IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
e-ISSN: 2278-1684, p-ISSN: 2320-334X, Volume 21, Issue 6 Ser. 3 (Nov. – Dec. 2024), PP 54-61
www.iosrjournals.org

Utilization of Plastic Bag Waste as A Substitute in Open-Graded LASTON AC-WC Mixtures with 60/70 Penetration Asphalt Binder

Firdaus[1], Alby Kastelany[2]
[1](*Department, Universitas Bina Darma, Indonesia*)
[2](*Department, Universitas Bina Darma,Indonesia*)

Abstract: *This study explores the use of Low-Density Polyethylene (LDPE) plastic waste as a substitute material in Asphalt Concrete Wearing Course (AC-WC) open-graded mixtures with 60/70 penetration bitumen binder. Aimed at reducing unmanaged plastic waste and mitigating water ponding on roads, the research evaluates the effects of varying LDPE substitution percentages (5%, 7.5%, 10%) and sizes (0.25 cm² to 12.25 cm²) on asphalt's mechanical and permeability properties.*
Key findings show that an optimal 7.5% LDPE substitution enhances Marshall stability, permeability, and void characteristics (VIM, VMA, VFA), meeting standards from the Indonesian Ministry of Public Works and Australian Asphalt Pavement Association. Permeability coefficients (0.1–0.5 cm/s) ensure effective drainage, reducing risks of water pooling. The study concludes that LDPE-modified asphalt improves road safety and durability while addressing environmental concerns, offering a sustainable, cost-effective solution for road construction. Future research should investigate long-term performance and scalability.

Keywords: *Low-Density Polyethylene (LDPE), Asphalt Concrete Wearing Course (AC- WC), Open-Graded Asphalt, Plastic Waste Utilization, Marshall Stability, Permeability, Sustainable Road Construction.*

Date of Submission: 12-12-2024 Date of Acceptance: 25-12-2024

I. Introduction

Road pavement plays a critical role in supporting transportation infrastructure, directly influencing safety, efficiency, and accessibility. In Indonesia, the tropical climate characterized by alternating rainy and dry seasons poses significant challenges to road durability and safety. Heavy rainfall during the rainy season often leads to water pooling and flooding, particularly in low-lying areas and urban regions, resulting in damaged infrastructure and increased traffic accidents. A major contributing factor to these issues is insufficient road drainage systems, exacerbated by improper waste management, including the rampant disposal of plastic waste.

Indonesia ranks among the largest contributors to global plastic waste, generating approximately 187.2 million tons annually, with a significant portion remaining unmanaged. This issue not only threatens environmental sustainability but also impacts public health and infrastructure. The Indonesian government, through the Ministry of Public Works and Housing (PUPR), has initiated measures to address these challenges, including the use of waste materials in infrastructure development. Notably, the incorporation of Low-Density Polyethylene (LDPE) plastic waste into asphalt mixtures has emerged as a promising solution for enhancing pavement performance and reducing environmental impact.

Porous asphalt mixtures, specifically the Asphalt Concrete Wearing Course (AC-WC) with open-graded designs, are designed to improve road safety by enhancing water drainage and reducing the risk of aquaplaning. Previous studies have demonstrated the potential of LDPE to improve asphalt mixture durability and stability while meeting the specifications set by the Ministry of Public Works and Housing. However, further research is needed to optimize LDPE substitution levels and particle sizes to achieve the desired mechanical and permeability properties in compliance with international standards such as those established by the Australian Asphalt Pavement Association (AAPA).

This study aims to investigate the effects of LDPE plastic waste substitution on the mechanical and permeability properties of AC-WC mixtures. Using a dry process design methodology, the research evaluates various substitution levels (5%, 7.5%, and 10%) and particle sizes (0.25 cm², 2.25 cm², 6.25 cm², and 12.25 cm²) to determine the optimal composition for achieving high-performance and environmentally sustainable asphalt mixtures. By addressing critical challenges in road construction and waste management, this research contributes to the development of cost-effective, durable, and eco-friendly pavement solutions for Indonesia's infrastructure.

II. Material And Methods

This study aims to evaluate the characteristics of Asphalt Concrete Wearing Course (AC- WC) mixtures with an open-graded design, using penetration 60/70 asphalt binder before and after substitution with LDPE plastic waste. The research examines the mechanical and permeability properties of the mixtures in compliance with the **PUPR 2018 Revision 2 Specifications**, utilizing the Marshall Immersion test. The relationship between dependent variables (mixture properties) and independent variables (asphalt content and LDPE substitution levels) is analyzed, considering mixing, spreading, and compaction temperatures as influencing factors, while maintaining AC-WC with penetration 60/70 asphalt as the control variable.

Study Design: A **laboratory-based experimental study** focused on evaluating the impact of substituting LDPE plastic waste in open-graded Laston AC-WC mixtures. This study investigates the material properties and characteristics in compliance with the 2018 Revised General Specifications by PUPR and the Australian Asphalt Pavement Association (AAPA) 2004 standards. **Study Location:** The research is conducted in the Civil Engineering Laboratory, Faculty of Engineering, Universitas Bina Darma, Palembang.
Study Duration: The study includes preparation, testing, and analysis phases within a specific timeline, adhering to the provided project schedule.
Sample Size: A total of 84 specimens are created to examine variations in asphalt content and LDPE plastic substitution percentages and sizes. The study ensures comprehensive testing for stability, permeability, and other asphalt mixture characteristics. This design provides the structured framework needed to achieve the objectives and analyze the variables influencing the performance of asphalt mixtures with LDPE substitution.
Subjects & Selection Method: Material components such as coarse and fine aggregates, fillers (cement), and LDPE plastic waste undergo strict testing for compliance with relevant technical standards. Specimens for testing are produced under controlled laboratory conditions using Marshall Mix design methodology.
Sample Size Calculation: The **sample size** for this research was determined based on experimental and observational factors related to the mixture performance. The study does not explicitly describe a statistical sample size calculation, as the focus is on laboratory experimentation and performance evaluation of asphalt mixtures.

Inclusion Criteria:

The **Inclusion Criteria** for this study are:

1. Asphalt mixtures designed for **Laston Wearing Course (AC-WC)** with an open-graded specification.
2. Use of **Low-Density Polyethylene (LDPE)** plastic waste as a substitution material.
3. Aggregates (coarse and fine) that meet the requirements of **PUPR 2018 General Specifications Revision 2**, including:
   - **Coarse Aggregates:** Clean, durable, and free of clay, with properties such as Los Angeles abrasion, soundness, and adhesion satisfying the specified limits.
   - **Fine Aggregates:** Sand or screened crushed stone with a size smaller than 4.75 mm, maintaining specific gradation and cleanliness.
4. Binders used are **penetration grade asphalt 60/70**, meeting Indonesian standards for durability and performance under hot climate and heavy traffic conditions.
5. Gradation designed according to **Australian Asphalt Pavement Association (AAPA) 2004 standards** for open-graded porous asphalt.

Exclusion Criteria for this study are as follows:

1. Aggregates that do not meet the required quality standards as specified in **PUPR 2018 General Specifications Revision 2**, including but not limited to:
   - Coarse aggregates with excessive fines or impurities.
   - Fine aggregates containing high levels of clay or undesirable materials.
2. Asphalt binders that do not comply with penetration grade 60/70 specifications or show significant deviation from required properties.
3. LDPE plastic waste that:
   - Contains contaminants or impurities that cannot be removed through preparation.
   - Fails to meet the required particle size or is inconsistent in quality.
4. Materials not conforming to the **open-graded gradation** specifications defined by the

AAPA 2004 standards.

5. Specimens that are improperly prepared, such as:
   - Insufficient mixing of components.
   - Variations in compaction or curing procedures.
6. Any substitution materials other than LDPE plastic waste.

Procedure Methodology

This research is divided into three main stages as follows in its process

Asphalt Characteristic Testing

The evaluation of asphalt characteristics involves measuring specific properties such as density, penetration, kinematic viscosity, softening point, ductility, and flash point. The procedures and standards for these tests are outlined in Table 3.1.

No	**Exmination**	Testing Standard	Unit
A. 1 2 3 4 5 6	Asphalt Density Pentreation at 25° Kinematic Viscosity 135°C Softening Point Ductilty at 25°C Flash Point	SNI 2441:2011 SNI 2456:2011 ASTM D2170-10 SNI 2434:2011 SNI 2432:2011 SNI 2433:2011	- (0,1 mm) (cSt)(3) (°C) cm (°C)

Table 3.1. Asphalt Testing Procedures

Aggregate Characteristic Testing

Aggregate testing involves procedures such as coarse aggregate abrasion, sieve analysis, bulk density measurement, saturated surface dry (SSD) specific gravity, apparent specific gravity, and water absorption for both coarse and fine aggregates. LDPE plastic waste was cleaned using a wet process, cut into sizes of 0.25 cm², 2.25 cm², 6.25 cm², and 12.25 cm², and dried to a maximum moisture content of 5% before use. The LDPE was mixed with hot aggregates using the Marshall Immersion method to optimize results.

No	Examination	Testing Standard	Unit
B. Coarse Aggregate			
1 2 3 4 5 6	Abrasion Gradation Bulk Specific Gravity Saturated Surface Dry (SSD) Specific Gr Apparent Specific Gravity Water Absorption	SNI 2417:2008 SNI ASTM C136:2012 SNI 1969:2016 SNI 1969:2016 SNI 1969:2016 SNI 1969:2016	% % - - - %
B. Fine Aggregate			
1 2 3 4 5	Gradation Bulk Specific Gravity Saturated Surface Dry (SSD) Specific Gr Apparent Specific Gravity Water Absorption	SNI ASTM C136:2012 SNI 1970:2016 SNI 1970:2016 SNI 1970:2016 SNI 1970:2016	% - - - %
C. Filler Material			
1 2	Gradation Bulk Specific Gravity	SNI ASTM C136:2012 SNI 2049:2015	% -

Evaluation of Asphalt Concrete Wearing Course (AC WC) Characteristics

In general, the evaluation of asphalt mixtures using the Marshall method (SNI 06-2489- 1991) includes the following steps:

1. **Preparation of test specimens**
2. **Determination of aggregate composition percentage** based on combined gradation to achieve an optimum composition.
3. **Initial sample preparation** involves creating test specimens for AC WC using 60/70 penetration asphalt with asphalt content variations of 3.5%, 4.5%, 5.5%, and 6.5%. The compaction process was performed by tamping each specimen 75 times on both sides (top and bottom) at a temperature range between 155°C and 145°C during mixing and compaction.
4. **Evaluation parameters include** bulk density, air voids in the mix (VIM), voids in mineral aggregate (VMA), voids filled with asphalt (VFA), Marshall stability, and deformation (flow). Additionally, the residual stability of the Marshall specimens was assessed at the optimum asphalt content after immersion

for 24 hours at 60°C.

5. **LDPE plastic substitution process**: After determining the optimum asphalt content that satisfies the characteristics of the AC WC mixture, further specimens were prepared using the optimum asphalt content with LDPE plastic waste substitutions. Variations included 5% LDPE with sizes of 0.25 cm², 2.25 cm², 6.25 cm², and 12.25 cm²; 7.5% LDPE with the same sizes; and 10% LDPE with the same sizes, based on the weight of the asphalt. Mixing was conducted using the dry process at an aggregate temperature of 155°C, stirring for 10 seconds until the LDPE coated the aggregate surface. This was followed by wet mixing with hot asphalt at 150°C for 35 seconds. Compaction was performed by tamping each side of the specimen 75 times at a temperature range of 150°C to 145°C, adhering to the mixing and compaction temperature requirements.
6. **Measurement of key parameters**: Bulk density, VIM, VMA, VFA, Marshall stability, and deformation (flow) were evaluated for each specimen to determine the optimum LDPE plastic content based on the relationship between variables.
7. **Final testing**: Specimens were prepared again using the optimum asphalt and LDPE plastic content with varying sizes to evaluate asphalt permeability using the falling head permeability (FHP) method (Kandall and Mallick, 2001). The residual Marshall stability was assessed after immersion for 24 hours at 60°C.

Research Variables

The following table presents the variables and parameters used in the research for the preparation and testing of asphalt concrete specimens.

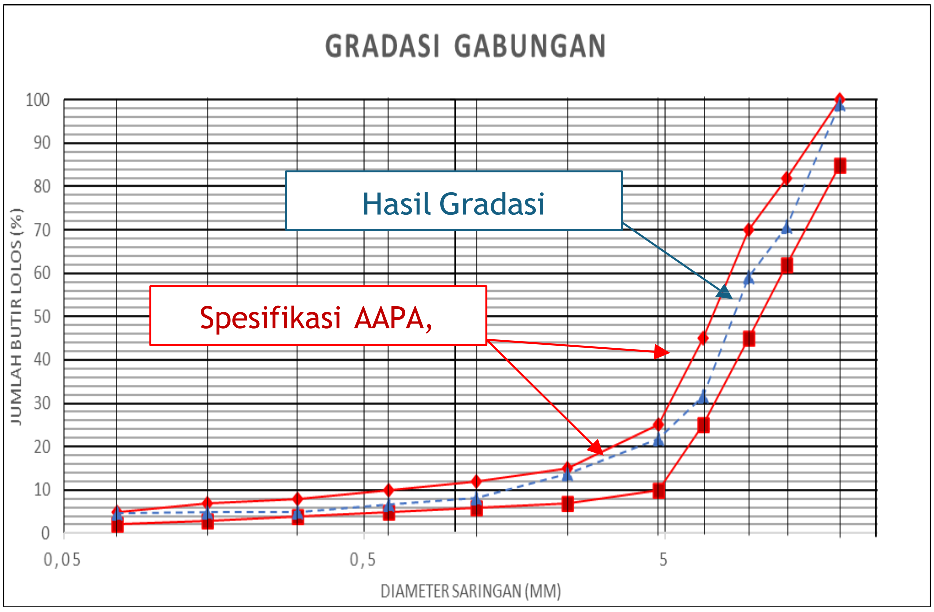
Asphalt Content (%)	LDPE Plastic Content (%)	LDPE Plastic Area (cm²)	Filler Percentage (%)	Number of Test Specimens	Sub Total Test Specimens
3.5%	-	-	1.5	3	21
4.5%	-	-	1.5	3	
5.5%	-	-	1.5	3	
6.5%	-	-	1.5	3	
OAC	-	-	1.5	3	
Permeability	-	-	1.5	3	
OAC Marshall Residual Stability	-	-	1.5	3	
OAC	5%	0.25	1.5	3	21
OAC	5%	2.25	1.5	3	
OAC	5%	6.25	1.5	3	
OAC	5%	12.25	1.5	3	
OAC Marshall Residual Stability	5%	0.25	1.5	3	
Permeability	5%	2.25	1.5	3	
OAC	7.5%	0.25	1.5	3	21
OAC	7.5%	2.25	1.5	3	
OAC	7.5%	6.25	1.5	3	
OAC	7.5%	12.25	1.5	3	
OAC Marshall	7.5%	0.25	1.5	3	
Residual Stability					
Permeability	7.5%	2.25	1.5	3	
OAC	10%	0.25	1.5	3	21
OAC	10%	2.25	1.5	3	

OAC	10%	6.25	1.5	3	
OAC	10%	12.25	1.5	3	
OAC Marshall Residual Stability	10%	0.25	1.5	3	
Permeability	10%	2.25	1.5	3	
					84

III. Result

Inspection of Mixed Materials/Materials

Graph 4.5. Combined Aggregate Gradation Combinations



Source: Research test

The purpose of this test is to evaluate several parameters, including the bulk specific gravity of the aggregate, the saturated surface-dry specific gravity (SSD), and the apparent specific gravity of both coarse and fine aggregates. Additionally, the test aims to determine the water absorption capacity of the aggregates.

AC-WC Mixture Design Before Substitution with LDPE Plastic Bags

COMPOSITION OF AGGREGATE + ASPHALT 3,5 %		**INDIVIDUAL WEIGHT**	**CUMULATIVE WEIGHT**
Aggregate	Percent	Gram	Gram
Crushed Stone 1-2	43,4	521,1	521,1
Crushed Stone 1-1	38,6	463,2	984,3
Stone Dust	13,0	156,3	1140,6
Filler	1,4	17,4	1158,0
Asphalt	3,5	42,0	1200
TOTAL MIX	100	1200	
COMPOSITION OF AGGREGATE + ASPHALT 4.5%		**INDIVIDUAL WEIGHT**	**CUMULATIVE WEIGHT**
Aggregate	Percent	Gram	Gram
Crushed Stone 1-2	43,0	515,7	515,7
Crushed Stone 1-1	38,2	458,4	974,1

Stone Dust	12,9	154,7	1128,8
Filler	1,4	17,2	1146,0
Asphalt	4,5	54,0	1200
TOTAL MIXTURE	100	1200	
COMPOSITION OF AGGREGATE + ASPHALT 5.5%		**INDIVIDUAL WEIGHT**	**CUMULATIVE WEIGHT**
Aggregate	Percent	Gram	Gram
Crushed Stone 1-2	42,5	510,3	510,3
Crushed Stone 1-1	37,8	453,6	963,9
Stone Dust	12,8	153,1	1117,0
Filler	1,4	17,0	1134,0
Asphalt	5,5	66,0	1200
TOTAL MIXTURE	100	1200	
COMPOSITION OF AGGREGATE + ASPHALT 6.5%		**INDIVIDUAL WEIGHT**	**CUMULATIVE WEIGHT**
Aggregate	Percent	Gram	Gram
Crushed Stone 1-2	42,1	504,9	504,9
Crushed Stone 1-1	37,4	448,8	953,7
Stone Dust	12,6	151,5	1105,2
Filler	1,4	16,8	1122,0
Asphalt	6,5	78,0	1200
TOTAL MIXTURE	100	1200	

Source: Research test results

From the calculation results in Table 4.16, three test specimens were prepared for each asphalt variation by weighing the cumulative weight of each material according to its percentage. In this study, a total weight of 1200 grams was used. After the aggregate mixture was heated to a temperature range of approximately ±160°C and the asphalt was heated to approximately ±155°C, the aggregate mixture was combined with asphalt and stirred evenly. The mixture was then placed into the specimen mold and compacted using the standard density method (2 x 75 blows) at a temperature of approximately ±145°C.

Analysis Results of AC-WC Mixture Before Substitution with LDPE Plastic Bag

Type of Analysis Marshall Test	**Test Results With Optimum Asphalt Content (OAC) 5.7%**	**Specifications General Specifications of PUPR Year 2018 Revision 2 and AAPA 2004**
Bulk Density	2,253	-
VIM	5,15	3 – 5
VMA	18,04	Min. 15
VFA	71,47	Min. 65
Stability	495,4	Min. 800
Flow	5,7	2 – 4
FHP	0,56	0,1 – 0,5 z
Stability Marshall remainder	90,18	Min. 90 %

Source: Research test results.

IV. Discussion

Comparison of AC-WC Mixtures Before and After Substitution with LDPE Plastic Bags.

Table 4.51. Comparison of Combined Variables of Optimum Asphalt Content Against Substitution Percentage of Plastic Bags, Variation in Plastic Bag Area, and Maximum Plastic Bag Area (MLPK).

Marshall Test Analysis Table

Type of Analysis	KAO (%)	Plastic Substitution (%)	Area (cm^2)	Bulk Density	VIM (%)	VMA (%)	VFA (%)	Stability (kg)	Flow (mm)	FHP (cm/s)	Remaining Stability (%)	General Standards	5%	7.5%	10%	Max Area
Marshall Test	5.7	5%	0.25	2.253	5.15	18.04	71.47	495.4	5.7	0.56	90.18	PUPR 2018 & AAPA 2004	6.5	-	-	-
			2.25	2.254	5.10	18.00	71.66	526.3	4.8		91.72					
			6.25	2.256	5.00	17.91	72.08	592.7	5.0		93.45					
			12.25	2.258	4.94	17.85	72.35	642.0	5.2	0.55	90.34					
		7.5%	0.25	2.255	5.07	17.97	71.79	521.9	4.9					6.31	-	-
			2.25	2.257	4.98	17.89	72.16	641.3	5.2							
			6.25	2.256	5.03	17.96	71.97	636.9	5.2							
			12.25	2.257	4.96	17.88	72.25	681.2	5.4							
		10%	0.25	2.261	4.85	17.78	72.73	737.2	5.5	0.47					1.59	-
			2.25	2.256	5.04	17.94	71.93	606.0	5.1							
			6.25	2.261	4.83	17.76	72.81	743.1	5.6							
			12.25	2.248	5.38	18.24	70.52	513.1	4.9							
			-	2.252	5.17	18.06	71.37	632.5	5.7							
			-	2.243	5.58	18.41	69.69	495.4	5.4							
			-	2.238	5.79	18.59	68.87	464.4	5.2							

Table 4.52. Comparison of each research variable with previous research variables:

Type of Analysis Marshall Test	Research Variable		Previous Research Variables						General Specifications PUPR 2018 Revision 2 and AAPA 2004
			Suraya Fitri, Sofyan M. Saleh (2018)	Nadya Tesalonika, Theo K. Sendow dan Steve Palenewen (2020)	Dwi Susanti Erni, Mirza Ghulam Rifqi dan M. Shofi'ul Amin (2021)	Ronald Porwadi (2021)	Gali Pribadi, Indriasari, Rafi Luthfir Rahman (2023)	M. Sa'dillah (2023	
Lps. Perkerasan	AC-WC Porous		AC-BC	AC-WC Porous	AC-WC	AC-WC	AC-WC	Porous	-
KAO (%)	5,7	5,7	5,35	5,5	6,5	-	6,3	5,0	-
LDPE (%)	-	7,5	5,3	-	5,5	3,0	5,0	8,0	-
VIM (%)	5,15	4,83	5,0	22,5	3,94	4,79	4,79	22,71	**3 - 5**
VMA (%)	18,04	17,76	18,46	-	15,95	15,20	18,76	22,77	**Min. 15**
VFA (%)	71,47	72,81	72,89	-	77,12	68,48	74,47	-	**Min. 65**
Stabilitas (kg)	495,4	743,1	1489,3	582,0	2167,4	2867,2	1858,4	1540,0	**Min. 800**
Flow (mm)	5,7	5,6	3,4	3,5	3,8	3,6	3,9	11,0	**2 - 4**
FHP (cm/s)	0,55	0,47	-	0,31	-	-	-	-	**0,1 – 0,5**
Marshall Sisa (%)	91,72	93,45	90,34	-	-	-	-	-	**Min. 90 %**

The use of LDPE plastic waste in asphalt mixtures demonstrates promising results, particularly in enhancing stability and meeting key performance standards. However, further research and optimization are required to address inconsistencies in parameters such as flow and VIM, ensuring compliance across all specifications. The findings support the feasibility of incorporating LDPE into asphalt mixtures, contributing to both improved performance and environmental sustainability.

The results of this study highlight the potential of incorporating LDPE plastic waste into Asphalt Concrete Wearing Course (AC-WC) mixtures as a sustainable alternative to enhance mechanical properties while addressing environmental concerns. The improvement in stability, VIM, and VMA values demonstrates that LDPE can contribute to creating more durable and environmentally friendly asphalt pavements. This finding aligns with efforts to recycle plastic waste and reduce reliance on traditional materials, offering a dual benefit of environmental sustainability and improved infrastructure quality. Moreover, these results provide a significant contribution to the ongoing discourse on integrating waste materials in road construction, particularly under the standards set by PUPR 2018 and AAPA 2004. The research also fills a gap in understanding the interaction between LDPE content and mixture performance, paving the way for practical applications in low-traffic and potentially high-traffic road constructions. While the findings are promising, the study has certain limitations. The experiments were conducted under controlled laboratory conditions, which may not fully capture the variability of field conditions. The focus on a single type of plastic (LDPE) limits the generalizability of the results to other types of plastic waste. Additionally, the impact of long-term durability and weathering on the performance of LDPE- modified mixtures was not explored. The study also did not investigate the economic feasibility of scaling up the use of LDPE in asphalt mixtures, which is critical for real-world implementation.

V. Conclusion

In conclusion, this study demonstrates that incorporating LDPE plastic waste in asphalt mixtures can improve stability and other key performance parameters, suggesting its viability as a sustainable material for road construction. However, further research is recommended to address the limitations identified, including field testing under varying environmental conditions, exploration of other types of plastic waste, and cost-benefit analyses. By expanding the scope of research, the potential for widespread adoption of this innovative solution can be more comprehensively evaluated.

REFERENCES

[1]. ASTM C136:2012, "Test Method for Sieve Analysis of Fine and Coarse Aggregates (ASTM C136-06, IDT)."
[2]. ASTM D2170-10, "Standard Test Method for Kinematic Viscosity of Asphalts (Bitumens)."
[3]. SNI 2441:2011, "Test Method for Specific Gravity of Hard Asphalt."
[4]. SNI 2456:2011, "Test Method for Asphalt Penetration."
[5]. SNI 2434:2011, "Test Method for Softening Point of Asphalt Using Ring and Ball Apparatus."
[6]. SNI 2432:2011, "Test Method for Asphalt Ductility."
[7]. SNI 2433:2011, "Test Method for Flash Point and Fire Point of Asphalt Using Cleveland Open Cup."
[8]. SNI 2417:2008, "Test Method for Aggregate Abrasion Using the Los Angeles Abrasion Machine."
[9]. SNI 1969:2016, "Test Method for Specific Gravity and Water Absorption of Coarse Aggregate."
[10]. SNI 1970:2016, "Test Method for Specific Gravity and Water Absorption of Fine Aggregate."
[11]. SNI 06-2489-1991, "Testing Asphalt Mixture Using Marshall Apparatus."
[12]. D. Erni, M. G. Rifqi, and M. S. Amin, "The Effect of Adding Low-Density Polyethylene Plastic Waste on the Characteristics of AC-WC Laston Mixtures," 2021.
[13]. G. Pribadi, I. Indriasari, and R. L. Rahman, "Analysis of Low-Density Polyethylene Plastic Waste Substitution on Marshall Characteristics of AC-WC Laston Mixtures," 2023.
[14]. M. Sa'dillah, "Characteristics of Porous Asphalt with Aggregate Additives Using Low-Density Polyethylene (LDPE) Plastic Waste," 2023.
[15]. N. Tesalonika, T. K. Sendow, and S. Palenewen, "Analysis of Porous Asphalt Mixture Using Materials from Kakaskasen, Tomohon Utara District, Tomohon City," 2020.
[16]. R. Porwadi, "The Effect of AC-WC Laston Mixture Using Kampar Materials with Low-Density Polyethylene (LDPE) Plastic Waste Additives on Marshall Characteristics,"2021.
[17]. S. Fitri, S. M. Saleh, and M. Isya, "The Effect of Adding Plastic Bag Waste as a Substitute for Asphalt Pen 60/70 on the Characteristics of AC-BC Laston Mixtures," 2018.
[18]. Research at the Center for Road and Bridge Research and Development (Pusjatan), "Utilization of Plastic Waste as an Additive for Asphalt Mixtures, with Limited Application at Universitas Udayana, Bali, along a 700-meter road," 2017.
[19]. Circular Letter from the Ministry of Public Works and Public Housing (PUPR), No. SP.BIRKOM/VIII/2017/383, "Innovations Supporting the Acceleration of PUPR Infrastructure Development," August 5, 2017.
[20]. Australian Asphalt Pavement Association (AAPA), "General Specifications," 2004.
[21]. PUPR Bina Marga, "General Specifications, 2018 Revision 2."