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Evaluation of the Performance of Buton Rock Asphalt-a Local Non-Petroleum Bitumen and Plastic Waste Mixture as a Sustainable Asphalt Concrete Mix in Tropical Region

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Key words: BRA, liquid Asbuton, PET, AC-WC

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Abstract: Numerous studies have explored ways to introduce additives or conjugating materials into asphalt mixture to reduce dependency on petroleum-based asphalt. However, research on investigating the potential of locally accessible materials to substitute conventional petroleum-based asphalt and assessment of its prospective mixture with recycled materials is limited. Buton asphalt (Asbuton)-an abundant local resource in Indonesia, has several advantages over petroleum extracted asphalt due to its natural occurrence, high resistance and flexibility. Exposure to sunlight and rain-dominant climate characteristics in tropical region, makes this material stronger and denser with the texture becoming flexible and thus it reduces the possibility of cracks to develop. Plastic wastes, with only a few such as Polyethylene Terephthalate (PET) that is utilized as a mixture for pavement are ideal candidates as a conjugating material for asphalt mixture. Therefore, this research aimed to assess the potential of utilizing PET as a conjugating asphalt mixture by investigating the effect of mixing plastic wastes into Asbuton Buton Rock Asphalt (BRA)-a manufactured Asbuton version-in asphalt concrete layer (Laston) using Marshall characteristics as performance indicators. The laboratory testing results demonstrated that adding of the BRA and plastic waste flakes mixture into the AC-WC concrete mixture saved 8% of weight with an optimum asphalt content of 6.5%. Using the mixture of liquid Asbuton with BRA and 6% PET plastic flakes was able to improve the stability performance of asphalt mixture. The mixture characteristics, i.e., the stability, Marshal Quotient (MQ) and VFB increased while the flow, VIM and VMA reduced with the increasing rate of effective asphalt contents due to the addition of plastic waste flakes content. Furthermore, the residual Marshall stability obtained was above 90% and the voids at refusal densities were in the range of <2%. It is concluded that the PET and local non-oil-based composite asphalt mixture exhibits structural advantages and therefore can be considered sustainable for road pavement in tropical areas.

INTRODUCTION

The declining resources of fossil fuels and the increased global price of asphalt generated from petroleum products have led to numerous researches on novel technology and application of various materials and products to ascertain the sustainable provision of asphalt for road work. While numerous researches have attempted to introduce additives or conjugating materials into petroleum-based asphalt mixture to reduce the content and thus improve the volumetric properties of asphalt mixture, research on investigating the potential of locally accessible materials to substitute conventional petroleum-based asphalt and assessment of its prospective mixture with recycled materials is limited.

Buton asphalt (Asbuton) which is only found and mined in Buton Island, Indonesia, is domestically obtainable material used in asphalt concrete mixture[1]. Asbuton is produced from asphalt rock which was firstly discovered in 1920[2]. This ore has abundant resources of around 663 million tons-only 0.06% of that has been mined. Asbuton Buton Rock Asphalt (BRA) is industrially refined and prepared granular Asbuton produced by local asphalt industries in Buton Island. BRA has numerous advantages compared to asphalts generated from petroleum[3]. The use of liquid BRA in road pavement has been found to be more economical due to its relatively lower price and better quality compared to petroleum-based asphalt[4]. Owing to its high degree of blending and non-chemical process it is considered an environmentally-friendly pavement material[5]. Moreover, it is more efficient for construction and maintenance due to its high resistance to harsh climate, water resistance, durability and flexibility[5,6]. Exposure to sunlight and rain makes BRA stronger and denser with the texture becoming less rigid,and hence the possibility of cracks to develop is diminished[6, 7]. Considering its potential and current global situation of petroleum-based asphalt, the government of Indonesia has planned to use BRA grain as a domestic substitution to achieve the national road pavement goals. To ensure sustainable mining and application of BRA, research on potential mixtures of BRA and other materials is essential[8, 9]. Some studies have explored its potential and effect of application[10, 11], construction variation[12], mixing consistency[13] and physical alteration[14].

The trend of recycled waste usage as a blend material is increasing. Plastic wastes are being generated and dumped annually. Therefore, plastic wastes-only a few such as Polyethylene Terephthalate (PET), utilized as a mixture for pavement, are good options as a conjugating material. A typical example is PET bottles which possess a short useful lifetime and become waste soon after use[15]. PET which is a semi-crystalline thermoplastic polymer materialized by polycondensation of terephthalic acid with ethylene glycol[16] is the most basic polymers and is widely used in world industry as synthetic fibers and a packaging material for various products, i.e., bottled water, soft drinks and food containers[17]. Worldwide, PET bottles have replaced conventional materials, e.g., tin and glass because of advantages they have such as chemical resistance, lightweight, easy production and storage[17]. This research used plastic from PET bottles as an additive in the asphalt mixture. The bottles were cut to small akes and then reduced to their nal size by shredding in a shredder[18].

This research, therefore, aimed to investigate and evaluate the addition of plastic waste materials from Polyethylene Terephthalate (PET) into liquid BRA in Asphalt Concrete Layer (Laston) using Marshall characteristics and the best blend proportion to reduce the asphalt content and achieve improvement of asphalt mixture. The examination included several properties, i.e., stability, flow, Marshal quotient, Voids in the Mixture (VIM), Voids Between Aggregates (VMA), Voids Filled with Bitumen (VFB), residual Marshall stability and refusal density.

MATERIALS AND METHODS

This research was performed at the Highway Engineering Laboratory, Department of Civil Engineering, Faculty of Engineering, Universitas Borneo, Tarakan, Indonesia. Figure 1 shows the research steps in this study. The coarse and fine aggregates, as well as the filler used were sourced locally. A stone crusher was used to obtain aggregate gradation according to therequired size for testing. The testing standards used included Revised Standar Nasional Indonesia (SNI) 03-1737-1989 (Indonesian standard procedure for the implementation of the asphalt concrete layer for job mix design in roads application) and SNI 06-2489-1991 (Indonesian standard procedure for asphalt mixture testing method with Marshall equipment) for Marshall testing[19]. Plastic waste flakes from Polyethylene Terephthalate (PET) were cleaned and shredded (Fig. 2) and itscontents were varied at 0, 4, 6 and 8 %. The specific gravity of PET was 1.94.

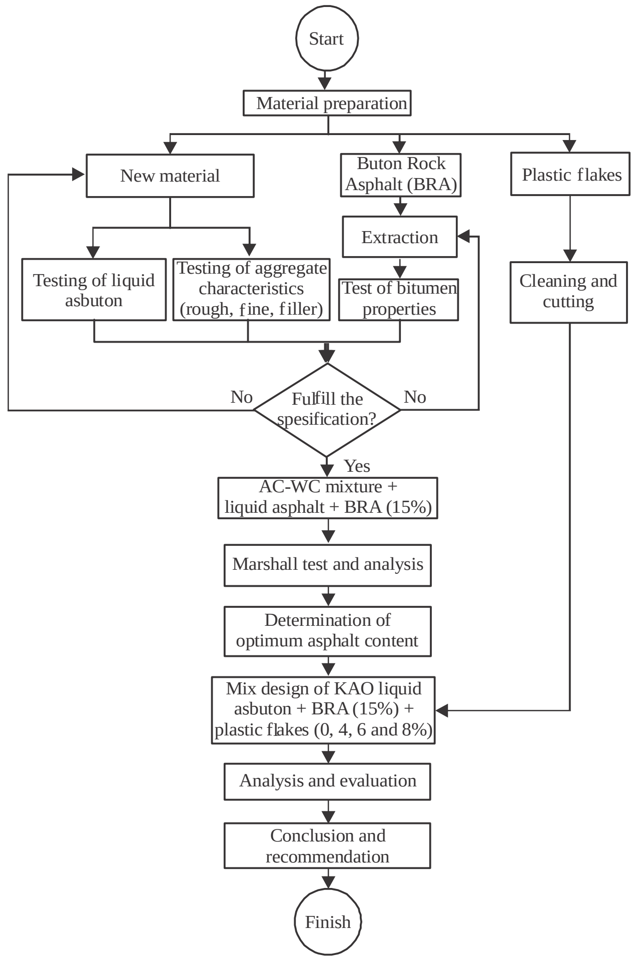

Fig. 1: Research steps

(a) (b)

Fig. 2(a, b): Plastic material, (a) Flake shape and (b) Shredded shape

RESULTS AND DISCUSSION

Characteristics of liquid asbuton: The physical properties of liquid Asbutonin relation to its performance as a component of the mixture were tested and the results are presented in Table 1. The SEM and EDX images of the 100% liquid BRA sample showed it contains a mixture of carbon, oxygen, aluminum, silica, sulfur and calcium in the form of Al_2O_3, SiO_2, SO_3 and CaO compounds.

Characteristics of butonrock asphalt: A physical test was conducted on extracted BRAbitumen to determine the content and properties in relation to its performance as a component of the mixture (Table 2).

Mix design of AC-WC asphalt concrete: Planning of Asphalt Concrete (AC-BC) using Butonrock asphalt. To determine the optimum content (KAO) of asphalt in the concrete mixture, the range was set between 4 and 7% with an increase of 0.5%. Moreover, the results of aggregate and asphalt compaction were used for the Marshall briquettes applied to determine several parameters, i.e., density, Voids in the Mixture (VIM), Voids in Mineral Aggregates (VMA), Voids Filled

Table 1: Physical test results of liquid BRA

Tests	Methods	Test results of liquid Asbuton	Required: Modified Asbuton Min	Max	Unit
Penetration before weight loss	SNI. 06-2456-1991	58.2	40	60	0.1 mm
Softening point	SNI. 06-2434-1991	56.5	55	-	°C
Ductility (25°C, 5 cm/min)	SNI. 06-2432-1991	96	50	-	cm
Solubility in trichlorethylene (C_2HCL_3)	SNI. 06-2438-1991	97	90	-	% weight
Flashpoint (COC)	SNI. 06-2433-1991	235.3	225	-	°C
Density	SNI. 06-2441-1991	1.141	1	-	kg/m^3
Weight loss 163°C, 5 h (thin film oven test)	SNI. 06-2440-1991	1.53	-	2	% weight
Penetration after weight loss	SNI. 06-2434-1991	85.62	-	-	% original
Viscosity at 170 Cst (temperature of mixing)	SNI. 03-6721-2002	164	-	-	°C
Viscosity at 170 Cst (temperature of compaction)	SNI. 06-6721-2002	144	-	-	°C

Table 2: Physical test results of BRA bitumen extraction

Type of testing	Testing result
Asphalt content (%)	28.72
Penetration at 25°C (100 g; 5 sec. 0.1 mm)	40.24
Softening point (°C)	54.35
Flashpoint (°C)	172
Ductility at 25°C (cm)	95
Density (kg/m^3)	1.054
Solubility in C2HCl3 (% by weight)	88.41
Weight loss (with TFOT) (% by weight)	0.46
Penetration after TFOT (% original)	67.34

Table 3: Physical test results of BRA bitumen extraction

Parameters	Variations in Asphalt Contents (%) 4.00	4.50	5.00	5.50	6.00	6.50	7.00	Specification
Stability(kg)	1,207.58	1,291.92	1,367.83	1,423.42	1,510.18	1,437.08	1,377.78	Min. 800
Flow (mm)	3.06	3.04	3.08	3.24	3.50	3.61	3.83	Min. 3
MQ (kg/mm)	394.63	424.97	444.10	439.33	431.48	398.08	359.73	Min. 250
VIM (%)	8.81	8.09	7.13	6.28	5.46	4.68	3.49	3.0%-5.5%
VMA (%)	19.58	18.61	18.21	17.60	16.99	18.09	19.17	Min. 15
VFB (%)	52.70	56.28	63.11	63.84	70.95	78.93	82.10	Min. 65

Bitumen (VFB), stability, flow and Marshall Quotient (MQ). The results are presented in Table 3 and Fig. 3.

Table 3 shows the VIM and VFB that fulfill the specifications were in the range of asphalt content of 6-7% while VMA, stability, flow and MQ were in all ranges. Moreover, the optimum asphalt content (KAO) for the AC-BC mixture with 15% BRA was recorded to be 6.5%. The data showed that the stability value tended to increase with the addition of BRA due to the low penetration of the mixture and the production of high friction at high asphalt content by the mortar.

The mixture with 15% BRA was found to have produced a small flow value due to the presence of minerals which made it brittle and sensitive to cracks. However, a large flow value and high stability tended to lead to flexibility which caused an easy shift of the grains, thereby causing deformation. The 15% BRA mixture was also discovered to have a greater MQ value due to high stability and small flow causing high rigidity and consequent vulnerability to cracking. A direct relationship was also observed between the BRA content and VIM value, at the same asphalt content such that an increase in

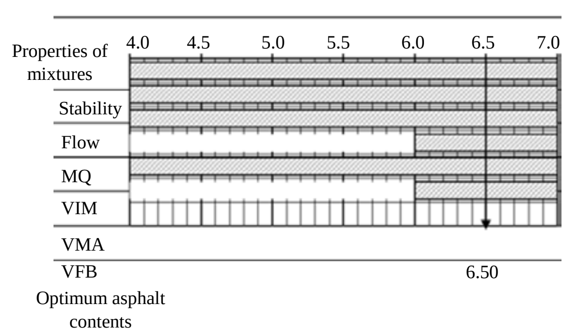

Fig. 3: Asphalt content that fulfills the specifications

one reflects in the other and this further increase the number of fine particles required to be covered and limited the movement of asphalt to fill the voids in the mixture. This subsequently led to more flexibility with a relatively increased stability value. In addition, the addition of BRA to the mixture was also found to increase the VFB value as shown in the table. This was due to the viscosity of the increasingly thick asphalt which thereby led to the tendency to only fill voids between aggregate

Table 4: Characteristics of AC-WC mixtures with and without the addition of plastic waste flakes

Characteristics of mixture (AC-WC)	Liquid Asbuton (%) + BRA 15%				
	6.5	6.46	6.44	6.42	
	Plastic content on asphalt (%)				
	0	4	6	8	Specification
Stability (kg)	1987.99	2068.5	2186.66	2239.19	Min. 800
Flow (mm)	3.75	3.85	3.58	3.38	Min. 3
Marshall quotient (kg/mm)	530.13	537.27	610.80	662.48	Min. 250
Voids in Mixture (VIM) (%)	4.20	3.91	3.69	3.34	3.0-5.0
Voids in Aggregate (VMA) (%)	21.99	20.17	18.15	16.06	Min. 15
Voids Filled with Bitumen (VFB) (%)	80.5	82.21	84.19	86.45	Min. 65
Residual Marshall stability (%) on 24 h immersion, 60°C	1890.65	1889.16	2119.44	2131.87	Min. 90
Voids in mixture (%) at refusal density	4.17	3.97	3.14	2.7	Min. 2

particles with greater VFB values or those filled with bitumen. The 15% BRA was shown to increase the VFB value due to the presence of more voids filled with bitumen compared to those without BRA.

Examination of the characteristics of AC-WC asphalt concrete mixture with and without the addition of plastic waste flakes using Marshall method of 75× collision (heavy traffic). The stability, flow, Marshal quotient, Voids in the Mixture (VIM), Voids Between Aggregates (VMA), Voids Filled with Bitumen (VFB), residual Marshall stability after 24 h immersion at 60°C and refusal density were examined. The results showed the mixtures containing liquid BRA had lower penetration and softening points compared to those without BRA and this further led to more rigid mortar bonds which increased the stability value. This was observed to be due to the increase in excessive mineral fillers and this made the gradation of the mixture to be relatively more than the fine minerals functioning as fillers to form mortar bonds with asphalt. Table 4 also shows the addition of plastic waste flakes to the AC-WC mixture can improve its ability to carry traffic loads.

Stability: Stability is a measure of the ability of a mixture to carry traffic loads until plastic flow occurs. It can, therefore, be tested directly when loaded with Marshall test equipment. The factors influencing stability include aggregate gradation and asphalt content. The result showed the mixtures containing liquid Asbuton and BRA cause excess mortar bonds which later produced more stiffness and small flexibility value.

Figure 4 shows the test of asphalt correlation with plastic using ductility and penetration and the results showed that the asphalt has the tendency not to fulfil the specified requirements at the addition of 8% of the plastic wastes. The addition at values less than this percentage is considered ideal but at 8% and above the AC-WC construction tended to compromise the rigid nature, breaking, cracking and fatigue.

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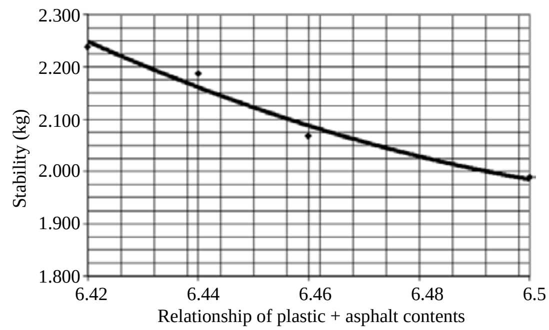

Fig. 4: Relationship of plastic+asphalt contents vs. stability

Flow: Flow is a measure of flexibility of mixture due to deformations caused by traffic loads without causing cracks and changes in volume. The Marshall analysis in Table 4 shows that the flow value tended to decrease with the increase in the plastic contents. This was caused by the hardening of the asphalt as a result of adding the plastics which further made the grains become not easily shifted and continuously reduced the flexibility of the mixture. Therefore, the plastic content was limited to 8% on the weight of asphalt and despite its ability to influence the hardness properties of the asphalt its tolerance limit or the value of flexibility was far below the required specifications. This means the introduction of the plastic in this research had no negative effect on the flexibility of the AC-WC mixture.

Marshall quotient: This is a ratio between stability and flow values of AC-WC mixtures with relatively high stability values have been discovered to have a greater MQ. It is also an empirical indicator of mixture's rigidity. Addition of plastic content into the AC-WC mixture could

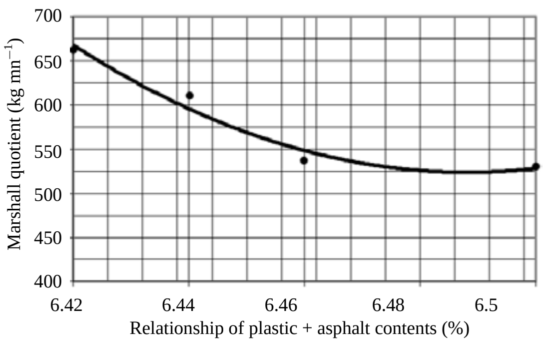

Fig. 5: Relationship of plastic+asphalt contents vs. stability (%)

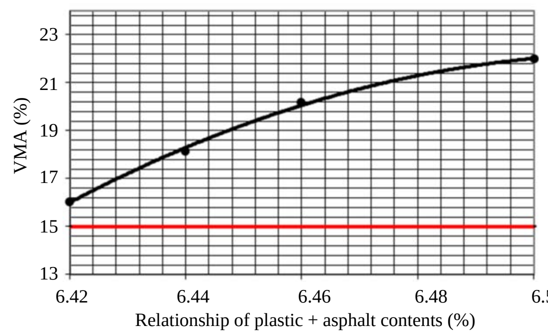

Fig. 6: Relationship of plastic+asphalt contents vs.VMA

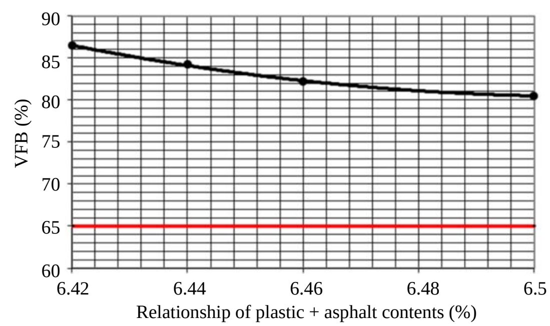

Fig. 7: Relationship of plastic + asphalt contents vs.VFB

increase the stability value and subsequently MQ. Figure 5 shows that the addition of plastic to the AC-WC mixture increases the MQ value and this means it has the ability to improve construction since the specifications require the value should not be <250 kg mm^{-1}.

Voids in mixture: The VIM content is related to the durability of the mixture such that a higher value means the mixture tends to be fragile and tends to crack early while smaller ones increase the resistance to asphalt hardening and particle peeling due to oxidation. However, if the value is too small, it has the capability of causing instability and a greater plastic flow due to the lack of enough space to accommodate asphalt expansion based on the continued compaction caused by traffic and the increasing temperatures in the pavement during the service period.

More portions of the plastic added to the mixture provided an opportunity for the enlargement of the density, thereby causing a decrease in the VIM value as shown in Fig. 5. The combination of plastic and BRA in the AC-WC mixture was advantageous to maintain the recommended level of VIM since it caused early cracking of the construction at higher values. For example, the study conducted "on the main roads (heavy traffic) of Java island reported the Laston with a VIM value of >10% generally showed initial indications of cracking while the pavement with <3% started showing an initial indication of plastic deformation".

Voids in mineral aggregate: This is the volume of air voids between aggregate grains in asphalt mixture in dense conditions. It consists of the VIM and effective asphalt volume and the results showed the addition of plastic waste flakes increased the weight of the mixture, thereby causing a decrease in the VMA value.

Figure 5 shows that the mixture using liquid Asbuton produced a greater VMA value due to the hardness caused in the asphalt by the addition of hard bitumen which further led to a more difficult relative compaction process and production of voids between larger grains. However, a larger value of VMA leads to a smaller VFB which is a percentage of the effective asphalt volume to the VMA. Figure 6 shows that the VMA value decreased while more plastic waste flakes were added. This is evident from the reduction of the value at the asphalt content of 6.46% at 4% plastic addition to 6.42% at 8%.

Void filled with bitumen: VFB is voids filled with bitumen as part of the VMA containing the effective asphalt content which is the total content minus the amount absorbed by the aggregate. Figure 7 shows that the VFB value increases with the addition of more plastic waste flakes which produced increasingly smaller voids in the mixture due to the increased density of asphalt with plastic. The VFB improvement was caused by the shrinking of the Voids in the Mixture (VIM). Moreover, the plastic waste added was discovered to have caused increasingly smaller absorption of asphalt into the pore of the material and this means the effective asphalt content increased with the VFB value to improve the performance of the mixture.

Residual strength index: Residual strength index (IKS) or Marshall Immersion Test is a method to determine the resistance or durability of a mixture to temperature,

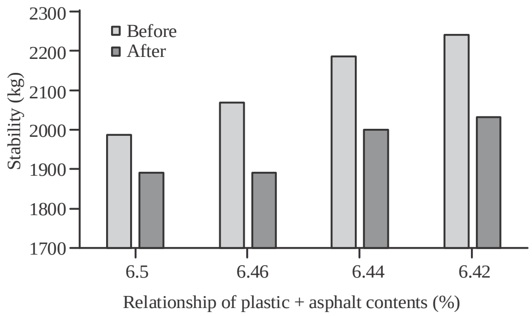

Fig. 8: Comparison of residual strength index for each proportion of the mixture

weather and water and the loss of the bond between asphalt and aggregate grains. It is obtained by comparing the stability value of the object as a yield of 1×24 h immersion with the standard test object as a yield of 30 min immersion at a temperature of 60°C. The value is, however, influenced by the viscosity level of the aggregate with asphalt which depends on the shape and number of aggregate pores, rheological properties of asphalt, its content, density, void content and aggregate gradation.

The study results showed the mixture with liquid Asbuton and 15% BRA was more resistant to changes in weather, temperature and water. It was indicated that the plastic waste flakes added to the AC-WC mixture have the ability to increase the resistance to severe weather as shown with the value of stability in accordance with the specifications after 24 h immersion at 60°C. Moreover, concerning residual strength after a 24 h immersion, the plastic content at 0% had asphalt content of 6.5% and residual stability of 95.1% while at 4% it was 6.46% and 91.3%, at 6% it was 6.34% and 91.7% and 8%, it was 6.42 and 90.7%, respectively (Fig. 8).

Voids in the mixture at refusal density: Refusal VIM was tested to determine the void content and absolute density. It was simulated as the continuation of the traffic compaction and illustrated by the change in the value of void in the mixture (VIM) due to the compaction/collision of 2×400 per part. The value of VIM on the standard compaction with the Marshall 2×75 collision fallen due to the refusal compaction with electric vibrating equipment/Marshall 2×400 collision. This method was, however, limited by the dependence on density after the vehicle has passed on it to reach a minimum of 3% air void required for the AC-WC mixture.

Table 4 shows that a minimum of 2% Refusal VIM specified in the 2018 BinaMarga was obtainable despite the reduction observed in the value of Refusal VIM with the addition of more plastic waste flakes into the AC-WC mixture. BinaMarga is an Indonesia government agency (under the Ministry of Public Work) whose responsibility is developing, maintaining and regulating road construction in Indonesia. Moreover, the results of the laboratory test conducted on 400 collisions per field did not exceed the permitted specification threshold and at a concentration of 8% plastic content, 2.70% was obtained and this was considered very close to the recommended value.

CONCLUSION

The goal of this research was to investigate the effect of mixing plastic wastes into Asbuton Buton Rock Asphalt (BRA) using Marshall characteristics in order to determine the potential of utilizing PET as a conjugating asphalt mixture. The results showed that using liquid Asbuton with BRA and 6% PET plastic flakes was able to improve the stability performance of asphalt mixture from 1987.99-2239.19 kg with an optimum asphalt content of 6.5%. The addition of plastic was observed to cause reduced penetration (harder) and increased viscosity (thicker) due to the increase in metal elements contained in the liquid Asbuton which strengthened the attachment to the aggregate. Adding plastic waste flakes influenced the characteristics of AC-WC asphalt concrete mixture at a maximum concentration of 8% to the asphalt weight by:

- Increasing the stability of the mixture which further improved its ability to carry traffic load until the occurrence of plastic flow
- Decreasing the flow value of the mixture which also reduced the flexibility to meet the specified threshold at plastic content of 3%
- Increasing the MQ value which indicates an improvement in the ability of road construction to carry the loads despite its flexibility
- Decreasing the VIM or reducing the pores in the mixture and this leads to improved durability of road construction without plastic deformation or bleeding
- Decreasing the VMA value or voids between aggregates to ensure more durability
- Increasing the VFB value or void filled with bitumen and this improves the effective asphalt content covering the material and determines the performance of the mixture in a construction
- Increasing the residual Marshall stability after 24 h immersion at 60°C and this aids the ability of the mixture to resist severe weather
- The Marshall refusal density conducted on 400 collisions showed the road constructed with the mixture was able to carry vehicle loads after service period

The weight of asphalt used was also saved by 8% due to the addition of the plastic in liquid Asbuton to AC-WC mixture. In conclusion, the mixture of PET and Asbuton

Buton Rock Asphalt (BRA)-a local non-oil-based material exhibits structural benefits and hence can be recommended as sustainable road pavement mix in tropical areas. The study indicates that by using the recommended PET content, bituminous concrete of required density and strength is obtained and an environment-friendly road pavement can be constructed with a reduced material cost.

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