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The Marshall Characteristics of Mixed Asphalt Concrete-Wearing Course Using Kudo Gum Additive

Asma Massara*, Bulgis, Aldi Reza Setiawan

Civil Engineering Study Program, Faculty of Engineering, Universitas Muslim Indonesia, Indonesia

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Abstract Asphalt Concrete–Wearing Course (AC-WC) is a pavement layer located at the top. Asphalt has characteristics that affect the performance of asphalt mixtures. Therefore, it is necessary to have the best quality asphalt so that later it can produce asphalt mixtures with good performance and be able to provide a strong enough bonding power. This study aimed to see the effect of variations in the added ingredients of Kudo gum on the Asphalt Concrete Wearing Course mixture. This research was conducted in 3 (three) stages. The first stage was testing the properties of the material in the aggregate and asphalt. The second stage of the Marshall Test was to determine the optimum asphalt content at variations of 0%, 0.1%, 0.2%, 0.3%, 0.4% and 0.5%. The third stage was analyzing the discussion and conclusions from the results of the tests carried out. The results show the value of variation with the addition of Kudo gum with Marshall testing obtained the optimum value of kudo 0.3% with a stability value of 1093.055 kg, Flow 2.67 mm, Marshall Quotient 410.522 %, VMA 15.442 %, VIM 3.708%, VFA 76.185% and Density 2.282 kg/mm^3.

Keywords Asphalt Concrete-Wearing Course, Kudo gum, AC-WC, Marshall Test

1. Introduction

In the past two decades, highway development has rapidly increased in Indonesia [1]. The road is pivotal in supporting economic development, such as penetrating markets, connecting cities and towns, increasing travel time and smoothing traffic flow [2]. Roads should adopt a strong and flexible pavement system to achieve that goal. Pavement is hardened using layers of structure with provisions for thickness, stiffness and stability [3]. Road pavement is a pavement layer that is located between the subgrade layer and the wheels of the vehicle; hence it is expected to have long durability [4]. The road pavement is built in several layers to meet adequate carrying capacity. On the top layer, there is the Asphalt Concrete–Wearing Course (AC-WC), which functions as a wear layer. This layer increases pavement durability and the service life of pavement construction [5]. The AC-WC has a thickness of about 5 cm and functions as a flexible wear layer or cover layer. The layer protects the pavement from the effects of water and provides a smooth and rough surface. This layer also functions to receive traffic loads and pass them on to the layer below without causing cracks [6,7].

The AC-WC layer consists of aggregate and asphalt with or without additives as a binder at a certain temperature. Asphalt, cement, and others act as binders to attach aggregate to form a uniform mixture [6]. Asphalt characteristics affect the performance of asphalt mixtures. Asphalt properties can change according to temperature. As it gets older, asphalt may experience various kinds of damage due to the effects of weather and traffic loads after several years of operation. Therefore, asphalt with good quality is needed to produce an asphalt mixture with good performance and can provide binding solid power.

Asphalt aging affects the Marshall characteristic value, which causes a decrease in the quality of the flexible pavement due to compressive and tensile loads. Under conditions in the tensile load field, cracks are more common, preceded by a crack initiation at the bottom of the pavement layer, which later spread to the surface. One way to prevent damage to road pavement due to vehicle loads is to improve the quality and stability of the pavement. For this reason, it is necessary to innovate road pavement methods that meet standards using the minimum possible material.

Aggregate used in asphalt concrete combines sand, gravel, crushed stone, rock ash, or other materials. The mixture should meet the balanced bonds between the forming materials on a mixture of asphalt, concrete, mortar, macadam, mastic, and other pavements. As an essential part of the pavement, the aggregate composition is generally 92-95% by weight or about 80% by volume [7]. The constituent materials of AC-WC must have good quality to produce a good coating. The ingredients for asphalt concrete are mixed in a mixing plant at a specific temperature, then transported to the location, spread and compacted [8]. Continuously graded Asphalt Concrete mixtures have fewer voids in their aggregate structure than gap-graded mixtures. This causes the AC-WC mixture to be more sensitive to variations in the proportions of the mixture.

The Marshall test method is most commonly used and standardized in the American Society for Testing and Materials 1993 (ASTM D6927-15) to determine the quality of AC-WC pavements. The performance of the asphalt concrete mixture can be checked using the Marshall inspection tool. Marshall tools are presses equipped with proving rings with a 2500 kg or 5000 lbs. capacity. The modified parameters of the AC-WC coating include stability, melting resistance (flow), Voids in Mineral Aggregate (VMA), Voids Filled with Asphalt (VFA), Void in Mix (VIM), and Marshall Quotient (MQ) determine the performance of the planned pavement layer. In Indonesia, AC-WC characteristics are regulated according to requirement standards (Table 1).

Table 1. AC-WC requirements for traffic density

No.	Parameters	Value
1.	Collisions	75 twice
2.	VIM	3-5%
3.	VFWA	Min. 65%
4.	Stability	Min. 800 Kg
5.	Flow	2-4 mm
6.	MQ	Min. 250 Kg/mm

Efforts to increase the strength of the pavement structure can be carried out using an asphalt mixture with a proper selection of material or modifying it by using additives. The addition of selected materials can improve the performance of the asphalt mixture. Several types of materials can be used as additives or fillers, such as latex, limestone, styrofoam, gypsum powder and other wastes [9-13]. Research to determine the optimum levels of additives is essential to get the best mixture characteristics. Previous studies generally use materials with economic value, such as latex and limestone [9,10]. A study using latex additives obtained an optimum asphalt content of 5.7%, where all Marshall characteristics were fulfilled. Mixtures containing latex have better resistance to deformation under dynamic creep loads at 40 ℃ [9]. The other study using the addition of limestone showed that the secondary density AC-WC mixture using lime and oil asphalt pen with a binder of 60/70 did not meet the Toll Road Requirements. In contrast, that used lime, petroleum, and asphalt pen with 60/70 binder and 10.5% oil asphalt pen meets Indonesian standard requirements [10].

For this reason, recent studies tried to use noneconomic materials, such as waste or other materials such as used tires, Styrofoam, and gypsum. A study using grated used tires showed that the highest stability value was obtained from a 2% mixture, which reached 1128.48 kg. The highest VIM value was found in a 5% of grated used tires, namely 16.94%. The highest VMA score was found in a mixture of 5% grated used tires which reach 27.88% and the highest flow value was in the mixture 5% which reached 4.97 mm [11]. A study using the addition of 5% Styrofoam has reached optimal values [12]. Another study using the same material which demonstrated the optimum stability value of 3126 kg was found at a Styrofoam content of 7.25%, and the best Marshall test results were obtained at 6.5% [13]. Another study with the addition of used Gypsum with substitution variations of 7%, 8% and 9% showed that the most ideal Marshall property value was gypsum powder waste at a variation of 7%, with a Stability value of 870.95 Kg [5].

This study utilizes Kudo tree (*Lanea coromandelica*) gum as an additive material for the AC-WC mixture. In Indonesia, trees are widely planted on roadsides or yards as living fences. In India, the kudo tree is known as the Indian Ash Tree and is widely used as a medicine for various ailments including toothache, stomach ache and impotence. Kudo gum is a natural polymer containing carbohydrates, proteins, terpenoids and polyphenols, which play an important role as an adhesive [14]. Previous research tested the potential of the craft industry's Kudo gum treated with Maleic Anhydride and Benzoyl Peroxide as an adhesive [15]. The physical properties of Kudo gum included 0.207 N/mm adhesion, 0.7 -1.4 poise viscosity and pH 3, which meet the requirements of the Indonesian National Standard. The use of Kudo gum is very economical compared to other resins, such as pine, because the material was considered as a waste. This study aimed to analyze the effect of using Kudo gum in the Asphalt Concrete–Wearing Course mixture on Marshall characteristics, deformation resistance, and indirect tensile strength.

2. Research Methods

2.1. Material and Method

This study adopted an experimental method conducted in the Road Pavement Materials Laboratory, Civil Engineering Study Program, Faculty of Engineering, Indonesian Muslim University. The Asphalt Concrete–Wearing Course (AC-WC) is made by mixing coarse aggregate, fine aggregate, asphalt and kudo gum. Coarse aggregate is crushed rock that is retained in sieve #4. Fine sand and stone ash aggregate passes sieve #4 and is retained at #200. Both coarse and fine aggregate were collected from Malino, Gowa Regency. The asphalt (60/70) was obtained from Public Works Bina Marga Baddoka. Kudo gum was collected from Panca Lautang, Sidenreng Rappang Regency.

The composition of the material is determined by combining the aggregates. The results of the mixture composition are used to determine the asphalt content by the sample testing method. Optimum Asphalt Content (OAC) was determined by testing on 5 (five) variations of asphalt content. After obtaining the composition of the mixed aggregate, the weight of the aggregate and asphalt were determined respectively. Preparation of the mixture for the Marshall specimens was carried out at a temperature of 100-120ºC at a viscosity of 170 ± 20 centistokes. The sample was heated in the oven until the weight remains constant. The aggregate was then mixed with asphalt according to the percentage of asphalt required for each sample. After the aggregate was thoroughly mixed, it was poured into the mold. The compaction was carried out from each side of the briquettes. In this study, 75 collisions were carried out for the test sample on each side.

After being pounded, the samples were tested with several parameters. The sample testing method follows the Indonesian National Standard (ISN), the American Association of State Highway and Transportation Officials (AASHTO) or the American Society for Testing and Materials (ASTM) as follows: Asphalt Testing in the form of Hard Asphalt Penetration (SNI 06-2456-1991), Softening Point (ISN 06-2456-1991), Viscosity (ISN 06 06-2456-1991), Flash Point Burning Point (ISN 06 06-2456-1991), Ductility (ISN 06 06-2456-1991), Weight Type (ISN 06 06-2456- 1991), Aggregate Testing in the form of Sieve Analysis (2010 Highways specifications), Fill Weight (AASHTO T-19-71 and ASTM C 27-71), Specific gravity and absorption (AASHTO T-85-74 and ASTM G. 127-68), Soundness Test (ASTM C. 88-60) and Aggregate Adhesion to Asphalt (AASHTO – 182).

2.2. Data Analysis

To analyze the effect of using Kudo gum on the Marshall characteristics of the mixed Asphalt Concrete – Wearing Course sample, the Marshall Test was used. The Marshall test is intended to obtain results from mixture performance, namely stability, flow, Marshall Quotient (MQ), Voids in Mineral Aggregate (VMA), Voids Filled with Asphalt (VFA), Void in Mix (VIM) and density. The sample's Deformation Resistance value was tested using a Well Tracking Machine. Wheel Tracking Machine testing is intended to obtain mixed performance results, namely total deformation, dynamic stability and deformation rate. In this test, we can find out the characteristics of the asphalt concrete mixture. An indirect tensile strength test was carried out using Indirect Tensile Strength test equipment. The values were determined by the formula as follows.

2.2.1. Stability

Stability is the ability of the pavement layer to accept traffic loads without permanent deformation, such as waves (permanent deformation), furrows, or bleeding (jumping of asphalt onto the surface). Stability occurs due to sliding between aggregates, interlocking of particles and good adhesion of asphalt layers. Values for the object's stability were obtained from the readings of the Marshall test kit. Furthermore, the Marshall test kit result is corrected again by calibrating the tool and the thickness of the test object. The stability value was calculated by formula 1.

$$S = q \times k \times H \times 0.454 \qquad (1)$$

Where:
S = Stability (kg).
q = Tool stability reading (lb).
k = Tool calibration factor.
H = Thickness correction of the test object.
0.454 = Unit conversion from (lb) to (kg).

2.2.2. Flow

Flow is the magnitude of the vertical deformation of the sample that occurs from the start of loading to maximum stability conditions. It was expressed in millimeters (mm). The flow measurement coincides with the Marshall stability value measurement. The flow value indicates that the mixture was elastic and more able to follow the deformation due to load. The quotient of stability and flow indicates the potential flexibility from cracks. It is called the Marshall Quotient. The flow value is calculated by formula 2.

$$f = \frac{s}{MQ} \qquad (2)$$

Where:
f = Flow value (mm)
MQ = Marshall Quotient (kg/mm)
s = Stability (kg)

2.2.3. VIM (Void in Mix)

VIM was the number of pores between aggregate grains covered with asphalt. This VIM was needed for places where aggregate grains shift, due to additional compaction that occurs due to repeated traffic loads, or where asphalt becomes soft due to temperature heating. The VIM value is calculated using the formula:

$$VIM = \frac{Gmm - Gmb}{Gmm} \times 100\% \qquad (3)$$

Where:
VIM = pore volume in dense asphalt concrete, % of the bulk volume of dense asphalt concrete
Gmm = Maximum specific gravity of asphalt concrete that has not been compacted (without pores/air)
Gmb = Bulk specific gravity of dense asphalt concrete

2.2.4. VMA (Voids in the Mineral Aggregate)

VMA (Void in the mineral aggregate) is the amount of pore volume in each aggregate grain in dense asphalt concrete, expressed as a percentage. VMA can be calculated by the formula:

$$\text{VMA} = \left(1 - \frac{Gmb \times Ps}{Gsb}\right) \times 100\% \quad (4)$$

Where:
VMA = pore volume between aggregates in dense asphalt concrete, % of the bulk volume of dense asphalt concrete.
Gmb = Bulk-specific gravity of dense asphalt concrete.
Ps = Aggregate content, % by weight of dense asphalt concrete.
Gsb = Bulk specific gravity of the aggregate forming dense asphalt concrete.

2.2.5. VWA

VWA is part of the VMA that is filled with bitumen, excluding adsorbed asphalt by each aggregate grain. Thus, the asphalt that fills the VWA is functioning asphalt to envelop the aggregate grains in the dense asphalt concrete. Or in other words, VWA is the volume percentage of dense asphalt concrete that forms the asphalt blanket. VWA was calculated using the formula as follows:

$$\text{VWA} = \left(\frac{VMA - VIM}{VMA}\right) \times 100\% \quad (5)$$

Where:
VWA = pore volume between aggregate grains filled with bitumen, % of VMA.
VMA = pore volume between aggregate grains in dense asphalt concrete, % of the bulk volume of dense asphalt concrete.
VIM = pore volume in dense asphalt concrete, % of the bulk volume of dense asphalt concrete.

2.2.6. Density

Density shows the amount of density in the mixture. Density is obtained from the following formula:

$$\text{D} = \frac{Wdry}{Ws - Ws} \quad (6)$$

Where:
D = Density/weight content
Wdry = dry weight/weight in the air (gr)
Ws = Weight of SSD (gr)
Ww = Weight in water (gr)

2.2.7. Marshall Quotient

Marshall Quotient is calculated using the following formula:

$$\text{MQ} = \frac{s}{f} \quad (7)$$

Where:
MQ = Marshall Quotient (kg/mm)
f = flow (mm)
s =stability (kg)

2.2.8. Indirect Tensile Strength (ITS)

Tensile strength is the ability to withstand external forces that tend to attract elements and test objects simultaneously. The indirect Tensile Test determines the tensile character of the pavement mixture. The test is for estimating the potential for cracks in asphalt mixtures. The ITS can be calculated using the following formula:

$$St = \frac{2000 \times P}{\pi \times t \times D} \quad (8)$$

Where:
St = ITS (Kpa)
P = maximum load (N)
T = height (mm)
D = sample diameter (mm)

2.2.9. Strains

Strain is defined as the ratio between the addition of an object's length ΔL to its initial length X. Strain is the ability of a material to withstand loads without breaking, for example, the nature of strain (strain) is the shape that an object experiences if two forces are in opposite directions (away from the center of the object). Strain is formulated as follows:

$$\varepsilon = \frac{\Delta L}{A} \quad (9)$$

Where:
Ɛ = Strain (without units)
ΔL = Length Gain (m)
A = Initial length (m)

2.2.10. Elastic Modulus

The elastic modulus is defined as the ratio between stress and strain. Stress (σ) is the magnitude of the force acting divided by the surface area. Stress is inseparable from a material. Many rigid materials have low densities to resist deformation from installation, gravity and vibration during operation. Stress shows the strength of the force that causes the force to change the object's shape. Stress can be calculated using the following formula:

$$\sigma = \frac{F}{A} \quad (10)$$

Where:
σ = Stress (N/m^2)
F = Large compressive/pull force (N)
A = Cross-sectional Area (m^2)

Elasticity is the ability of a material to return to its original shape, in other words, the greater the tensile force, the greater the increase in spring length. The growth of spring length is constant. Strain is proportional to the stress, where what is meant by strain is the percentage change in dimension. The Elastic Modulus is calculated using the following formula:

$$E = \frac{\sigma}{\varepsilon} \qquad (11)$$

Where:
E = Elastic Modulus
σ = Stress
Ɛ = Strain

3. Results Analysis and Discussion

3.1. Aggregate and Asphalt Testing

The results of the aggregate test showed that 83.10% of 0.5-1 aggregate passed the 9.52 mm sieve and 19.58% passed the 4.75 mm sieve. 59.27% of aggregate 1-2 passed the 12.7 mm sieve and 17.98% passed the 9.52 mm sieve (Table 2). These results indicate that the size of the aggregate that passes the filter is in accordance with Indonesian standards.

Table 2. Coarse aggregate gradation test results

Filter Type	% Pass the Sieve	
	Aggregate 0.5-1	Aggregate 1-2
¾" (19.1 mm)		100
1/2" (12.7 mm)	100	59.27
3/8" (9.52 mm)	83.10	17.98
No. 4 (4.75 mm)	19.58	1
No. 8 (2.36 mm)	1.20	

Table 3. Results of Testing Characteristics of Coarse Aggregate Properties

Testing	Test result		Standard	
	Aggregate 1-2	Aggregate 0,5-1	Min	Max
Type Weight (Bulk)	2.61	2.49	2.4	2.9
Type Weight (SSD)	2.67	2.56	2.4	2.9
Apparent Specific Gravity (Apparent)	2.77	2.68	2.4	2.9
Water Absorption (%)	2.20	2.88	0	3
Loose Fill Weight (gr/cm^3)	1.43	1.42	1.4	1.9
Density Weight (gr/cm^3)	1.45	1.43	1.4	1.9
Soundness Test #3/8" (%)	10.26	10.26	0	12
Aggregate adhesiveness to asphalt	96%	96%	95%	-

The test results for the physical characteristics of the coarse aggregate showed that all test parameters have met the Indonesian standard requirements (Table 3).

3.2. Fine Aggregate Test Results

The fine aggregate test results showed that the fine aggregate consisted of various stone sizes from less than 0.075 to 4.75 mm. The majority of stones are 0.6 to 1.18 mm (23.75%) (Table 4)

Data on the results of testing the physical properties of fine aggregate showed that all test parameters met the requirements of Indonesian standards (Table 5).

Table 4. The results of the fine aggregate gradation test

Size (mm)	Percentage (%)
< 0.075	10.35
0.075 to 0.15	6.78
0.15 to 0.3	9.25
0.3 to 0.6	11.84
0.6 to 1.18	23.75
1.18 to 2.36	22.27
2.36 to 4.75	15.76

Table 5. The results of testing the physical properties of fine aggregate

Test	Result	Specification	
		Max	Min
Type Weight (Bulk)	2.58	2.4	2.9
Type Weight (SSD)	2.70	2.4	2.9
Apparent Specific Gravity (Apparent)	2.51	2.4	2.9
Water Absorption (%)	2.89	0	3
Sand Equivalent (%)	79.74	1.4	1.9
Loose Fill Weight (gr/cm^3)	1.52	1.4	1.9
Density Weight (gr/cm^3)	1.68	2.4	2.9
Soundness Test #50 (%)	7.15		10

3.3. Asphalt Testing Results

The percentage of asphalt penetration decreased as the Kudo gum content increased. The softening point, ductility, flash point and specific gravity of the sample increased with increasing concentration of Kudo gum. Burn point values fluctuate, and the lowest value occurs at 0.1% content, while the highest is at 0% and 0.5% levels (Table 6).

3.4. Results and Analysis of Marshall Test on AC-WC Mixture for Determination of Optimum Asphalt Content

Prior to analyzing the results of the Marshall test using Kudo gum added, the Marshall characteristic value of the control sample was measured. The parameters measured consisted of stability, flow, Marshall quotient, voids in mix (VIM), voids in mineral aggregate (VMA), voids filled with asphalt (VFA) and density using several variations of asphalt content to be used in mixtures with added ingredients Kudo gum (Table 7).

Table 6. Asphalt Testing Results

Test	Values of tested parameters						Specification
Kudo gum (%)	0	0.1	0.2	0.3	0.4	0.5	
Penetration on 25 ℃	72	70	68	67	66	65	59 – 70
Soft Point (℃)	51	52	53	54	55	55	48 – 56
Ductility on 25 ℃ (cm)	137	140	143	146	150	152	> 100
Flashpoint (℃)	265	266	269	270	271	273	> 200
Burn Point (℃)	275	255	260	265	270	275	> 200
Specific gravity	1.025	1.033	1.043	1.067	1.083	1.086	1.0-1.16

Table 7. Recapitulation of the Marshall characteristic test of 60/70 penetration WC AC-WC mixture for optimum bitumen content (OAC)

Properties of Mixtures	Asphalt Content (%)					Specification
	4.5	5	5.5	6	6.5	
Density	2.239	2.248	2.254	2.258	2.262	≥2.2 kg/mm^3
VIM (%)	6.936	5.884	5.012	4.201	3.360	3-5%
VMA (%)	16.05	16.12	16.36	16.66	16.93	≥ 15%
VFA (%)	5681	63.67	69.43	74.79	80.23	≥ 65%
Stability (kg)	879.9	949.9	964.6	940.9	882.1	800-1800 kg
Flow (mm)	3.43	3.10	2.97	3.17	3.50	2-4 mm
MQ (kg/mm)	256.2	306.7	325.2	297.2	252.0	Min. 250 kg/mm

From the results of testing the parameters of the properties of the AC-WC mixture, the Optimum Asphalt Content (OAC) value of 6% was obtained (Figure 1). The optimum asphalt content value can be seen in the following graph:

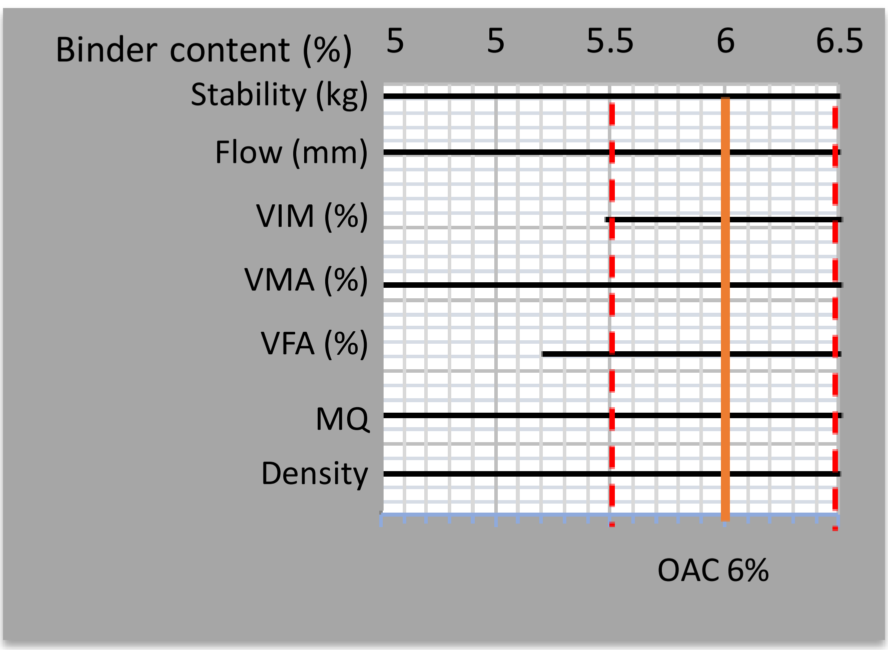

Figure 1. Optimum asphalt content (OAC)

Table 8. Results and analysis using the Marshall test using Kudo gum-added ingredients

Properties of Mixtures	Test result						Specification
	0	0.1	0.2	0.3	0.4	0.5	
Stability (kg)	955.142	1024.493	1063.896	1093.055	1108.028	1078.673	800-1800kg
Flow (mm)	3.03	2.87	2.70	2.67	2.70	2.97	Min 2 mm
VIM (%)	15.745	15.612	15.575	15.442	15.306	15.297	≥ 15%
VFA (%)	74.289	75.064	75.252	76.185	76.928	76.860	≥ 65%
VMA (%)	4.053	3.901	3.895	3.708	3.552	3.542	3 – 5 %
Density	2.273	2.277	2.278	2.282	2.285	2.286	≥ 2.2kg/mm^3
MQ (kg/mm)	315.025	357.92	394.467	410.522	410.6	364.3	Min 180

3.5. The Effect of Kudo gum Additives on Marshall Characteristics

After the optimum asphalt content value is determined, the Marshall test is continued using Kudo gum additives (Table 8). The test results show that all Marshall measurement parameters meet the criteria.

3.5.1. Stability Value

Variation of Kudo gum content from 0% to 0.5% has fulfilled the specifications of asphalt concrete stability. The greater value of the Kudo gum content increased the stability value of asphalt concrete. It reached the optimum at Kudo gum content of 0.28% (Figure 2). If the addition of variations in asphalt content exceeds the optimum value, the stability decreased, because the excessive Kudo gum content would not effectively cover the aggregate and the interlocking properties between aggregates decreasing.

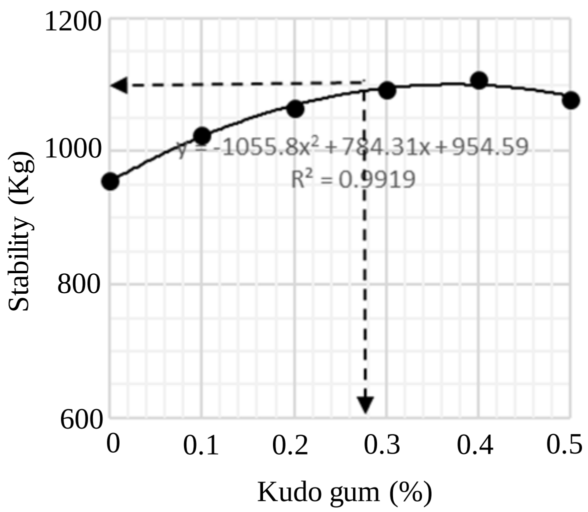

Figure 2. Graph of Stability relationship to kudo gum

3.5.2. Flow

The Flow values of Asphalt Concrete with the addition of 0.1 – 0.5% Kudo demonstrated a concave curve pattern, with the lowest value at the Kudo gum content of 3%. The overall flow values are still within 2 to 4 mm (Figure 3). The reduction of asphalt content to cover the aggregates leads to easy fatigue or collapse of the asphalt mixture and the large flow value in the mixture can illustrate that the mixture is more susceptible to deformation that occurs. The smaller flow value produces more resistantance to melting or collapse in the mixture.

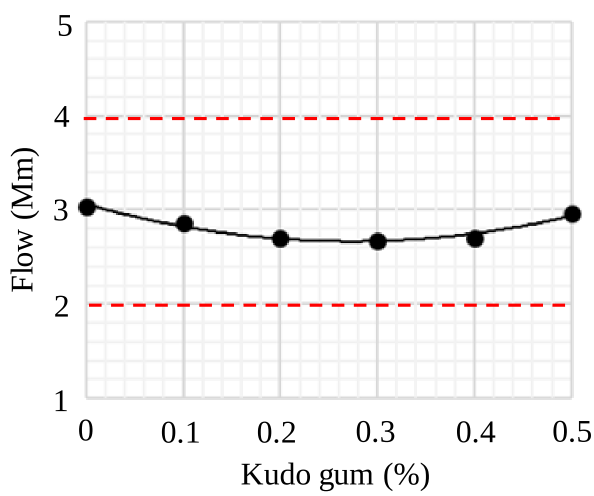

Figure 3. The relationship between Flow and Kudo gum

3.5.3. VIM

Void in Mixture values decreased as the concentration of Kudo gum in Asphalt Concrete increased (Figure 4). Kudo gum filled the cavity volume in the texture, so the cavity percentage decreases. A decrease in the VIM value indicates an increase in the quality of the Aspalt Concrete mixture.

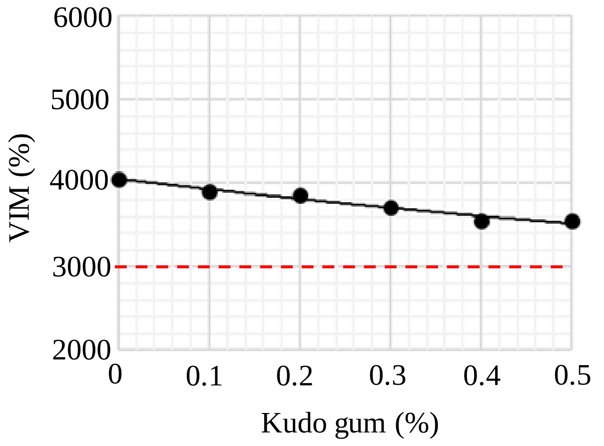

Figure 4. The relationship between Void in Mix (VIM) and Kudo gum

3.5.4. VFA

Void Filled with Asphalt (VFA) increased with increasing Kudo Gum concentration (Figure 5). The VFA value decreases because the voids between the aggregates are getting smaller thereby increasing the density and density of the mixture.

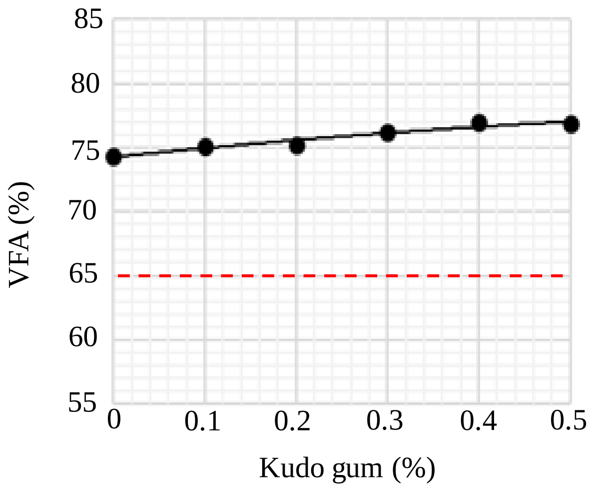

Figure 5. The relationship between Void Filled with Asphalt (VFA) and Kudo Sap

3.5.5. VMA

Void in Mineral Aggregate (VMA) values decreased as the concentration of Kudo gum in Asphalt Concrete increased (Figure 6). Kudo gum filled the cavity volume in the texture, so the cavity percentage decreases. A decrease in the VMA value indicates an increase in the quality of the Aspalt Concrete mixture.

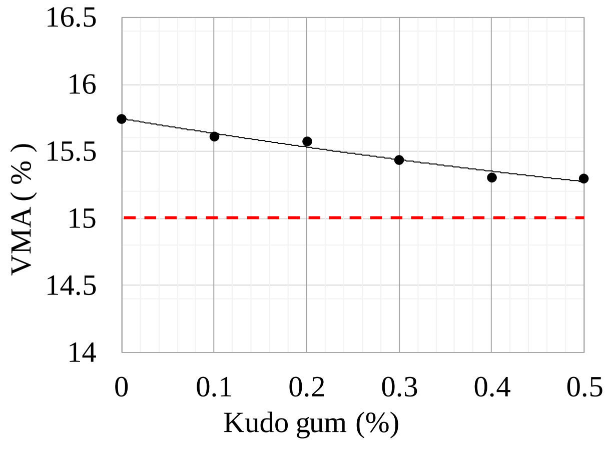

Figure 6. The relationship between Void in Mineral Aggregate (VMA) and Kudo gum

3.5.6. Density

Density increased with increasing Kudo Gum concentration (Figure 7). The density value is directly proportional to the VFA value. Because, the higher the percentage of voids covered by asphalt, the density of the mixture also increased.

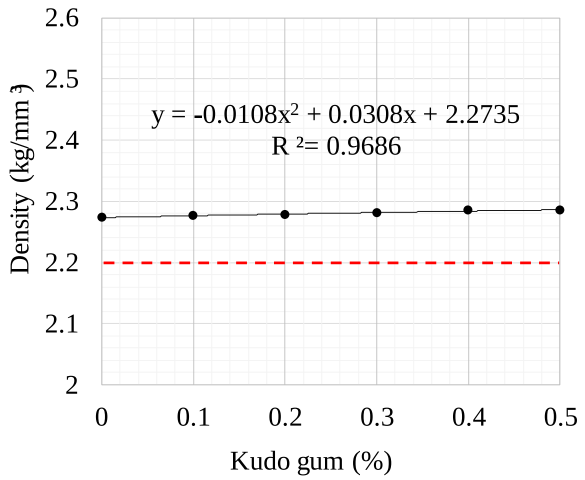

Figure 7. The relationship between Density and Kudo gum

3.5.7. Marshal Quotient

The MQ value meningkat dengan penambahan Kudo gum konsentrasi, dan peaked at concentration of 0.3%. That decreased with addition of Kudo gum in concentrations of 0.4 to 0.5% (Figure 8). The stability decreased with the addition of bitumen content that has exceeded the maximum value of stability, in addition, the melting was higher with increasing bitumen. The value of stability and melting affects the Marshall Quetient, and the higher the value of stability and melting value is obtained, but if there is too much bitumen content, the value of stability will decrease.

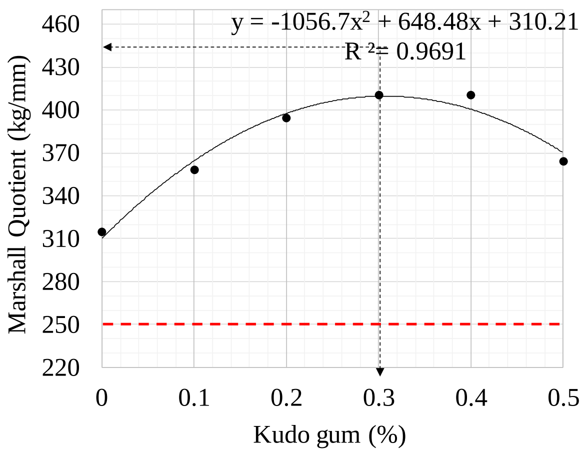

Figure 8. The relationship between Marshall Quotient (MQ) and Kudo gum

From the results of the analysis of the characteristics of the mixed Marshall using Kudo gum additives, it can be concluded that the relationship between Kudo gum content and the characteristics of the mixture uses the mid value on the graph that meets the characteristics of the Marshall Test, so that an OAC of 0.3% is obtained.

$$OAC = \frac{0.1\% + 0.5\%}{2} = 0.3\%$$

The test results show that all mixtures with the addition of Kudo gum content as an added asphalt ingredient in the mixture fulfill Marshall's characteristics.

3.6. Effect of Kudo gum Additives on Deformation Resistance

The total deformation for all treatments with the addition of kudo gum was lower than the control. The lowest total deformation occurred in samples with the addition of 0.4% kudo gum (1.063). The highest total deformation occurred in samples with the addition of 0.1% kudo gum (2,697) (Table 9). The highest dynamic stability was in the sample with 0.1% kudo gum addition, while the lowest was in the sample with 0.3% kudo gum addition. The highest deformation rate occurred in samples with the addition of 0.3% kudo gum, while the lowest occurred in samples with the addition of 0.5% kudo gum.

3.7. Results and Analysis of the Indirect Tensile Strength (ITS) Test

3.7.1. The Results of the ITS Test on the Use of Kudo gum Additives were Carried out Based on OAC

From the results of the Indirect Tensile Strength test using Kudo gum added to the asphalt mixture, the ITS results obtained at a percentage of 0.1% Kudo gum content up to 0.3% levels showed an ITS value or an indirect increase of tensile strength, then the ITS value increased. 0.4% to 0.5% level Indirect Tensile Strength or ITS decreases (Figure 9).

Table 9. Results and analysis by testing wheel tracking using Kudo Gum as added material

		Kudo gum (%)					
		0%	0.1%	0.2%	0.3%	0.4%	0.5%
0	0	0	0	0	0	0	0
1	42	0.13	0.10	0.15	0.19	0.13	0.21
5	210	1.90	1.50	1.45	0.97	0.41	0.64
10	420	2.58	2.49	1.86	1.50	0.62	1.10
15	630	3.05	2.80	2.15	1.79	0.79	1.43
30	1260	3.73	3.53	3.19	2.39	1.47	2.34
45	1890	4.63	4.10	3.50	2.96	1.82	2.72
60	2520	4.90	4.36	3.79	3.52	2.20	2.94
Total Deformation (D0) (mm)		2989	2697	2299	1904	1063	1626
Dynamic Stability (DS) (track /mm)		4667	4846	4345	2211	3316	5727
Deformation Rate (RD) (mm/ minute)		0.0180	0.0173	0.0193	0.0380	0.0253	0.0147

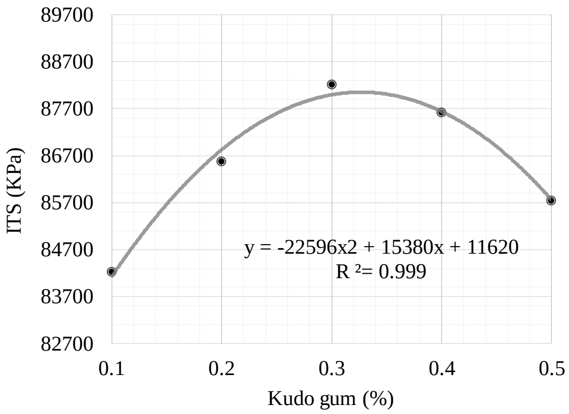

Figure 9. Relationship between ITS and Kudo gum

3.7.2. Relationship of Strain (Ɛ) to Variation of Kudo gum Content Based on OAC

Based on the graph above, the percentage of the material content of Kudo gum from 0.1% to 0.5% has an increase in strain values. Then at 0.4% content, there is a decrease in the strain value, so, if the added Kudo gum used for the mixture has reached its maximum or optimal value, there will be a decrease in the strain value (Figure 10).

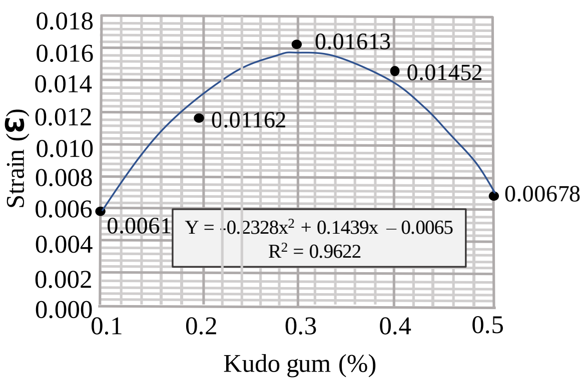

Figure 10. The relationship between Strain and Kudo gum

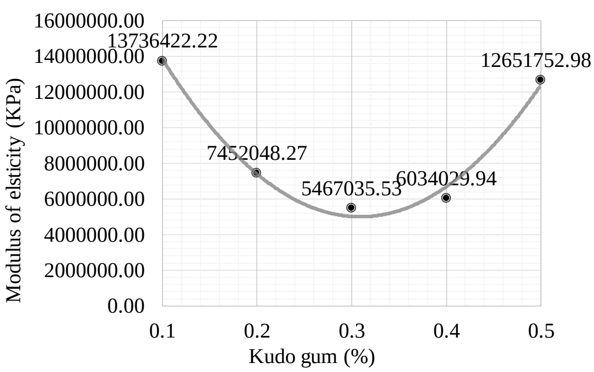

Figure 11. The relationship between the modulus of elasticity and Kudo sap

3.7.3. The Relationship between the Modulus of Elasticity and the Levels of Kudo gum on OAC

The elastic modulus value decreased from the sample with the addition of 0.1% Kudo gum, and was at the lowest point in the sample with 0.3% Kudo gum content. Then, the elastic modulus value increases again until the kudo gum content is 0.5% (Figure 11).

4. Discussion

Marshall value measurement is the standard method for determining the quality and durability of asphalt mixtures. It helps in determining the optimum amount of ingredients required to make a strong and stable asphalt mixture as well as in monitoring the production quality of the asphalt mixture during the manufacturing process. The results showed that the variation value of the Marshall test of the AC-WC samples with the addition of Kudo gum demonstrated the optimum value at 0.3%. The test demonstrated the Marshall value as follows stability value of 1093.055 kg; the deformation value decreased from 2,989 mm (0%) to 1,904 mm (0.3% kudo sap); Flow value was 2.67 mm, Marshall Quitment was 410.522 %, VMA was 15.442 %, VIM was 3.708%, VFA was 76.185% and Density was 2.282 kg/mm^3. The stability value in this study was lower than that in the other study using AC-WC samples with the addition of latex, but it higher when compared to that with the addition of gypsum. The addition of 6% latex showed a stability value of 1179 kg [9], while the addition of gypsum showed a stability value of 870.95 Kg [11]. The other study on AC-WC with the addition of styrofoam produced a variety of stability. The addition with the wet method using 5.50% asphalt and 12% styrofoam demonstrated the stability value was 1000.52 kg while using the dry method using 15% styrofoam produced a stability of 1623.40 kg. Research on asphalt content of 6.126% and 5% Styrofoam showed a stability value of 1115.52 kg [13].

In the other study using limestone and granular asphalt with ratio of 5:3 and a concentration of 5 – 10%, the VIM value ranged between 3 – 5, but at concentrations above it, the VIM value was above 5, hence it fell below the standard [10]. In research with gypsum powder waste as a filler substitute, VIM only met the requirements for a waste content of 7%, whereas at concentrations above it, the VIM value did not meet the requirements [5]. Marshall Properties of AC-WC with the addition of gypsum powder waste at 7% concentration showed that the parameters were observed as follows, Stability was 870.95 Kg, VFWAwas 88.81%, VMA was 19.35%, VIM was 4.57%, Flow was 3.50 mm and Marshall Quotient (MQ) was 252.72 Kg/mm. Furthermore, the addition of 60% dry rubber produced a VIM value of 4.74%.

Marshall value measurement involves measuring various factors such as stability, bearing capacity and consistency of asphalt mixture. Those determine the level of strength and capability of AC-WC to withstand loads. This method involves preparing a sample of the asphalt mixture and measuring various factors such as stability, bearing capacity and consistency. Furthermore, those factors are converted into a Marshall value. A higher Marshall value indicates that the asphalt mixture is stronger, more stable and has better resistance to loads and other external environment stress. However, too high value can also indicate excess material, increasing production costs and affecting road quality. Hence, the optimal Marshall value conforms to the established specifications is essential for good asphalt mix quality.

In this study AC-WC samples with the addition of 0% to 0.5% Kudo gum has fulfilled the specifications. The greater value of the Kudo gum content increased the stability value, and it peaked on 0.4%. Furthermore, on 0.5% Kudo gum content, the stability decreased slightly, because the excessive Kudo gum content has not effectively covered the aggregate. When the the asphalt blanket becomes thicker, the interlocking properties between aggregates were decreasing.

Asphalt content of 0.1% Kudo gum decreased to 0.4% asphalt content. This explains that the lack of asphalt content to cover the aggregates results in easy fatigue or collapse of the asphalt mixture and the large flow value in the mixture can illustrate that the mixture is more susceptible to deformation that occurs. The smaller the flow value, the more resistant the mixture is to melting or collapse that occurs in the mixture. The variation in the Kudo gum asphalt content increased, the VIM value decreased to a variation of the Kudo gum content of 0.5%. This illustrates that the volume of voids filled with air in the mixture decreased in the percentage of voids due to the addition of variations in Kudo gum content so that the Kudo gum content fills the voids in the mixture. The smaller the percentage of voids in the mixture, the better the quality of the mixture.

The variation in asphalt content in the mixture as fulfills the VMA value for the mixture based on highways specifications, namely at least 15%. Along with increasing the variation in the asphalt content of Kudo gum, the VMA value decreased because the voids between the aggregates were getting smaller, thereby increasing the density and density of the mixture. When density increases the variety of Kudo gum added asphalt used in the mixture, the higher the density value or density produced. The density value is directly proportional to the VFA value, because, the higher of voids covered by asphalt, the density of the mixture increased.

The MQ value of the variation of added ingredients of 0.1% to 0.2% Kudo gum has increased, after that it decreased again at the variation of 0.3%. This is because the stability decreases with the addition of bitumen content that has exceeded the maximum value of stability, in addition, the melting will be higher with increasing bitumen. The value of stability and melting affects the Marshall Quetient. The higher the value of stability and melting value are obtained, but if there is too much bitumen content, the value of stability decreases.

Using Kudo gum as an added material can increase the tensile strength value because it contains chemical compounds similar to the chemical compounds in asphalt. In this test, the highest tensile strength value was obtained at 0.3% Kudo gum content, having a tensile strength of 88206.45 Kpa. Therefore, Kudo gum is a potential additive to the mixture because it increases the tensile strength value. The mixture has robust strength in carrying traffic loads at the optimum or suitable level.

The effect of Kudo gum as an additive to strain may increase the strain value. However, as the level of Kudo gum increases, the strain value becomes stiffer up to 0.3%. This might increase Kudo gum content. It affects the characteristics and viscosity of the asphalt, making the mixture brittle.The maximum strain value occured in the addition of 0.3% Kudo gum. If the strain value starts to increase, then the test object begins to crack or collapse so that the strain value slowly decrease. The relationship between tensile strength and strain is positive, because the mixture is more able to withstand tensile loads and the strain that occurs in the mixture is high.

Excessive use of Kudo gum as an additive can increase the value of the elastic modulus. The relationship between elastic modulus and strain is inversely proportional. Because if the elastic modulus value is high, then the mixture is more difficult to change shape. This is alsobecause the properties of the elastic modulus can change due to the addition of additives and heat treatment.

5. Conclusions and Recommendations

5.1. Conclusions

Based on the results of research on asphalt concrete wearing course (AC-WC) mixtures with the influence of the use of Kudo gum added material, the results showed that the properties of asphalt penetration 60-70 using Kudo gum additives meet the specifications and can be used as a mixture of AC-WC (Asphalt Concrete Wearing Course). The addition of Kudo gum to asphalt has an effect on the AC-WC mixture on various Marshall characteristics with Optimum Additive Content at a variation of 0.3% with a stability value of 1093.055 kg, a flow value of 2.67 mm, for an MQ value of 410.522 kg/ mm, VIM of 3.708%, VMA of 15.442%, VFA of 76.928% and a density value of 2.282 kg/mm^3.

5.2. Recommendation

Based on the research results, some suggestions are proposed as follows:

1. It is hoped that this research can be developed for further research by testing the indirect tensile strength (ITS) and deformation resistance with added kudo sap.
2. It is suggested for further research to examine using different temperature variations on asphalt performance.
3. It is hoped that this research can be further developed for further research on the characteristics of different mixtures such as cold asphalt mixtures or warm asphalt mixtures using Kudo gum additives.

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Conflict of Interest

The authors declare that there is no conflict of interest with other parties

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