpoint	284	200	-	°C
7	Flabby point	52	48	58	°C

2.3. Characteristics of HDPE Plastic Waste

High-density polyethene (HDPE) or polyethylene high-density (PEHD) is a thermoplastic polymer produced from the monomer ethylene (Figure 1). According to Turku et al. [22], it is sometimes called "*alkaline*" or "*polythene*" when used for HDPE pipes. HDPE can be found in rigid and soft plastic forms in everyday items such as milk and ice cream containers, shampoo and conditioner bottles, detergent bottles, and kid's toys. A soft plastic HDPE is found in freezer bags and other plastic food packaging, making it the most common commodity accounting for over 34% of the global market. It is a polymer of many repeating units or monomers, with a generalized chemical formula of C2H4n. The lack of branches in its structure allows the polymer chains to pack closely together, leading to a dense, highly crystalline material of significant strength and moderate stiffness. With a melting point above 20 °C (36°F) higher than LDPE, this commodity can withstand repeated exposure to 120°C (250°F). The branching in high-density polyethene is of a relatively low degree compared to other categories. Hence it is long-lasting and easy to maintain. Food stored in HDPE containers does not get contaminated by the polymer and can dissolve in 60/70 penetration asphalt at 154°C, thereby making it safe for humans [23].

Figure 1. Thin surface polyethene high-density

Numerous studies have been conducted on plastic waste as a substitute material for asphalt levels with the manufacture of specimens by mixing hot asphalt and cold plastic. However, this study used HDPE [11] with its physical properties are shown in Table 5. HDPE plastic in the form of flakes is processed first by burning until it melts completely and left for about 30 minutes to harden. The combustion plastic that has been cooled is poured into the specimen's media, mixed, and weighted according to the portion. A 2021 study by Nawir & Mansur (2021) [11] obtained a 4% optimal level of HDPE plastic waste from 5 variations that greatly help improve the quality of the flexural pavement. With the addition of 4% waste levels, the requirements for AC-WC layers will meet all specifications of the ministry of public works in Bina Marga (2018).

Table 2. Physical Properties of HDPE

Parameter	Value
Density	0.92 gr/cm^3
Melting point (°C)	125
Fiber type	Polyethene
Acid and alkali resistance	strong
Length (mm)	2
Break elongation	760 %
Fiber diameter (mm)	1-3

2.4. The Chemical Additives

In this research, additives, such as Wetfix-Be, were used to increase the durability of asphalt pavement against flood soaking. Wetfix-Be is an anti-stripping chemical that contains 100% polyamine condensate tall oil fatty acids with a dosage of use in hot asphalt mixtures of 0.2-0.5% against bitumen content. It is a liquid additive obtained in building goods stores with functions specifically designed for hot asphalt mixtures with excellent heat stability [7, 8]. Wetfix-Be is an anti-stripping chemical with a recommended dose of 0.3% against asphalt levels. It helps improve bonding and stabilize the mixture between aggregates and asphalt, especially during the rainy season. This additive is resistant to 170°C continuously for five days but experiences a decrease after this timeframe [24]. Compared to other additives, the use of Wetfix-Be is considered to extend the life of the road by 3-4 years.

Table 3. Characteristics of Wetfix liquid additives used in this study

Characteristics	Wetfix-Be
Viscosity at 20°C, cP	3,600
Viscosity at 40°C, cP	410
Density at 20°C, kg/m^3	980
For point, °C	<0
Appearance at 20°C	Brown, viscous liquid
Flashpoint, °C	>100

The characteristics of this material are provided in Table 6. Compared to other additives, the use of Wetfix-Be is considered very efficient and economical because it is slightly against asphalt levels and capable of producing maximum pavement structure. Another advantage of using Wetfix-Be additives on road pavement is it increases aggregate and asphalt bonds, can be used for various types of aggregates, reduces routine maintenance, and extends the road's life by 3-4 years. This additive contains NH2 (Amina), which can increase the ability of asphalt to bind aggregates at a viscosity of 3.600 cP and 410 cP at temperatures of 20°C and 40°C.

2.5. Laboratory Tests

Aggregate research from sampling to implementing testing procedures was carried out at the Transportation Engineering Laboratory of the University of Borneo Tarakan by the Bina Marga Standards Department of Public Works [19]. The flow chart of the research procedure in outline can be seen in Figure 2.

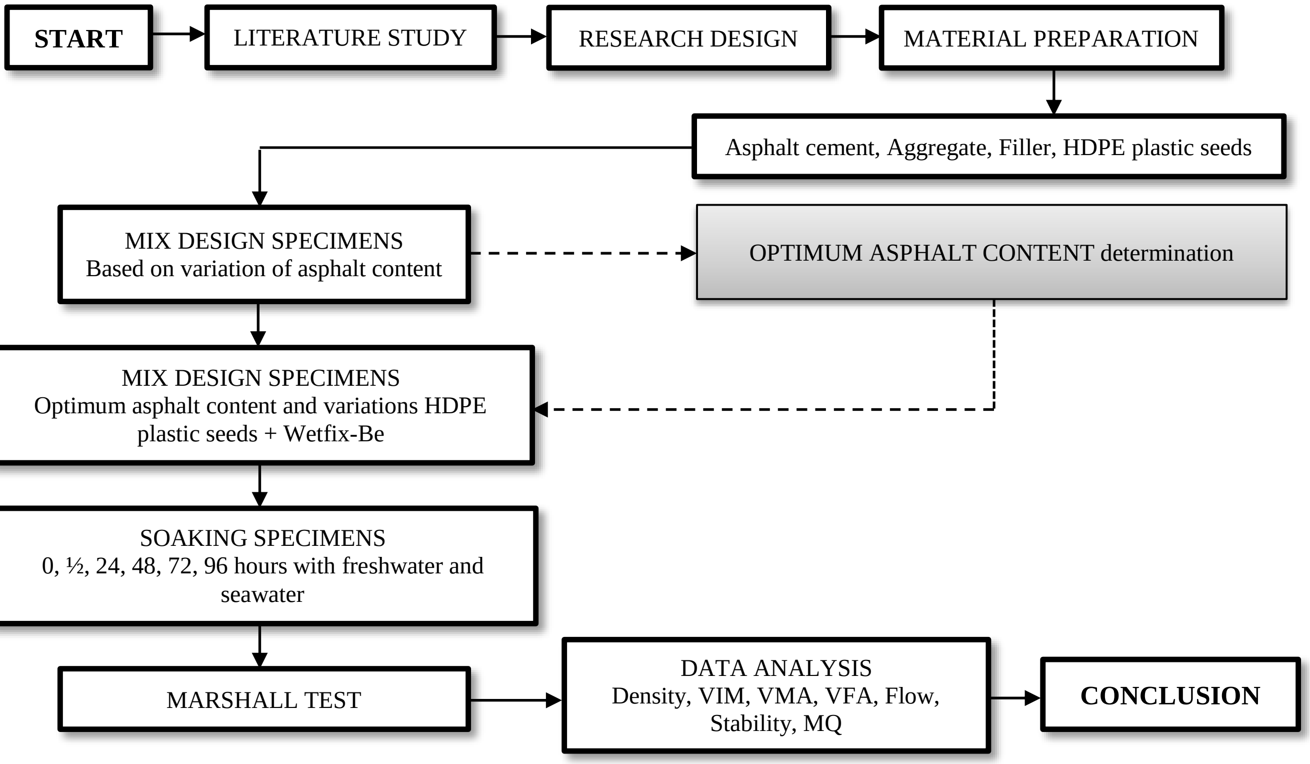

Figure 2. Research procedure flowchart

2.5.1. Marshall Test Method

The Marshall tests were undertaken according to Indonesia National Standard (SNI) 06-2489-1991. Harnaeni et al. [25] stated that the process of making AC-WC specimens has a mechanism set out in the mix specification requirements, where the test of the Asphalt mixture layer AUS comprises stability testing, flow, Marshall Quotient (MQ), VIM, VMA, and VFB with 2 X 75 blows. Furthermore, the Optimum Asphalt Content (OAC) was carried out through several trials to determine the composition of aggregate gradations. The proportion result of the mixture is then made into a specimen with varying asphalt levels. After obtaining OAC, plans were made to test the sea and freshwater immersion with the addition of Wetfix-Be. OAC consists of the immersion variation of six specimens, with the first three soaked in water at a temperature of 60°C for 24 hours, with the Marshall test used to obtain a stability value. On the following three specimens, the Marshall test was carried out following SNI 06-2489-1991. The soaking stability value with standard stability Retaining strength index (RSI) is expressed in percentage. The modification process was carried out with 3 specimens immersed for 0.5, 24, 48, 72, and 96 hours, respectively.

2.5.2. Durability Testing Index

Developed a single parameter that can describe the durability of a mixture of concrete immersed in the sea and fresh waters for 0, 24, 48, 72, and 96 hours [26]. This mixture durability test was carried out to determine the active power of asphalt against aggregates after immersion performed at 60±1ºC for 24 hours. Durability testing procedures followed the SNI M-58-1990 reference. The comparison of stability modifications with standard stability is expressed as a percentage known as the Residual Stability Index (IRS).

2.5.3. Cantabro Test

According to Wu et al. [27], Cantabro test is conducted to determine the durability and flexibility of the paved mixture. Tests were conducted on AC-WC combinations that used Wetfix-Be and non-Wetfix-Be in briquettes and then soaked in a tub for 0, 48, 96, 144, and 192 hours using 3 specimens, respectively. The test was conducted based on procedures specified in the TEX-245-F (Texas Department of Transportation), where existing briquette samples were inserted in Los Angeles engines and rotated 300 times at 30-33 rpm without the use of steel balls. Subsequently, it was evaluated using a Los Angles machine for 300 rounds without steel balls. Cantabro tests were conducted using the 3 specimens inserted into the Los Angles machine after rotating for 300 laps or more than 10 minutes. The test results showed that mixtures using Wetfix-Be produce small wear values, while those without this commodity were more excellent.

3. Results and Discussion

3.1. Asphalt Concrete Wearing Course (AC-WC) Combined Aggregate Gradation

Concrete asphalt mixture (AC-WC) is one of the surface layers on the construction of highway flexural pavement consisting of asphalt, gravel, sand, and ash stones. According to Mahardi et al. [28], asphalt serves as a binding material to unite aggregate fractions but is expected to remove the air cavity as recommended by specifications. Split aggregates play a significant role in determining the carrying capacity of the AC-WC mix.

Figure 3 shows that the combined aggregate gradation is within the standard specification according to the 2018 General Specifications of Bina Marga and has met the requirements for surface coating. The mixture design can be optimal with coarse, medium, and refined grains in the combined aggregate. Fly ash was used as a filler to produce a fine texture with a combination of add-point-by-point-up degrees on the Indonesian National Standard (SNI) for the Asphalt Concrete Wearing Course (AC-WC). Based on a combined aggregate assessment, the final composition is 15 percent CA (coarse aggregate), 47 percent MA (medium aggregate), 41 percent FA (fine aggregate), and 4 percent FF (Filler). All tests were conducted on asphalt with a 60/70 entrance audit respect. The chemical and physical test results conducted in the inquiry office are based on recent investigations' judgments and standard codes.

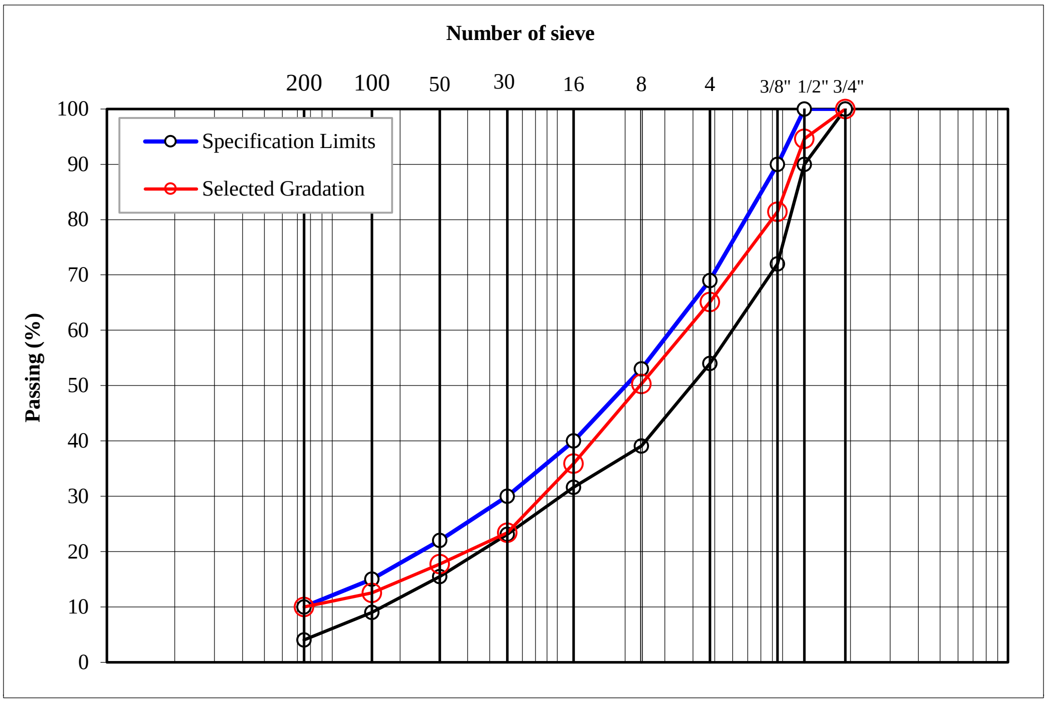

Figure 3. Wearing course aggregates gradation

3.2. Mixture Design Results

HDPE flakes are mixed into Hot-Mix Asphalt (HMA) with levels of 0% to 7% at mixing temperatures of 145-155 as well as 165 °C for 5 - 15 and 30 minutes. The analysis results of maximum HDPE plastic waste levels that meet Bina marga requirements are shown in Table 7. The test results obtained from the utilization of HDPE plastic waste (PW) levels that meet Bina Marga's requirements in terms of penetration, type-specific gravity, ductility, softening point, flash pointing, and viscosity are 0% to 4%, 0% to 7%, 0% to 6%, 0% to 7%, 4%, and 0% and 6%. Therefore, the maximum level of HDPE plastic waste that can be mixed into asphalt to make modified asphalt is 4%.

Table 4. Characteristics of asphalt modification HDPE Plastics waste

No.	Properties	Bina Marga Standards 2018	HDPE waste variations							
			0%	1%	2%	3%	4%	5%	6%	7%
1.	Specific gravity	≥ 1								
2.	Ductility in 25°C, 5 cm/minutes (cm)	≥ 100								
3.	Penetration at 25°C (0.1 mm)	≥ 40								
4.	Softening point (°C)	48 -58								
5.	Flashpoint (°C)	≥ 200								
6.	Kinematic viscosity	≤ 3000 at 135°C								

The results of Table 7 show that the maximum HDPE plastic waste (PW) addition that meets the requirements for modified asphalt is 4%. This indicates that it meets the effects of specific gravity, flexibility, softening point, and kinematic viscosity tests for asphalt with plastic content from 0% to 6%. The test is only up to adding plastic with a rate of 8% because the mixing temperature is very high and close to the 60/70 penetration asphalt flashpoint, which is about 190°C. Asphalt modification with HDPE plastic waste decreases the penetration value, weight, plasticity level, flash and burn point, and viscosity, with an increase in flaccid point [11]. This makes the asphalt harder and resistant to high temperatures, making it difficult to change shape. When mixed directly into Asphalt, HDPE waste plastic produces a mixture not perfectly homogeneous (clumping) because its melting point is higher. A stirring device in the form of a high-power mixer is needed to produce a homogenous mixture.

3.3. Marshall Analysis

Figure 4 showing specimens have been tested marshall, data results for testing and analyzing marshall parameters are Stability, flow, Marshall quotient (MQ), Void filled asphalt (VFA), Void in the mixture (VIM), and Void in aggregate (VMA), as shown in Table 8. The Optimum Asphalt Level (OAC) of the concrete asphalt coating mixture (AC-WC) in this study used asphalt levels ranging from 4% to 7% at a 0.5% increase. Based on the previous results that analyzed the optimum asphalt content was 5.75%, a mix design was designed to make the specimens with various levels of oil asphalt content, namely 4.5%, 5.0%, 5.5%, 6.0%, 6.5%, and 7% by weight of the mixture.

Figure 4. Marshall Test result specimens

Table 5. Characteristics of Marshall Test with OAC 5.75%

Marshall Characteristic Test	Standard	AC-WC Optimal Aspahlt Content (OAC) 5.75%											
		Freshwater						Seawater					
		0 hour	1/2 hour	24 hour	48 hour	72 hour	96 hour	0 hour	½ hour	24 hour	48 hour	72 hour	96 hour
VIM (%)	3-5	0.17	3.98	4.21	4.34	4.54	4.67	3.72	3.87	4.55	4.76	4.83	4.92
VMA (%)	Min 15	15.21	15.32	15.55	16.32	16.74	16.94	15.78	15.92	16.43	16.78	17.12	17.54
VFA (%)	Min 65	78.53	77.45	72.51	70.82	68.31	66.43	78.64	77.53	75.43	73.42	71.54	68.52
Stabilitas (kg)	Min 800	1573.32	1501.45	1411.45	1298.43	1190.43	980.52	1582.13	1511.92	1398.43	1176.73	993.54	910.43
Flow (mm)	2-4	3.32	3.36	3.47	3.51	3.57	3.82	3.34	3.39	3.48	3.56	3.67	3.98
MQ (kg/mm)	Min 250	473.89	446.86	406.76	369.92	333.45	256.68	473.69	445.99	401.85	330.54	270.72	228.75
Density (gr/cm^3)		2321	2310	2287	2124	2086	2011	2314	2309	2265	2165	2097	2008

Nawir & Mansur [11], and Nawir [14] stated that the immersion modifications from standard Marshall bars are carried out by soaking a specimen in a heating tub (waterbed) for 24, 48, 72, and 96 hours. It is subsequently cooled for 30 minutes at a temperature of 60°C. Marshall Tests is used to determine the maximum point, stability, and flow of the tool. The AC-WC asphalt mixture in the Marshall test contains 4% HDPE plastic waste, soaked using fresh and sea water with the aim of testing durability until it reaches the point of destruction. The Marshall test and the results of the calculation are shown in Table 9. Table 10 shows the results of using 0.3% Wetfix-Be additive chemicals as an anti-stripping material, which serves as adhesion to glue aggregates and asphalt. The wear and durability level of the Asphalt Concrete Wearing Course (AC-WC) can be stable due to weather and vehicle load reps. A mixture of 4% HDPE plastic waste with an additional Wetfix-Be of 0.3% is soaked in sea and freshwater for 30 minutes and 24 hours to obtain a composition of 5.75%.

Table 6. Characteristics of Marshall Test with Plastic Waste Mixture

Marshall Characteristic Test	Standard	AC-WC (4% HDPE plastic waste)											
		Freshwater						Seawater					
		0 hour	1/2 hour	24 hours	48 hours	72 hours	96 hours	0 hour	1/2 hour	24 hours	48 hours	72 hours	96 hours
VIM (%)	3-5	4.40	4.41	4.53	4.64	4.72	4.81	4.46	4.52	4.62	4.72	4.84	4.9
VMA (%)	Min 15	15.66	15.71	15.79	16.11	16.17	16.28	15.72	15.82	15.9	16.09	16.29	16.47
VFA (%)	Min 65	74.31	76.54	75.44	70.83	68.73	65.42	77.31	76.81	75.52	74.63	73.42	70.72
Stability (kg)	Min 800	1898.4	1834.3	1787.5	1675.6	1542.6	1495.5	1898.6	1798.3	1701.81	1677.4	1561.9	1410.3
Flow (mm)	2-4	3.35	3.37	3.44	3.51	3.56	3.62	3.34	3.47	3.52	3.64	3.75	3.86
MQ (kg/mm)	Min 250	566.69	544.31	519.62	477.37	433.32	413.11	568.46	518.25	483.47	460.82	416.51	365.37
Density (gr/cm^3)		2338	2340	2281	2107	2050	1978	2350	2352	2154	2065	1998	1896

Table 7. Characteristics of Marshall Test with Plastic Waste Mixture and Wetfix-Be

Marshall Characteristic Test	Standard	AC-WC (4% HDPE plastic waste + 0.3% *Wetfix-Be)*											
		Freshwater						Seawater					
		0 hour	1/2 hour	24 hours	48 hours	72 hours	96 hours	0 hour	1/2 hour	24 hours	48 hours	72 hours	96 hours
VIM (%)	3-5	4.41	4.43	4.56	4.65	4.74	4.87	4.46	4.53	4.64	4.78	4.88	4.92
VMA (%)	Min 15	15.64	15.74	15.82	16.04	16.12	16.23	15.72	15.88	15.93	16.11	16.26	16.42
VFA (%)	Min 65	74.34	74.54	70.64	69.75	68.54	66.65	78.74	78.65	75.43	72.44	70.72	68.94
Stability (kg)	Min 800	1998.4	1986.5	1898.2	1868.6	1832.9	1810.5	1898.6	1888.3	1881.8	1797.4	1761.9	1720.3
Flow (mm)	2-4	3.34	3.37	3.48	3.52	3.58	3.73	3.37	3.42	3.54	3.62	3.71	3.83
MQ (kg/mm)	Min 250	598.33	589.48	545.47	530.86	511.97	485.40	563.39	552.14	531.58	496.52	474.91	449.17
Density (gr/cm^3)		2334	2333	2323	2310	2302	2998	2339	2342	2323	2312	2301	2997

3.3.1. Stability

The stability of the mixture is affected by internal friction and cohesion, with Tables 8 to 10 showing that using HDPE waste plastic with a rate of 4% increases the stability value of the AC-WC mixture by 32%. Fathollahi et al. [9] and Nawir and Mansur [11] stated that AC-WC use is limited to the concentration of plastic waste shale addition at 4% to the weight of asphalt. This is because the powdery penetration test of 60/70 indicates a tendency for asphalt to qualify as asphalt penetration, assuming the proportion of plastic is above 5% of its weight. The stability value of the asphalt mixture in the submerged condition of fresh and sea waters continuously decreased by 42% after being given anti-striping on the AC-WC concrete asphalt mixture. The acidity factor of seawater influences the decrease in the strength of the AC-WC asphalt mixture with a pH of 5.82. It also contains the chemical elements of Sodium Chloride (NaCl) and Magnesium (Mg) which can result in reduced durability for immersion [29]. The decrease in stability value does not affect the specifications of Bina Marga (2018) [19], with a stability limit value of 800 kg.

Figure 5 shows the relationship between the lengths of freshwater soaking with stability. The size of immersion time decreased strength using the Wetfix-Be mixture, increasing from 11.76 kg to 137.9 kg. The freshwater soaking without Wetfix-Be mixture experienced a rise in stability from 64.09kg to 472.94 kg in 92 hours. Ant-striping Wetfix-Be can provide stability resistance even when submerged in extreme conditions, such as in coastal areas that experience high tides until puddles occur on the road. Figure 6 shows the strong effect of seawater soaking on the stability of the AC-WC asphalt mixture with a significant decrease in strength between the content of Wetfix-Be and the mixture. For AC-WC combinations with and without Wetfix-Be, there was an increase in force from 25.90 kg to 242.65 kg and 124.72 kg up to 597.64 kg, respectively.

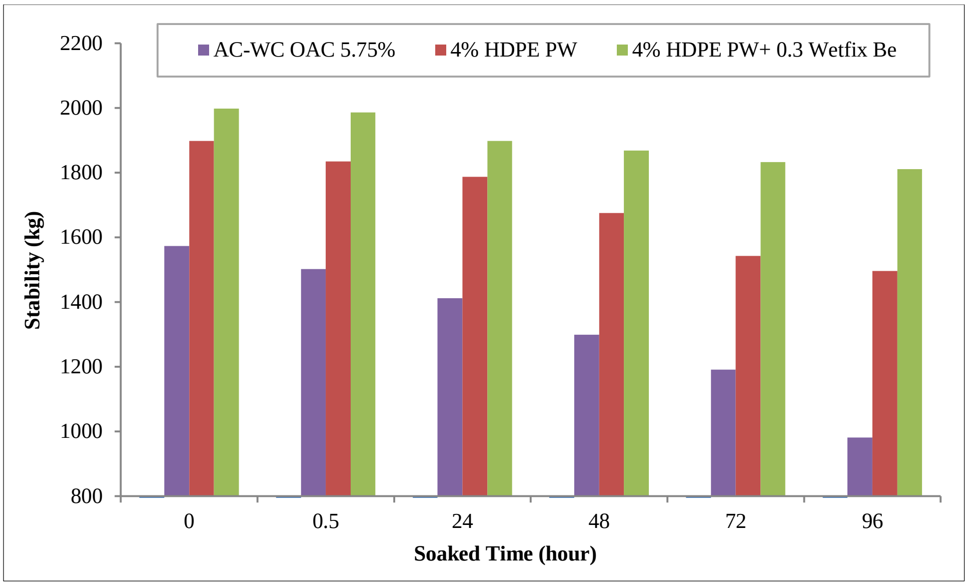

Figure 5. Stability Relationship with AC-WC Immersion in Freshwater

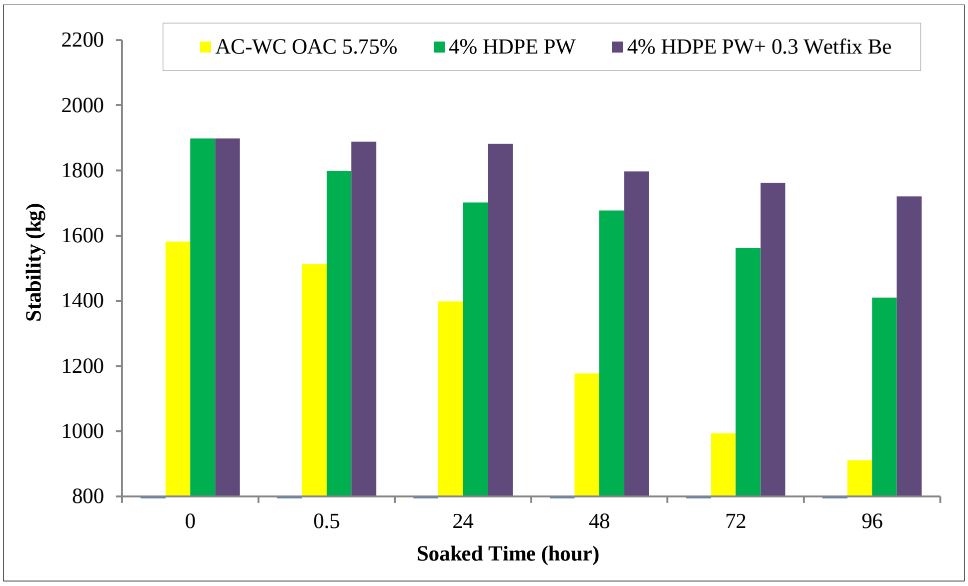

Figure 6. Stability Relationship with AC-WC Immersion in Seawater

3.3.2. Flow

Fatigue or flow is a measure of the flexibility of the mixture to follow the deformation that occurs due to traffic loads without causing cracks and changes in volume [6, 10, 16]. Table 4 showed that the more plastic levels increase in the AC-WC mixture, the less flexibility of the mix. Therefore, hardening the asphalt by 4% causes the plastic to be incorporated into the mixture. The malleability nature of the AC-WC mixture with the inclusion of plastic does not negatively affect the variety. Flow value for testing ac-WC asphalt mixture with the freshwater immersion of 3.35 mm and 3.62 mm compared to seawater of 3.34 mm and 3.86 mm led to significant differences of 0.15 mm. Tables 4 and 5 show that the flow value for all immersion tests of AC-WC asphalt mixture modifications increased from 0.05 to 0.08 mm and 0.03-0.10 mm in freshwater with and without adding Wetfix-Be. Regarding Sea Water, the flow of asphalt mixture AC-WC with and without Wetfix-Be decreased from 0.03 to 0.14 mm, and 0.03 to 0.14 mm. The increase in flow value in the test above still meets the required specification of at least 3.0 mm.

3.3.3. Marshall Quotient (MQ)

Marshall Quotient results from the difference between the values of stability and flow indicate that the addition of Wetfix-Be as an anti-striping can reduce the decrease in the value of the MQ [30]. The presence of plastic in the AC-WC mixture can directly affect the increase in MQ value because plastic contributes positively to a rise in stability with a decrease in flow below 250 kg / mm. The inclusion of plastic content into the AC-WC mixture increases the value of MQ without specification restrictions. Table 4 shows that the inclusion of plastic into the AC-WC mixture will improve the construction. The value of Marshall Quotient (MQ) continues to decrease due to the length of fresh water and seawater soaking for AC-WC mixtures until the anti-stripping Wetfix-Be reduces. According to preliminary studies, AC-WC's stability is influenced by the acidity factor with a pH of 5.83, which decreases the chemical elements of Sodium Chloride (NaCl) and Magnesium (Mg) in seawater and freshwater by 563.39 kg and 449.17 kg as well as 598. 33 kg and 485. 40. There is a more significant decrease in seawater than freshwater, by 33.12 kg. MQ values for AC-WC mixtures with and without Wetfix-Be content soaked with Fresh Water at 24, 48, 72, and 96 hours have a difference in value from 33.46 to 69.87 kg/mm, and 60 to 110.65 kg/mm. Compared to the Marshall Quotient Value (MQ) for the AC-WC with and without Wetfix-Be mixture soaked with seawater decreases from 46.67 to 89.19 kg/mm and 67.88 to 125.33 kg/mm. The required value on the Marshall Quotient (MQ) is 250 kg/mm at a minimum, hence this test still meets the required specifications.

3.3.4. Voids in the Mixture (VIM)

The addition of HDPE plastic waste to the AC-WC concrete asphalt mixture can affect the vim value, thereby shrinking the asphalt and plastic weight with an increase in its content [10]. When the content is related to the mixture's durability, when the VIM value is too high, the combination becomes fragile and crack early. Meanwhile, a small VIM value will increase the resistance of the mix to asphalt hardening, thereby peeling the particle due to oxidation, which makes the mixture unstable. The possibility of more significant plastic discharge due to insufficient space to accommodate asphalt expansion is associated with the compaction of traffic and temperature, which increases pavement during service. The presence of plastic in the AC-WC mixture is perfect for making and maintaining the VIM to ensure it is more significant than the specifications often found in the actual condition of road pavements with heavy traffic. An early indication of plastic deformation and cracking on pavement generally is usually below the VIM value of 3 % and 10%.

The air cavity between asphalt-covered aggregates indicates the mix's resistance to changes in shape due to loading. VIM is needed to shift aggregate grains and asphalt places with an increase in temperature. HDPE plastic waste is usually added to the AC-WC mixture to keep it enlarged due to the difficulty of cases that often occur on the pavement of the surrounding roads. Vim value is strongly related to the mixture's content weight and type, with its importance strongly related to the kind of asphalt plus plastic. Therefore, more portions of plastic in the mixture will allow weight enlargement of the type of asphalt plus plastic, thereby decreasing the value of VIM. When the values are too high, the paved mixture becomes brittle, thereby decreasing the exposure to water. At the same time, the increase in the oxidation process of asphalt accelerates aging and reduces its durability.

Vim Value Testing on AC-WC increased from 3.5 to 5.5%, with a rise in Seawater with Standard Marshall testing from 4.46% to 4.92%. In comparison, the immersion with Fresh Water was 4.41% and 4.87%, leading to a rise in the vim value by 0.07% from the mixed cavity. Tables 1, 4, and 5 show that the length of immersion time results in VIM values of AC-WC pavement layers. The V.I.M. value increased for Freshwater immersion from 0.04% to 0.10% and 0.05% to 0.15% with and without Wetfix-Be. For seawater, the VIM layer increased from 0.07% to 0.31 and 0.03% to 0.47% with and without Wet-Be.

3.3.5. VMA (Voids in the Mineral Aggregate)

VMA is the volume of air cavities between aggregate grains in a paved mixture under stable conditions [20]. VIM and practical asphalt volume are part of the VMAs. The addition of plastic waste flakes into the AC-WC mixture influences the weight of the contents, whose value tends to increase, thereby leading to a decrease in the value of the VMAs in the sea and fresh waters by 15.72% and 16.42%, as well as 15.64% and 16.23%, with a 0.08% rise. The required specification in the VMAs value is at least 15%, therefore, all these tests meet the specification standards.

Cavities between aggregate particles in a solid mixture, including air cavities and adequate asphalt levels, are expressed in percent total volume of at least 15%, per standard specifications. The VMA value on concrete Asphalt AC-WC with and without Wetfix-soaked in freshwater increased from 0.07% - 0.12% and 0.05% - 0.11%, respectively. For VMA deals in Sea Water immersion with and without Wetfix-Be mixture, the difference is between 0.06-0.28% and 0.04% - 0.42%. This indicates that there is an effect of changes in durability on the duration of immersion to affect the value of VMA.

3.3.6. VFA (Voids Filled in Asphalt)

The volume of solid asphalt concrete cavities filled by asphalt levels is effectively known as VFA. VFB is an asphalt-filled cavity that is part of a VMAs consisting of effective asphalt content [27]. Subsequently, the effective asphalt content is the total asphalt content minus the amount of asphalt absorbed by the aggregate. Its levels will effectively envelop the outer aggregate surface and ultimately determine the performance of the asphalt mixture. The addition of plastic waste flakes into the AC-WC asphalt mixture will result in increasingly reduced cavities due to its weight [20]. This study's increase in VFB value is due to the shrinking of holes in the mixture (VIM), which is part of the divider determining VFB values. In addition to this, this study also suggests that with the inclusion of plastic waste shale into the mixture, the absorption of asphalt into the material pore decreases. Hence, the level of effective asphalt rises as the value of VFB increases. This indicates that adding HDPE plastic waste shale into the AC-WC mixture can improve the mix performance. In Table 1, the VFA for Freshwater immersion is 78.53% to 66.43%, and 78.64% to 68.52%, in the sea and fresh waters for 96 hours, with a difference of 0.42%. The percentage value of pores between asphalt-filled aggregate grains (VFA) meets the required specification of at least 65%. In Tables 4 and 5, VFA values for AC-WC asphalt mixture with and without Wetfix-Be in Freshwater immersion at 24.48.72 decreased from 0.32% to 0.62and 0.21% to 0.58 % within 96 minutes. Meanwhile, for seawater immersion with and without Wetfix-Be, the difference was from 0.75% to 1.12% and 0.23% to 1.87%. A decrease in the value of a VFA that is too high can lead to expansion. The percentage value of the pore between asphalt-filled aggregate grains (VFA) still meets the required specification of at least 65%.

3.3.7. Density

The density value is a volume weight that shows the dense value of the asphalt concrete mixture is thicker [13]. It is influenced by compaction temperature, constituent materials, filler substance, compaction energy, and asphalt substance. Tables 1, and 4 show that the density values continue to decrease in the existing system with a more effective modulus of smoothness. In Table 5, density values gradually experience stability influenced by extreme conditions with Wetfix-Be content of 0.3% because the asphalt mixture has a bond.

3.3.8. Retaining Strength Index (RSI) of Marshall Immersion Test

The Marshalled Strength Index (RSI) is intended to determine the durability of the mixture to the influence of weather and temperature between the asphalt and aggregate grains [31]. The value in Quotient is affected by the degree of aggregate attachment to asphalt, which depends on the shape and number of aggregate pores. The rheology properties, levels, density, cavity content, and aggregate gradation are obtained from the Comparison results of the stability value of the object, thereby leading to a 1 x 24-hour soak with a standard specimen's stability value at a temperature of 60°C.

This study shows that using HDPE plastic waste shale inserted into the AC-WC mixture can increase the asphalt mix's ability to fight tough weather. Figure 7 indicates that ac-WC with Wetfix-Be has a high level of durability compared to when Wetfix-Be is excluded. Furthermore, seawater runoff has a degree of influence on reducing the stability of Laston AC-WC compared to freshwater. The strength of the AC-WC medicine increases resistance value, evidenced by the stability results. This is shown in Table 5, where the stability of the mixture containing plastic contributes positively to immersion for 0.5, 24, 48, 72, and 96 hours at 60°C. It explains that at plastic content of 4% with 5.75% 0AC and 0.3% Wetfix-Be, the stability value before seawater and freshwater immersion is above 90% in accordance with the specifications set by Bina Marga (2018) [19].

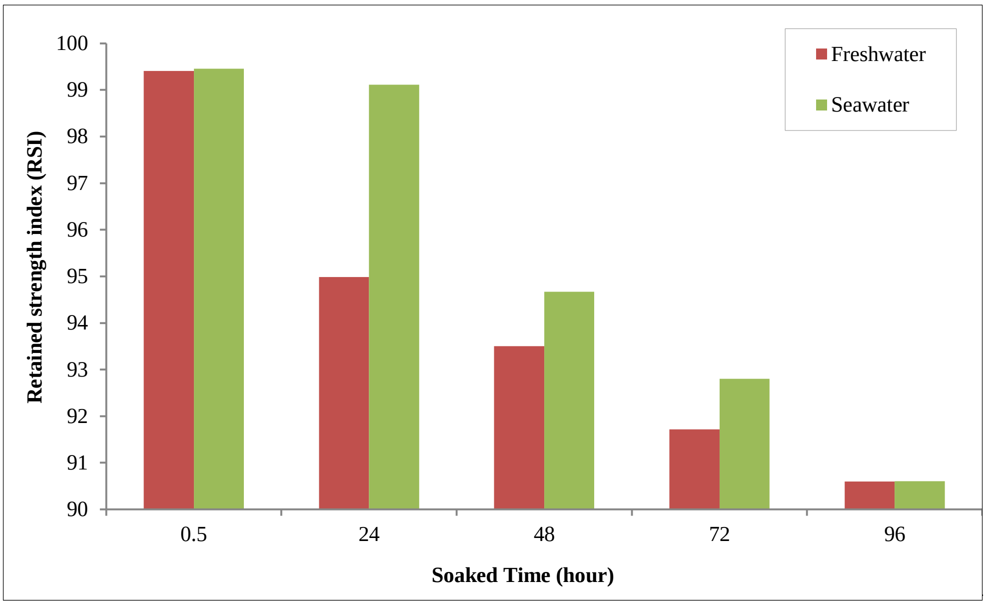

Figure 7. Retained strength index (RSI) of Marshall Immersion test

3.4. Cantabro Test Results

The Cantabro Test was conducted at the optimum bitumen content with a variation of 300 rounds using a machine manufactured in Los Angeles to determine its disintegration with other aggregates [15]. The initial weight of each test specimen was recorded before placing it in a Los Angeles machine without the steel balls. Three variations are made to perform the Cantabro test using AC-WC asphalt with OAC 5.75, 5.75, and 5.75 and an additional 4% HDPE plastic waste with 0.3% Wetfix-Be. As shown in Table 11, each variation is made up of 3 specimens and then averaged.

Table 8. Cantabro test results

Variation	Initial Weight before testing (gram)	Final weight after 300 cycles (gram)	Weight Loss (%) ≤ 20%
Variation 1	1254.76	1007. 54	19.74
Variation 2	1273.72	1155.29	9.30
Variation 3	1285.43	1187.22	7.64

HDPE plastic content as a substitute for asphalt adds strong bonds between aggregates. It is made into three variations with the addition of Wetfix-Be anti-striping as resistance to repetisi load compared to the mixture under normal conditions, as shown in Table 11. The results of Cantabro tests of AC-WC concrete asphalt mixture with the addition of Wetfix-Be are better when compared to those without using it as an anti-stripe.

4. Conclusions

The utilization of plastic waste and the addition of Wetfix-Be to the AC-WC concrete asphalt mixture led to the following conclusions:

- Testing of coarse, fine aggregate gradation, stone ash (filler), and careerists asphalt resulted in an optimum asphalt content of 5.75% on the AC-WC concrete asphalt mixture in accordance with Bina Marga standards (2018). Marshall's tests showed that immersion durations of 24, 48, 72, and 96 hours in fresh and seawater affected the increase in VIM and Laston AC-WC flow. Seawater acidity factor with a pH of 5.83 also contains Sodium Chloride (NaCl) and Magnesium (Mg), which decreases stability, VFA, and Marshall Quotient (MQ), thereby resulting in reduced durability;
- The addition of wet mix-be additives of 0.3% as anti-stripping can increase the stability value because it makes it easier for asphalt to cover the aggregate perfectly; the use affects the durability of Laston AC-WC. Marshall's tool testing showed that the Residual Strength Index (IKS) decreased in freshwater immersion by 95.65% (plus Wetfix-Be) and 91.35% (no plus Wetfix-Be). At sea water immersion, 93.54% (plus Wetfix-Be) and 89.31% (no plus Wetfix-Be). Cantabro tested asphalt concrete AC-WC using three variations of specimens, namely 19.74 % (not plus Wetfix-Be) and 7.64 % (plus Wetfix-Be);
- Asphalt concrete AC-WC immersion in sea and fresh water influences its durability. Substitution of 4% HDPE plastic waste shale against 60/70 penetration asphalt can affect the AC-WC concrete asphalt mixture even in submerged conditions. The addition of Wetfix-Be additives has been tested in extreme weather conditions, primarily floods and road pavement in coastal areas. Wetfix-Be influences asphalt bonding and aggregate absorption to improve the concrete AC-WC mixture;
- The findings suggest that HDPE plastic waste and concrete asphalt modified for AC-WC mixtures have mutually beneficial material bonds. This implies that it can be applied in the future as an environmentally friendly material for asphalt pavement technology.

5. Declarations

5.1. Author Contributions

Conceptualization, D.N., and A.Z.N.; methodology, D.N., and A.Z.N.; formal analysis, D.N., and A.Z.N.; investigation, D.N., and A.Z.N.; resources, D.N.; writing—original draft preparation, D.N., and A.Z.N.; writing—review and editing, D.N. and A.Z.N. All authors have read and agreed to the published version of the manuscript.

5.2. Data Availability Statement

The data presented in this study are available in article.

5.3. Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

5.4. Conflicts of Interest

The authors declare no conflict of interest.

6. References

[1] Handayani, W., Chigbu, U. E., Rudiarto, I., & Surya Putri, I. H. (2020). Urbanization and increasing flood risk in the Northern Coast of Central Java-Indonesia: An assessment towards better land use policy and flood management. Land, 9(10), 343. doi:10.3390/LAND9100343.

[2] Dwirahmadi, F., Rutherford, S., Phung, D., & Chu, C. (2019). Understanding the operational concept of a flood-resilient urban community in Jakarta, Indonesia, from the perspectives of disaster risk reduction, climate change adaptation and development agencies. International Journal of Environmental Research and Public Health, 16(20), 3993. doi:10.3390/ijerph16203993.

[3] Dalhat, M. A., Al-Abdul Wahhab, H. I., & Al-Adham, K. (2019). Recycled Plastic Waste Asphalt Concrete via Mineral Aggregate Substitution and Binder Modification. Journal of Materials in Civil Engineering, 31(8), 4019134. doi:10.1061/(asce)mt.1943-5533.0002744.

[4] Khan, M. Z. H., Koting, S., Katman, H. Y. B., Ibrahim, M. R., Babalghaith, A. M., & Asqool, O. (2021). Performance of high content reclaimed asphalt pavement (RAP) in asphaltic mix with crumb rubber modifier and waste engine oil as rejuvenator. Applied Sciences (Switzerland), 11(11). doi:10.3390/app11115226.

[5] Jimenez-Relinque, E., Grande, M., Rubiano, F., & Castellote, M. (2021). Durability and safety performance of pavements with added photocatalysts. Applied Sciences (Switzerland), 11(23). doi:10.3390/app112311277.

[6] Badejo, A. A., Adekunle, A. A., Adekoya, O. O., Ndambuki, J. M., Kupolati, K. W., Bada, B. S., & Omole, D. O. (2017). Plastic waste as strength modifiers in asphalt for a sustainable environment. African Journal of Science, Technology, Innovation and Development, 9(2), 173–177. doi:10.1080/20421338.2017.1302681.

[7] Muis, Z. A., Batubara, M., Lubis, A. S., & Manurung, R. (2019). Measurement of anti-stripping agent content in asphalt mixture with Colorimetric test. International Journal of GEOMATE, 17(63), 378–385. doi:10.21660/2019.63.94587.

[8] Khairini, N. (2020). Asphalt Concrete Mix Performance-Wearing Course (AC-WC) using Concrete Waste as Course Aggregate with the Addition of Wetfix-Be. International Seminar of Science and Applied Technology (ISSAT 2020), 259-264. doi:10.2991/aer.k.201221.044.

[9] Fathollahi, A., Makoundou, C., Coupe, S. J., & Sangiorgi, C. (2022). Leaching of PAHs from rubber modified asphalt pavements. Science of the Total Environment, 826, 153983. doi:10.1016/j.scitotenv.2022.153983.

[10] Lapian, F. E. P., Ramli, M. I., Pasra, M., & Arsyad, A. (2021). The performance modeling of modified asbuton and polyethylene terephthalate (PET) mixture using response surface methodology (RSM). Applied Sciences (Switzerland), 11(13). doi:10.3390/app11136144.

[11] Nawir, D., & Mansur, A. Z. (2021). The impact of HDPE plastic seeds on the performance of asphalt mixtures. Civil Engineering Journal (Iran), 7(9), 1569–1581. doi:10.28991/cej-2021-03091744.

[12] Ki, D., Kang, S. Y., Ma, G., & Oh, H. J. (2021). Application of Waste Plastic Films in Road Infrastructure and Construction. Frontiers in Sustainability, 2, 79. doi:10.3389/frsus.2021.756723.

[13] Owaid, K. A., Hamdoon, A. A., Maty, R. R., Saleh, M. Y., & Abdelzaher, M. A. (2022). Waste Polymer and Lubricating Oil Used as Asphalt Rheological Modifiers. Materials, 15(11), 3744. doi:10.3390/ma15113744.

[14] Nawir, D. (2020). Resistance Test of Porous Asphalt Using Liquid Ashburton and Beach Sand against Immersion Time and Temperature. Solid State Technology, 63(5), 5043-5056.

[15] Costa, L. M. B., Peralta, J., Oliveira, J. R. M., & Silva, H. M. R. D. (2017). A new life for cross-linked plastic waste as aggregates and binder modifier for asphalt mixtures. Applied Sciences (Switzerland), 7(6), 1–16. doi:10.3390/app7060603.

[16] Hasan, M. R. M., You, Z., Satar, M. K. I. M., Warid, M. N. M., Kamaruddin, N. H. M., Ge, D., & Zhang, R. (2018). Effects of titanate coupling agent on engineering properties of asphalt binders and mixtures incorporating LLDPE-CaCO3 pellet. Applied Sciences (Switzerland), 8(7). doi:10.3390/app8071029.

[17] Suksiripattanapong, C., Uraikhot, K., Tiyasangthong, S., Wonglakorn, N., Tabyang, W., Jomnonkwao, S., & Phetchuay, C. (2022). Performance of Asphalt Concrete Pavement Reinforced with High-Density Polyethylene Plastic Waste. Infrastructures, 7(5), 1–11. doi:10.3390/infrastructures7050072.

[18] Peng, C., Guo, C., You, Z., Xu, F., Ma, W., You, L., Li, T., Zhou, L., Huang, S., Ma, H., & Lu, L. (2020). The effect of waste engine oil and waste polyethylene on UV aging resistance of asphalt. Polymers, 12(3), 1–18. doi:10.3390/polym12030602.

[19] General Specifications of Indonesia 2018 Indonesia Requirement. (2018). Director General of Bina Marga. Public Work Ministry of Indonesia, Jakarta, Indonesia.

[20] Nawir, D., & Mansur, A. Z. (2021). The Effects Of The Combination Of Buton Rock Asphalt And Plastic Waste Flakes Using Liquid Asbuton In Asphalt Concrete Mixture. Journal of Engineering and Applied Science, 16(1), 34–41. doi:10.36478/jeasci.2021.34.41.

[21] Remišová, E. (2018). Improvement in properties of bitumen using selected additives. Road and Rail Infrastructure V, 5(17-19 May), 383–388. doi:10.5592/co/cetra.2018.737.

[22] Turku, I., Keskisaari, A., Kärki, T., Puurtinen, A., & Marttila, P. (2017). Characterization of wood plastic composites manufactured from recycled plastic blends. Composite Structures, 161, 469–476. doi:10.1016/j.compstruct.2016.11.073.

[23] Camacho, W., & Karlsson, S. (2000). Quality-determination of recycled plastic packaging waste by identification of contaminants by GC-MS after microwave assisted extraction (MAE). Polymer Degradation and Stability, 71(1), 123–134. doi:10.1016/S0141-3910(00)00163-4.

[24] Remišová, E., & Holý, M. (2017). Changes of Properties of Bitumen Binders by Additives Application. IOP Conference Series: Materials Science and Engineering. doi:10.1088/1757-899X/245/3/032003.

[25] Harnaeni, S. R., Pramesti, F. P., Budiarto, A., Setyawan, A., Khan, M. I., & Sutanto, M. H. (2020). Study on structural performance of asphalt concrete and hot rolled sheet through viscoelastic characterization. Materials, 13(5), 1133. doi:10.3390/ma13051133.

[26] Khater, A., Luo, D., Abdelsalam, M., Ma, J., & Ghazy, M. (2021). Comparative life cycle assessment of asphalt mixtures using composite admixtures of lignin and glass fibers. Materials, 14(21), 6589. doi:10.3390/ma14216589.

[27] Wu, H., Yu, J., Song, W., Zou, J., Song, Q., & Zhou, L. (2020). A critical state-of-the-art review of durability and functionality of open-graded friction course mixtures. Construction and Building Materials, 237, 117759. doi:10.1016/j.conbuildmat.2019.117759.

[28] Mahardi, P., Risdianto, Y., Wibisono, E., & Karismanan. (2020). Effect of HDPE Based Wastes on the Performance of AC-WC Mixture with RAP as coarse aggregate substitute. Journal of Physics: Conference Series, 1569(4), 42019. doi:10.1088/1742-6596/1569/4/042019.

[29] Cui, S., Blackman, B. R. K., Kinloch, A. J., & Taylor, A. C. (2014). Durability of asphalt mixtures: Effect of aggregate type and adhesion promoters. International Journal of Adhesion and Adhesives, 54, 100–111. doi:10.1016/j.ijadhadh.2014.05.009.

[30] Esmaeili, N., Hamedi, G. H., & Khodadadi, M. (2019). Determination of the stripping process of asphalt mixtures and the effective mix design and SFE parameters on its different phases. Construction and Building Materials, 213, 167–181. doi:10.1016/j.conbuildmat.2019.04.043.

[31] Wilson, L. J., Cockburn, E., Paice, K., Sinclair, S., Faki, T., Hills, F. A., Gondek, M. B., Wood, A., & Dimitriou, L. (2018). Recovery following a marathon: a comparison of cold water immersion, whole body cryotherapy and a placebo control. European Journal of Applied Physiology, 118(1), 153–163. doi:10.1007/s00421-017-3757-z.