Sustainable Construction

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Sustainable Construction: Optimization of Road Potholes Repair with Polymer Mix Aggregates

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Abstract The roads in Banyuwangi city have sustained considerable damage; the asphalt supply has not met the need because 45% of the roads are built using gravel and soil. Another problem is related to plastic, which is a type of waste that is difficult to recycle. Thereby, to solve these two problems, we conducted research in making polymer-modified asphalt by utilizing food packaging plastic waste. The process followed the standard specification of Highway Construction Division 6, revision 3: the polymer blending process was performed when the hot asphalt mixing temperature was 145°C-155°C. The research results found that the variation of asphalt content used in the mixture was 4.5%, 5%, 5.5%, and 6%. Moreover, the optimal asphalt content was 6%. The polymer was mixed with the optimal asphalt content of 0%, 1%, 2%, 3%, and 4%. The test results showed that the optimal polymer content was 1% polymer. For optimizing and repairing road potholes, polymer asphalt with asphalt content of 6% mixed and 1% polymer can be chosen as a solution. Polymer-modified asphalt had a high stability value, which was 1181.9 kg. The discovery of this mixture of materials is very appropriate for sustainable road construction in Indonesia.

Keywords Asphalt Infrastructure Management, Pavement Stability, Polymer Modification

1. Introduction

Today, Indonesia's population growth rate increases daily, especially in Banyuwangi. Furthermore, the use of plastic is inseparable from our needs; food packaging, shopping bags, and even our home furnishings are made of polymer or plastic materials [1–3]. If the plastics are no longer in use, many people throw them away. Some people have been recycling plastic waste, but many do not act the same way [4]. Therefore, the researchers considered changing or reusing plastic by adding plastic materials to asphalt for building roads [5].

Recently, research on asphalt added with polymer materials to improve the physical and mechanical properties of asphalt has been widely published [6]. The method is possible for roads in Indonesia and can reduce the state's annual budget expenditures. Polymer asphalt is a material produced by adding natural or synthetic polymers to asphalt [7].

Polymer-modified asphalt (commonly abbreviated PMA) has been produced in the last few decades [8,9]. A little addition of polymer material can improve the resistance to deformation, overcome cracks, and increase wear resistance attributable to road age. Consequently, the road is more durable and it can reduce road maintenance or repair costs. The road is a transportation infrastructure asset susceptible to traffic loading, weather, environment, and road user behavior. Roads must be managed following the principles of infrastructure asset management [10].

Road construction and maintenance need to be economical; one of the methods is by using a new mix of asphalt to make the pavement process economical [11].

Roads should be built using asphalt and a mixture of materials providing a high stability value to prevent damage. With the existing low supply of asphalt, a mixture with low asphalt content will meet the need for road construction. Roads using asphalt mixtures with high stability values can improve the aggregate strength and tensile of the asphalt mixture [12]. Thus, the road will have damage resistance. Road repair and construction lead to an increased need for asphalt materials. However, the supply has not met the current need for asphalt; moreover, the asphalt must be of good quality because it will suffer damage due to water, cracks, utility development, and others over time. Road damage can reduce driving comfort or cause accidents, and asphalt stability affects the damage. Thus, excellent road infrastructure in asset management is essential to provide good road services. Therefore, good-quality asphalt is necessary for producing a good asphalt mixture. Asphalt is the topmost layer of pavement directly affecting traffic, so it must be strong, stable, and must stay in place despite traffic loading [13].

Based on the background, the researcher addresses the effect of polymer asphalt on the highest compressive strength of normal asphalt; we discussed the ability of polymer mixture added to the normal asphalt composition affecting the compressive strength of normal asphalt and compared the selected asphalt materials in their efficiency and suitability for road pavement. The study aimed to determine polymer asphalt's effect on the highest compressive strength of normal asphalt, the effect of polymer asphalt on existing road holes, and the addition of polymerized asphalt to normal asphalt composition, which affected the compressive strength of normal asphalt. The scope of the current research problems included the asphalt design's compressive strength and a characteristic test involving the asphalt compressive strength; the polymer asphalt being tested was a cylinder with a 15-cm diameter and 30 cm height. The current research can provide information in engineering science, especially about the effect of adding polymers to the compressive strength of normal asphalt. It also provides comparisons and recommendations for developmental research to similar studies. The research can be used as a reference for the latest innovations in asphalt-polymer blend manufacture.

2. Literature Review

2.1. Plastic Waste in Asphalt

The research found that a mixture of synthetic and pure asphalt created near-optimum conditions in each experiment; the parameters used in the experiments were penetration, softening point, ductility, flash point, and specific gravity. Mixing asphalt and aggregate added with polymer additives, such as plastic waste from food packaging and polystyrene, will only lead to a physical bond so that the additive simply functions as an aggregate [14]. At room temperature, asphalt is a solid or semisolid and a thermoplastic material. Consequently, asphalt melts when heated at a certain temperature and freezes when the temperature drops. Asphalt mixed with aggregate is a material that forms road pavements. Generally, the chemical composition of asphalt is 82-88% carbon, 0-1.5% oxygen, 0-16% sulfur, 8-11% hydrogen, and 0-1% nitrogen. Based on the chemical composition, asphalt is categorized into (1) natural asphalt such as lake and rock asphalt, and (2) refined asphalt, such as cement asphalt, liquid asphalt, and emulsified asphalt [15].

2.2. Polymer Types for Asphalt Material

A polymer is a giant molecule with very long chains composed of simple molecules (monomers) [16]. Polymers are also known as macromolecules and are often used in everyday life, viz. plastic, rubber, nylon, and tetoron. Some polymers are essential to our body, such as carbohydrates, proteins, and nucleic acids. Polymers are classified into several groups. Based on their origin, polymers are divided into natural and synthetic polymers:

1. *Natural polymers* are available in nature and are formed naturally, viz. natural rubber (polyisoprene), protein, glycogen, and starch.
2. *Synthetic polymers* or artificial polymers are imitations. Synthetic polymers include plastics, synthetic rubber, and synthetic fibers. Some examples are plastic, PVC, Teflon, SBR rubber, nylon, and tetron.

Based on the type of monomer, constituent polymers are divided into copolymers and homopolymers:

1. *Copolymers* are composed of different monomers, such as dacron, bakelite, nylon, and nitrile rubber.
2. *Homopolymers* are composed of the same monomer, such as PVC, Teflon, polyethylene, and polypropylene.

Based on their properties to heat, polymers are divided into thermosetting polymers and thermoplastic polymers, such as:

1. *Thermosetting polymers* do not soften when heated. This polymer can only be heated once when manufactured. Thus, if it breaks, it cannot be restored or reprinted by heating (it cannot be recycled). Thermosetting polymers consist of cross-links between chains to form a harder and stiffer material. Some examples of thermosetting polymers are bakelite and melamine.
2. *Thermoplastic polymers* soften when heated. This polymer can be repeatedly heated because it softens when heated and hardens when cooled. Thus, if it breaks, it can be restored or reprinted by heating (it

can be recycled). Thermoplastic polymers consist of straight or branched chain molecules: there are no cross-links between the chains as in thermosetting polymers. Some examples are polyethylene, PVC, and polystyrene.

According to research by A, regarding the effect of rainwater in industrial cities on the performance of polymer-modified asphalt mixtures, it shows that the road pavement surface layer is a layer that directly interacts with traffic loads and the environment. Stagnant water on the road surface causes a loss of bond between asphalt and aggregate.

This research is slightly different from the research by B on the Use of Crumb Rubber as a Substitute for Fine Aggregate for Hot Rolled Asphalt with SBS E-55 Modified Asphalt Bonding Material. Due to the development and needs of pavement, not only focus on the road pavement, but also flexible pavement for the convenience of road users according to its function. This study shows that polymer modification is higher than ordinary fine aggregate, so polymer materials are used as road pavement materials.

This research is almost the same as that conducted by C to measure the prediction performance of asphalt concrete mixtures with 60/70 penetration asphalt and bituplus polymer asphalt. One effort to overcome the shortcomings of conventional 60/70 penetration asphalt is to use polymer-modified asphalt as a hot mix asphalt which can increase durability.

That a good asphalt layer must meet 4 requirements, namely stability, durability, flexibility and shear resistance. If using a density grade, it will produce a good density, meaning that it provides good stability but has a small pore cavity so it provides poor flexibility due to additional compaction from repeated traffic loads and asphalt melting due to weather effects. will provide a small shear resistance. On the other hand, if you use an open gradation, you will get good flexibility, but little stability. Too little bitumen content will cause the asphalt binder layer to peel off quickly and reduce durability. From this explanation, it can be concluded that the optimal mixture of aggregate and asphalt must be determined. In other words, a mixture must be planned which includes the gradation of aggregate (by also paying attention to the quality of the aggregate) and the asphalt content so that a pavement layer is produced that can meet the requirements, namely:

1. Asphalt content is sufficient to provide flexibility
2. Stability is sufficient to provide the ability to carry loads so that destructive deformation does not occur.
3. The void content is sufficient to provide the opportunity for additional compaction due to repeated loading and flow of the asphalt.
4. Can provide ease of work so that there is no segregation
5. Can produce a mixture that ultimately produces a pavement layer that meets the requirements in the pavement layer selection at the planning stage.

Therefore, there are several factors that can affect the quality of asphalt, namely:

1. Asphalt absorption
2. Effective asphalt content
3. Inter-grain cavity (VMA)
4. Air cavity in the mix (VIM)
5. Aggregate grading

3. Methods

3.1. Time and Location of Research

This research used plastic polymer waste as the experimental material to examine the compressive strength of pothole asphalt road filling. The material testing, sample printing, and sample testing were performed on 17 August 1945 University Banyuwangi Laboratory at Jl. Admiral Adi Sucipto, Taman Baru, Banyuwangi Subdistrict, Banyuwangi Regency, East Java.

3.2. Research Materials and Instruments

Elastomer polymers, asphalt, and rubber are SBS (Styrene Butadiene Styrene), SBR (Styrene Butadiene Rubber), and SIS (Styrene Isoprene Styrene) elastomers. Rubber is the type of elastomer polymer commonly used as a hard asphalt mixture. Adding this type of polymer to a mixture is meant to improve the rheological properties of asphalt, including penetration, viscosity, softening point, and elasticity of hard asphalt. A mixture made with polymer elastomeric asphalt will have a higher level of elasticity than that made with hard asphalt. The percentage of additives when manufacturing polymer asphalt must be determined with laboratory tests because the addition needs to reach a certain extent. Types of elastomer polymers widely used include EVA (Ethylene Vinyl Acetate), Polypropylene, and Polyethylene. The percentage of adding this polymer into hard asphalt must also be determined with laboratory tests because, to a certain extent, the addition can improve the rheological properties of asphalt and a mixture; however, excessive addition will have a negative effect. The elastomeric polymer material binds the asphalt elasticity, while the elastomer polymer binds the asphalt's physical properties. The test includes measuring the stability and flow of an asphalt mixture with a maximum grain size of 25.4 mm (1 inch).

3.3. The Test Method of Asphalt Mixture Compressive Strength

The test method aimed to determine the compressive strength of the hot asphalt mixture used for the surface layer and road foundation layer. Test specimens are generally cylindrical with a diameter of 102 mm or 4.0 inches and a height of (102 ± 2.5) mm or (4.0 ± 0.1) inches. The size of the specimen affects the results of the compressive strength test. The dimensions of the test object are not always 102 mm (4 inches); however, we need to consider that:

1. The height of the test object must be the same as its diameter, with a tolerance of ± 2.5%.
2. The diameter of the specimen is not less than four times the nominal size of the largest aggregate.
3. The diameter of the test object is not smaller than 50 mm.

3.4. The Implementation of the Compressive Strength Test

1. The test method for the real specific gravity of compacted asphalt mixture using saturated surface dry test objects. This method aims to determine each test object's real specific gravity using Pd M-31-1998-03.
2. Performing tests on specimens with axial pressure, without side pressure, at a speed of 1.3 mm per minute per 25 mm height of the specimen. For specimens that are 100 mm high, we use a speed of 5.1 mm per minute.

Each asphalt content must be tested on the Compressive Strength Test as indicated in Pascal. The compressive strength test value and average compressive strength must be determined through at least three experimental objects.

4. Results and Discussion

This section addresses the results of the tests performed, viz. material preparation, testing of aggregate and asphalt materials, and making briquette test objects. Polymer-modified asphalt was manufactured following the standard specification of Highway Division 6, revision 3: the polymer blending process was performed when the hot asphalt mixing temperature was 145°C-155°C. The research results found that the variation of asphalt content used in the mixture was 4.5%, 5%, 5.5%, and 6%; the optimum asphalt content was 6.0%. Polymer mixing was performed with the optimal asphalt content of 0%, 1%, 2%, 3%, and 4%. The test results show that the optimum polymer content was 1% and 3% polymer at maximum. The polymer-modified asphalt had a high stability value of 1181.9 Kg; moreover, its VIM was 3.57%, VMA was 15.12%, VFB was 76.39%, and the Marshall quotient value was 358.2Kn/mm.

4.1. Aggregate Material Test

The researcher tested the mixed material before the aggregate. The coarse aggregate test in this study included sieve analysis, specific gravity, water absorption, and aggregate wear. The results showed the aggregate's physical properties. The test determining the feasibility of using polymers in asphalt mixtures was conducted at the Civil Engineering Study Program Laboratory of UNTAG (*Universitas 17 Agustus 1945*), Banyuwangi; the results corresponded to the test method and followed the specifications required by the Indonesian National Standard and Highways General Specifications of 2018 [17].

4.2. Asphalt AC (pen 60/70)

The current research used asphalt AC with pen 60/70. The test was performed following the characteristic values of the asphalt material to determine whether its quality met the test requirements such as the standard set, as listed in Table 1.

Table 1. The Test Results of Comparing Hard Asphalt with Standard Asphalt

Inspection Type, pen 60/70	Min	Max	Test Results	Unit	Status
Asphalt penetration of 25°, 100 gram, 5 seconds	60	79	62.8	0.1 mm	OK
Asphalt Softening point of 5°C	48	58	49	°C	OK
Asphalt flash point	232	-	320	°C	OK
Asphalt weight loss	-	0.4	0.19	% weight	OK
Solubility in CCl4	99	-	99.5	% weight	OK
Ductility	100	-	> 100	cm	OK
Penetration after weight loss	75	-	89.17	% initial	OK
Specific gravity	1	-	1.031	gr/cc	OK

Source: General Specification for Highway and Bridge Construction Project [17]

4.3 Polymer-modified Asphalt (PMA)

The current research used asphalt AC with pen 60/70. The test was performed following the characteristic values of the asphalt material to determine whether its quality met the test requirements such as the standard set, as listed in Table 2. The examination of polymer asphalt's physical properties included penetration, softening point, flash point, burn point, and asphalt ductility. Polymer-modified asphalt is asphalt with an AC penetration of 60/70, of which the brand is Pertamina.

4.4. Planning the AC-WC Asphalt Mixture

Figure 1 displays the making of the AC-WC test object sample based on the variations and levels of asphalt that have been planned. The test object was made with five variations. This research used polymer mixtures of 0%, 1%, 2%, 3%, and 4% with asphalt content of 4.5%, 5%, 5.5%, and 6%. The aggregate gradation used in planning asphalt AC - WC, OGA 14 (Open Graded Asphalt), followed the 2018 General Specifications for Highway and Bridge Construction [17]. Furthermore, the researcher weighed the coarse aggregate per fraction and asphalt content per subsequent variation, then weighed the mixed materials composing the test object (the weight was 1,200 grams). The weight of this mixture was used based on the weight per sample composition of the asphalt mixture variation. The calculation result was obtained from the material weight per fraction; the value was obtained from the percentage fraction of each aggregate with five variations of polymer-asphalt mixtures, viz. 0%, 1%, 2%, 3%, and 4% with asphalt content of 4.5% - 6%.

Figure 1. The Test Object of AC – WC Asphalt Briquette

Table 2. The Test Results of Comparing Polymer Asphalt with Standard Asphalt

Inspection Type, pen 60/70	Specs		Test Results			Status
	Min	Max	Pol 1%	Pol 1%	Unit	
Asphalt penetration of 25°, 100 gram, 5 seconds	50	75	52	50	0.1 mm	OK
Penetration after weight loss	75	-	79.74	88	% initial	OK
Asphalt Softening point of 5°C	54	-	53	87	°C	OK
Asphalt flash point	232	-	325	311	°C	OK
Asphalt burn point	232	-	329	322	°C	OK
Ductility	50	-	> 100	> 100	cm	OK
Weight Loss (RTFOT)	-	1.0	0	0	% weight	OK

Source: Test Results, 2021

Table 3. Asphalt and Coarse Aggregate Weight in AC – WC Polymer Asphalt Mixture

Asphalt Level	Asphalt to Mixture Weight	*MIX DESIGN OF AGGREGATE MIXTURE*				Total of Combined Aggregate	Total of Mixture Weight
		15-10 (20%)	*10-5* (30%)	*0-5* (50%)	AMP (0%)		
(%)	(gr)	(gr)	(gr)	(gr)	(gr)	(gr)	(gr)
4.5	54	229.2	343.8	573	0	1,200	1,200
5.0	60	228	342	570	0	1,200	1,200
5.5	66	226.8	340.2	567	0	1,200	1,200
6.0	72	225.6	338	564	0	1,200	1,200

Source: Test Results, 2021

Table 3 presents the results of material weight per fraction obtained from the percentage of each aggregate fraction: 15-10 (20%), 10-5 (30%), 0-5 (50%), and 0% polymer with variations in asphalt content of 4.5% - 6%. With an interval value of 0.5%, the weight of each fraction was combined with each variation of asphalt content; it was used as material to manufacture the test object. Table 4-7 respectively shows the results of material weight per fraction obtained from the percentage of each aggregate fraction: 15-10 (20%), 10-5 (30%), 0-5 (50%), and 1% polymer with variations in asphalt content of 4.5% - 6%. With an interval value of 0.5%, the weight of each fraction was combined with each variation of asphalt content; it was used as material to manufacture the test object.

4.5. Test Result of Marshall Test

After the test object was created, the researcher analyzed the asphalt mixture strength function by comparing the results of the test parameters following the 2018 General Specifications for Highways and Bridge Construction Project [17], including stability, flow, Marshall Quotient (MQ), Voids in Mixture (VIM), Voids in Mineral Aggregate (VMA), and Voids Filled Bitumen (VFB). Stability is essential to determine the pavement's strength to withstand traffic loads without causing permanent alterations such as waves, grooves, and bleeding. The test results obtained the stability values used for the Marshall test data. After obtaining the results of the stability recapitulation values for each polymer variation, the asphalt AC-WC stability recapitulation graph was created to determine the stability value for the asphalt polymer mixture. The recapitulation is presented in Table 8.

Figure 2 indicates that the stability value for each variation of asphalt content is beyond the asphalt AC – WC specifications required by the 2018 General Specifications Highways and Bridge Construction Project [17], which is a minimum of 800 kg. In the test results, the stability value increased from 4.5% to 6%, and the highest stability value was in the 1% polymer asphalt variation with 6% asphalt content, weighing 1181.9 kg. The lowest stability value was 0% polymer variation with 6% asphalt content, weighing 1157.5 kg. The variation of the mixture with asphalt content increased along with the stability value because the polymer filled the voids between the aggregate grains; consequently, the asphalt and aggregate formed a strong bond, which is expected to have a good stability value of a pavement layer during the service life of the road.

Table 4. Asphalt and Coarse Aggregate Weight in 1% Polymer Asphalt Mixture

Asphalt Level	Asphalt to Mixture Weight	*MIX DESIGN OF AGGREGATE MIXTURE*				Total of Combined Aggregate	Total of Mixture Weight
		15-10 (20%)	*10-5* (30%)	*0-5* (50%)	AMP (1%)		
(%)	(gr)	(gr)	(gr)	(gr)	(gr)	(gr)	(gr)
4.5	54	227	340	567	11.35	1,135	1,199
5.0	60	225	338	564	11.28	1,128	1,198
5.5	66	224	336	561	11.23	1,123	1,198
6.0	72	223	335	558	11.17	1,117	1,199

Source: Test Results, 2021

Table 5. Asphalt and Coarse Aggregate Weight in 2% Polymer Asphalt Mixture

Asphalt Level	Asphalt to Mixture Weight	*MIX DESIGN OF AGGREGATE MIXTURE*				Total of Combined Aggregate	Total of Mixture Weight
		15-10 (20%)	*10-5* (30%)	*0-5* (50%)	AMP (2%)		
(%)	(gr)	(gr)	(gr)	(gr)	(gr)	(gr)	(gr)
4.5	54	227	340	562	22.48	1,124	1,199
5.0	60	225	338	559	22.36	1,118	1,199
5.5	66	224	336	556	22.68	1,112	1,199
6.0	72	223	335	553	22.56	1,106	1,199

Source: Test Results, 2021

Table 6. Asphalt and Coarse Aggregate Weight in 3% Polymer Asphalt Mixture

Asphalt Level	Asphalt to Mixture Weight	*MIX DESIGN OF AGGREGATE MIXTURE*				Total of Combined Aggregate	Total of Mixture Weight
		15-10 (20%)	*10-5* (30%)	*0-5* (50%)	AMP (3%)		
(%)	(gr)	(gr)	(gr)	(gr)	(gr)	(gr)	(gr)
4.5	54	222	333	556	34.38	1,112	1,199
5.0	60	221	331	553	34.20	1,106	1,199
5.5	66	220	330	550	34.02	1,110	1,200
6.0	72	219	328	547	33.84	1,095	1,199

Source: Test Results, 2021

Table 7. Asphalt and Coarse Aggregate Weight in AC – WC 4% Polymer Asphalt Mixture

Asphalt Level	Asphalt to Mixture Weight	*MIX DESIGN OF AGGREGATE MIXTURE*				Total of Combined Aggregate	Total of Mixture Weight
		15-10 (20%)	*10-5* (30%)	*0-5* (50%)	AMP (4%)		
(%)	(gr)	(gr)	(gr)	(gr)	(gr)	(gr)	(gr)
4.5	54	220	330	550	44.80	1,101	1,198
5.0	60	219	329	548	43.60	1,097	1,199
5.5	66	218	327	545	43.36	1,091	1,199
6.0	72	216	324	541	43.32	1,083	1,198

Source: Test Results, 2021

Table 8. The Results of Stability Recapitulation

Asphalt Content Variation	**Stability Recapitulation**				
	AMP 0%	AMP 1%	AMP 2%	AMP 3%	AMP 4%
4.5%	1020.7	1025.6	1030.5	1069.6	1025.6
5.0%	1123.3	1133.1	1157.5	1152.6	1147.7
5.5%	1147.7	1157.5	1167.2	1167.2	1157.5
6.0%	1157.5	1181.9	1177	1172.1	1162.4
the 2018 General Specifications for Highway Construction	> 800				

Source: Test Results, 2021

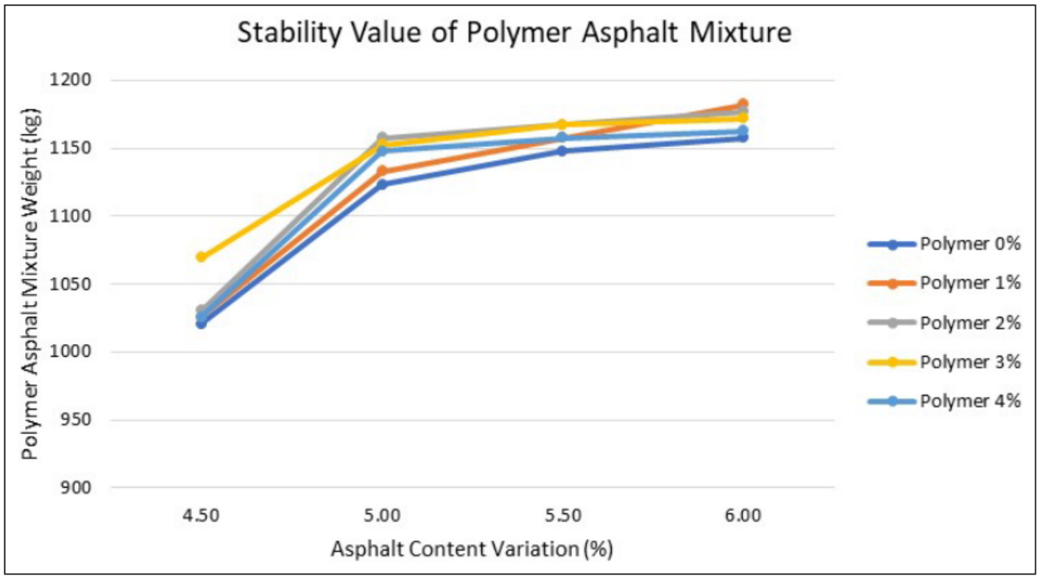

Figure 2. Stability Recapitulation Graphic

Flow is the amount of deformation of the test object from the beginning of loading until the maximum stability condition. The failure limit is indicated by mm. Flow shows the level of flexibility of a mixture. A high flow value indicates that the mixture is plastic and can better follow the deformation due to load. Flow is measured along with the Marshall stability value.

After obtaining the recapitulation values of each polymer mixture variation in Table 9, a recapitulation graph of the flow values in the AC-WC asphalt mixture is created to determine the flow value increase of the polymer asphalt mixture.

Figure 3 presents the highest flow results in the variation of 4% polymer asphalt with 6% asphalt content, equivalent to 3.9 mm. The lowest flow was in 0% polymer asphalt variation containing 4.5% asphalt (2.6 mm). The flow value increased due to increased asphalt content; thus, the mixture became more elastic, following the nature of asphalt as a binding material. The more asphalt covers the rock, the better the bond between the aggregate and the asphalt, and the higher the flow value. The flow value exceeding the specification limit can cause the pavement to bleed easily and make the road more slippery. Therefore, the use of asphalt content must follow the design of the polymer-asphalt mixture.

VIM (Void in Mixture) is the number of voids or pores between the aggregate grains covered by asphalt. The VIM value is needed to determine the percentage of pore volume that remains after the asphalt mixture is compacted. The VIM value was obtained from the results of the Marshall test.

Table 10 shows the recapitulation of VIM values based on the variation of the polymer mixture with the planned asphalt content. As seen in Figure 4 and Table 10, it can be concluded that the percentage of pores increased and decreased in the asphalt mixture.

Table 9. The Results of Flow Recapitulation

Asphalt Content Variation	Flow Recapitulation (mm)				
	AMP 0%	AMP 1%	AMP 2%	AMP 3%	AMP 4%
4.5%	2.6	2.7	2.8	3.0	3.0
5.0%	3.1	3.1	3.2	3.2	3.3
5.5%	3.2	3.3	3.1	3.1	3.4
6.0%	3.2	3.3	3.5	3.8	3.9
the 2018 General Specifications for Highway Construction	2 - 4				

Source: Test Results, 2021

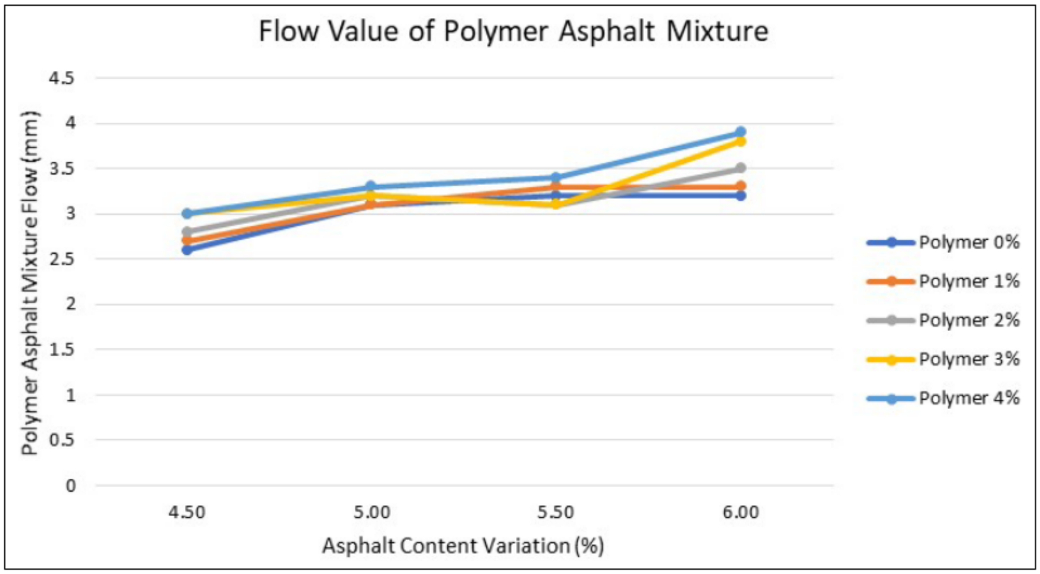

Figure 3. Graph of Flow Recapitulation Results

Table 10. The Results of VIM (Voids in Mixture) Recapitulation

Asphalt Content Variation	VIM Recapitulation				
	AMP 0%	AMP 1%	AMP 2%	AMP 3%	AMP 4%
4.5%	6.0	5.9	5.9	5.9	5.9
5.0%	5.2	5.1	5.1	5.1	5.2
5.5%	4.2	4.3	4.3	4.3	4.4
6.0%	3.6	3.6	3.5	3.5	3.5
the 2018 General Specifications for Highway Construction	3 - 5				

Source: Test Results, 2021

Figure 4 affirms that the VIM value decreased due to the increase in asphalt content and variations in the polymer mixture, leading to tighter pores caused by asphalt and aggregates filling the air pores in the asphalt mixture. Thus, the VIM value fluctuated along with the variation of the mixture. The VIM value is one of the important properties in the asphalt AC-WC mixture design. This type of construction is planned; after laying and compacting, the construction can have a pavement layer with large pores in the mixture. This type of construction has good water absorption, water escape properties.

Voids in Mineral Aggregate (VMA) is the volume of voids between the aggregate grains of a compacted asphalt mixture, indicated by a percentage of the total mixture volume. The Marshall test generated the VMA value.

As seen in Table 11, the VMA recapitulation values are based on the polymer mixture variation, illustrated by a graph in Figure 5. Voids in Mineral Aggregate (VMA) shows the percentage of voids filled with air and asphalt. The value of VMA affects the impermeability and durability of the mixture to water and air, as well as the mixture's stiffness.

Figure 5 displays that the test results follow the 2018 General Specifications for Highways and Bridge Construction Project [17],with 6% asphalt content. The more asphalt content in the mixture, the more aggregate can be covered; however, excessive asphalt can cause bleeding on the road. The decreased value was due to the smaller voids in the aggregate leading to increased specific gravity in the mixture. In contrast, the increased value was caused by the large voids in the aggregates leading to quick water absorption.

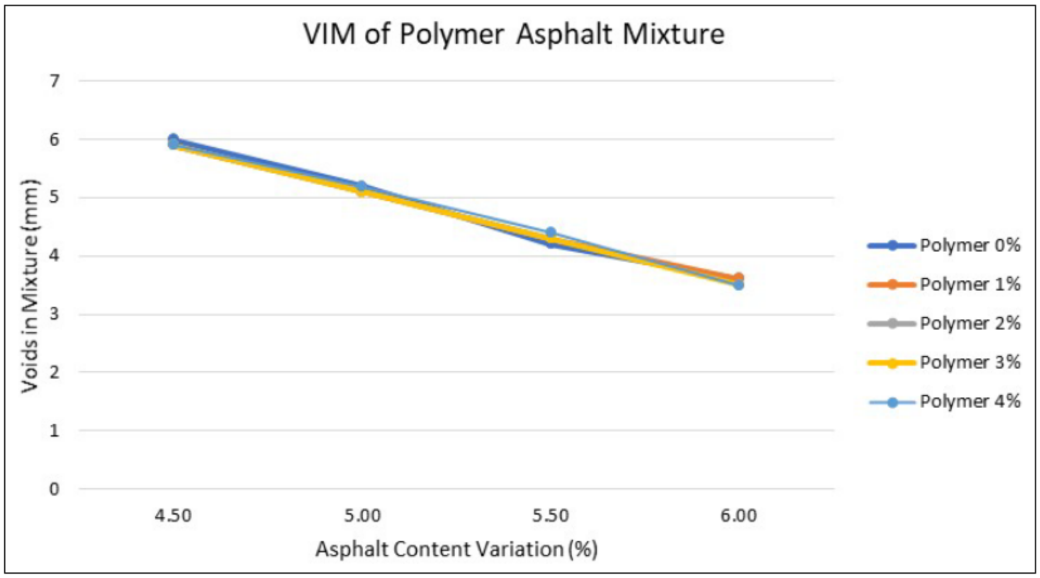

Figure 4. VIM (Voids in Mixture) Recapitulation Graphic

Table 11. The Results of VMA (Void in The Material Aggregate) Recapitulation

Asphalt Content Variation	**VMA Recapitulation (%)**				
	AMP 0%	AMP 1%	AMP 2%	AMP 3%	AMP 4%
4.5%	14.0	14.0	14.0	13.9	14.0
5.0%	14.4	14.3	14.3	14.3	14.4
5.5%	14.6	14.6	14.7	14.7	14.7
6.0%	15.1	15.1	15.1	15.1	15.0
the 2018 General Specifications for Highway Construction	> 15				

Source: Test Results, 2021

Void Filled Bitumen are the pore volumes between aggregate particles in the compacted mixture, including asphalt-filled pores. It is indicated by a percent of the mixture's total volume. The Marshall test generated the VFB value. As seen in Table 12, the VFB recapitulation fluctuated along with the increased proportion of the polymer mixture, resulting in decreased pores filled with asphalt and the value being below the specifications. Therefore, the pores in the mixture were tighter. The Marshall test results are described in Figure 6.

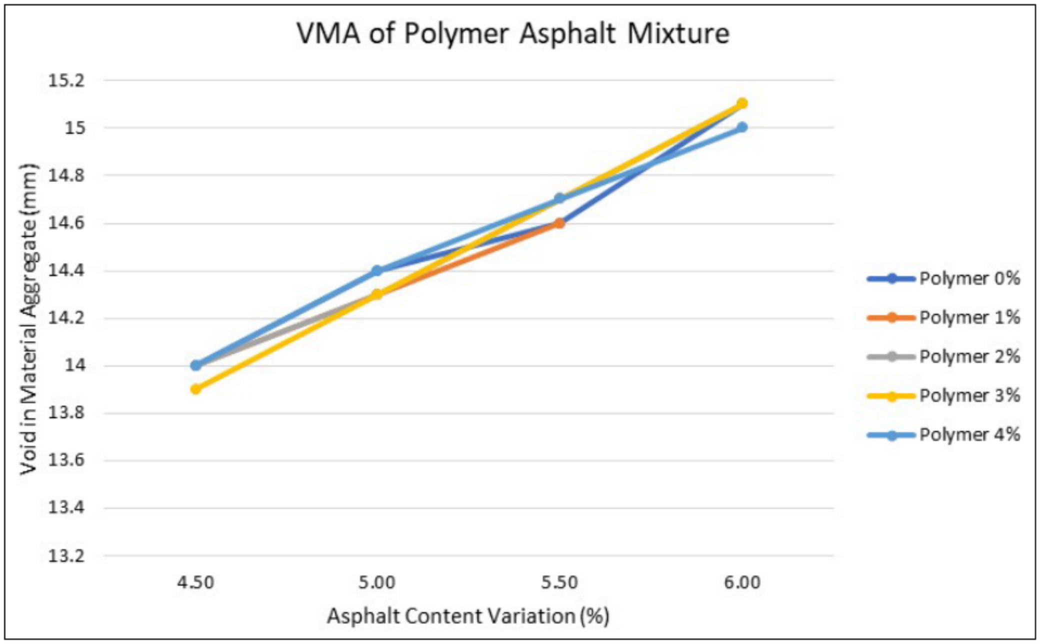

Figure 5. VMA Recapitulation Graph

Table 12. The Results of VFB (Void Filled Bitumen) Recapitulation

Asphalt Content Variations	**VFB Recapitulation (%)**				
	AMP 0%	AMP 1%	AMP 2%	AMP 3%	AMP 4%
4.5%	57.4	57.6	57.8	57.8	57.8
5.0%	64.0	64.4	64.5	64.3	63.9
5.5%	71.0	71.0	70.8	70.9	70.4
6.0%	76.4	76.4	76.6	77.0	77.0
the 2018 General Specifications for Highway Construction	> 65				

Source: Test Results, 2021

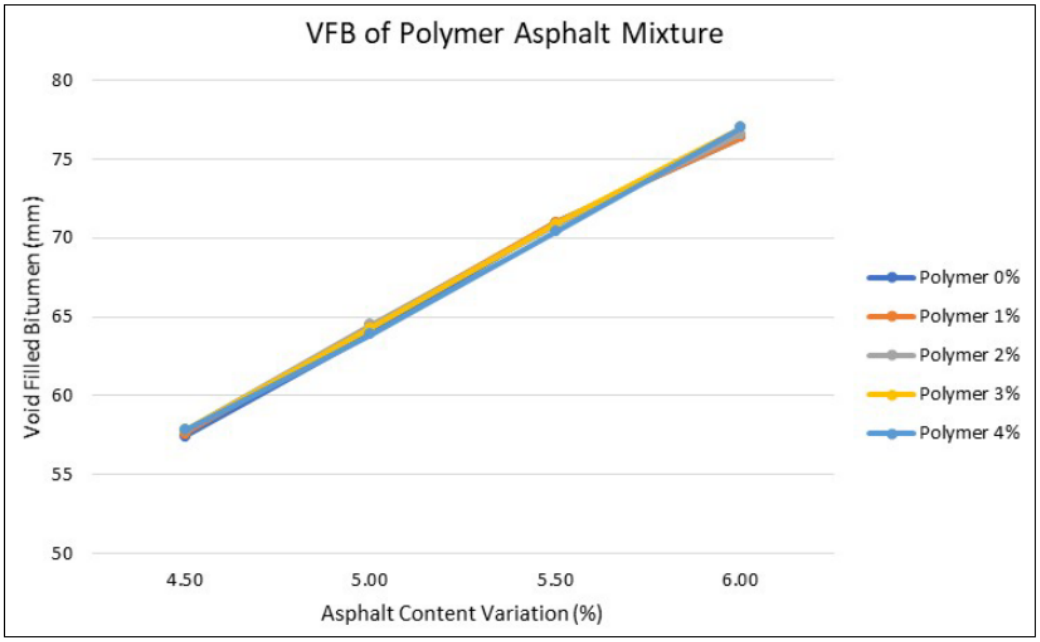

Figure. 6. VFB Recapitulation Graph

Table 13. The Results of MQ Recapitulation

Asphalt Content Variations	**Marshall Quetient Recapitulation (Kg/mm)**				
	AMP 0%	AMP 1%	AMP 2%	AMP 3%	AMP 4%
4.5%	392.6	379.9	363.7	356.5	338.1
5.0%	366.3	361.6	365.5	360.2	347.8
5.5%	362.4	350.8	376.5	376.5	343.8
6.0%	361.7	358.2	333.1	311.2	283.5
the 2018 General Specifications for Highway Construction	≤ 250				

Source: Test Results, 2021

Figure 6 illustrates that the VFB value did not meet the requirements in the 2018 General Specifications for Highways and Bridge Construction Project [17], (which is a minimum of 65%). The VFB values of 5.5% and 6% asphalt content were above 65%. The more asphalt content with variations in the polymer mixture, the better the VFB value. The aggregate has high asphalt and water absorption; thus, a small VFB value causes decreased mixture's resistance to water, resulting in only a few pores filled with asphalt, and water can easily enter the pavement layer. The AC – WC asphalt provided large pores in the mixture, and the AC-WC layer was used in the pavement.

Marshall Quotient (MQ) is an index of the mixture flexibility in a ratio between stability to flow, indicated by kg/mm. An MQ value is related to the pavement resistance to deformation. The larger the MQ value, the stiffer/brittle the mixture; therefore, it can cause cracks when given a load. On the contrary, the smaller the MQ value, the more flexible the mixture; thus, it can deform when given a load.

Table 13 presents the results of the MQ recapitulation. The higher the polymer proportion, the smaller the MQ value; a high flow value means a high melting point, affecting stability. At 4.5% asphalt content, the MQ value was 392.6%, which was very high; while at 6% asphalt content, the MQ value was 283.5%, which was lower than the previous one. The results of the MQ recapitulation can be seen in Figure 7.

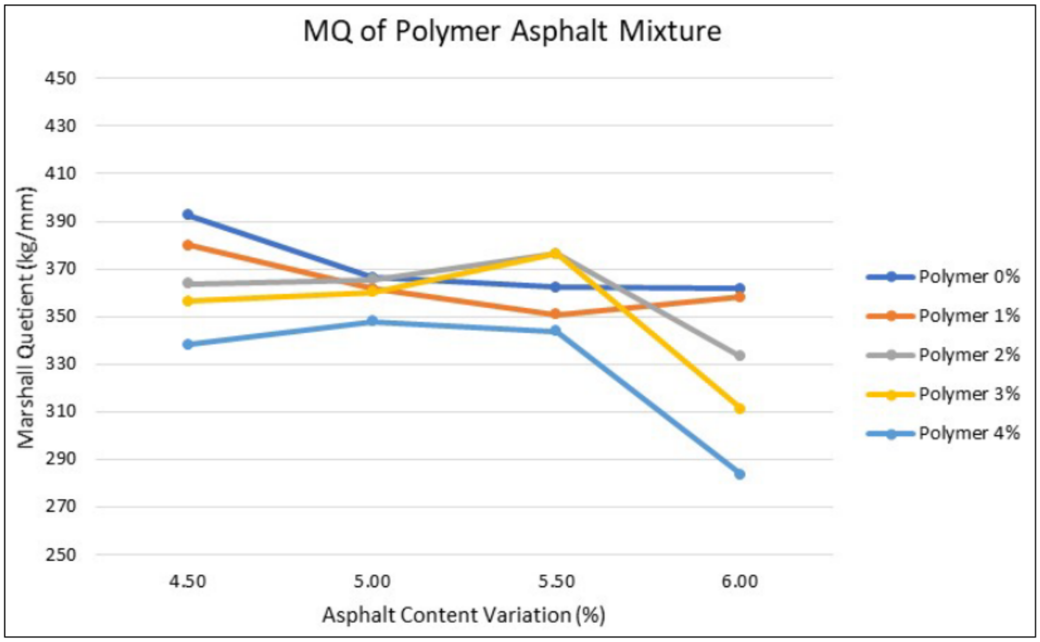

Figure 7. MQ Recapitulation Graph

Figure 7 shows that the highest value was obtained in the 0% polymer variation with a 4.5% asphalt content of 392.6 kg/mm. The lowest value was the 4% polymer variation with a 6% asphalt content of 283.5 kg/mm. The increase and decrease in the MQ value were influenced by the quotient between stability and flow in the mixture, indicating the stiffness and flexibility of an asphalt mixture. The larger the value of MQ, the harder the mixture; on the contrary, the smaller the value, the more flexible the mixture.

5. Conclusion and Suggestion

5.1 Conclusion

Based on data analysis, calculations, and laboratory experiments, the research concludes as follows:

1. The asphalt content of 6% added with 1% polymer is very suitable because it has a high stability value. However, the higher the polymer mixture value, the lower the stability value; it is due to the high melting value, and it greatly affects the stability value of the pavement layer's ability to withstand traffic loads without permanent deformation, such as waves or bleeding.
2. The characteristic values followed the 2018 General Specifications for Highway Construction: the polymer-modified asphalt showed a high stability value of 1181.9 kg. In addition, the VIM value was 3.57%, the VMA value was 15.12%, the VFB value was 76.39%, and the MQ value was 358.2 Kn/mm. The high stability value of polymer-modified asphalt can optimize and reduce road potholes in order to achieve sustainable construction goals.

5.2. Suggestions

From the research results, the use of 6% asphalt content with 1% polymer met the requirements of the 2018 General Specifications for Highway Construction with the appropriate VIM, VMA, VFB, and MQ values (VIM: 3.57%, VMA: 15.12%, VFB: 76.39% and, MQ: 358.2Kn/mm). The researcher provides the following suggestions:

1. Maintain the temperature when mixing and testing the material to follow the standard. Pay careful attention to the heating temperature of the polymer-modified asphalt until the softening point temperature is reached before the mixing process with the aggregate, and keep the compaction temperature not less than 150 °C (polymer mixture compaction temperature) for optimal results.
2. Before being added, the polymer should be cleaned, dried, and cut into various parts because the polymer might coagulate and is not evenly distributed in the melting process of hot asphalt.
3. For pothole repair, using a polymer mixture is a breakthrough in asphalt mixing; it can be an option to save cost and overcome excess waste, also to reach sustainable construction management.

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