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RESEARCH ARTICLE

Mechanistic Characteristics of HRS-WC Mixture Using Tabas Stone Waste Coated With Plastic Waste As Aggregate

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Abstract

Utilization of tabas stone waste and polypropylene (PP) plastic waste has not been carried out massively and optimally because it lacks economic value. The Tabas stone waste can be used as an aggregate for pavement. The porous characteristic of tabas stone results in a high rate of absorption and abrasion, so modifications are made by coating the aggregate with an PP plastic. The aim of this experiment was to determine the characteristics of the HRS-WC mixture with the aggregate of tabas stone coated with plastic. The initial step of this research was testing the tabas stone aggregates, bitumen material, and PP plastic according to the SNI procedure, the next step was Marshall test to find the Optimum Bitumen Content (OBC), the OBC value was obtained by 10%. Coating the aggregate with shredded plastic measuring ± 1 cm^2 was done on coarse aggregate only using the dry method with the proportions of plastic are 5% and 10% of the total weight of coarse aggregate. The characteristics of the aggregate coated with plastic decrease in the value of absorption and abrasion, but only 10% of the plastic content met the specifications with a value of 2.5% and 19.63%. The Marshall testing on the HRS-WC mixture with plastic-coated aggregates was done at variations in bitumen content of 8.5%; 9%; 9.5%. The mixture at 5% plastic content only 9.5% bitumen content met the specifications, namely: stability 1352.72 kg, flow 3.39 mm, MQ 402.23 kg/mm, VIM 5.75%, VMA 18.62% , and VFB 69.16%. When at 10% plastic content, only 9% and 9.5% bitumen content met the specifications, namely the stability of 1370.06 kg; 1456.21 kg, flow 3.81 mm; 3.98 mm, MQ 365.31 kg/mm; 370.06 kg/mm, VIM 5.77%; 4.89%, VMA 18.07%; 18; 15%, and VFB 68.05%; 73.04%. Asphalt mixture of 9% bitumen content, 10% plastic content has more ITSM value compared to 5% plastic content. This is due to the plastic content in the mixture of 10% plastic content which causes the mixture to be stiffness. Asphalt mixture with a plastic content of 5%, with an bitumen content of 9.5% faster than the mixture with an bitumen content of 8.5% and 9% in the ITFT test. Asphalt mixture with a plastic content of 5%, with a variation of bitumen of 8.5% experienced a decrease in the dynamic creep strain value until the bitumen content was 9.5%. A mixture with a plastic content of 5% aggregate coating is recommended for HRS WC that uses tabas stone.

Keywords: Tabas Stone, Plastic Waste, HRS-WC

1. Introduction

Tabas stone is the term people in Bali call basalt stone, which is a type of igneous rock that comes from frozen volcanic lava. Its characteristics are black, light, porous with a sharp surface. This stone is generally processed (cut) into handicraft items such as carved ornaments, temple buildings or statues, and the remaining processed stone waste is around 30% of the total raw material (Salain et al., 2017). This waste has not been used optimally because the characteristics of the rock are that it is susceptible to destruction (degradation). Preliminary test results showed that the wear value reached 49.87% and Samadhi (2019) stated that the absorption of tabas stone was 5.88% (specification limit 3%).

Utilization of plastic waste for asphalt mixtures has been widely used, especially for Polyethylene Terephathalatae (PET) and High Density Polyethylene (HDPE), while Polypropylene (PP) is rarely used. This type of PP plastic can coated rocks using dry mixing (dry process), where PP plastic is mixed with aggregate that has been heated to the temperature of the asphalt mixture (Suroso, 2009). Preliminary test results for PP plastic melts and tend not to clump when heated to a temperature of ±165^{0}C. Coating the coarse aggregate with used LDPE plastic showed a decrease in the absorption value from 1.22% to 1.149% and the wear value from 30.836% to 15.562% (Primaswari, 2018). The most effective plastic content used in road pavement mixtures is 6% of the bitumen weight (Susanto and Suaryana, 2019).

Tabas stone aggregate with high absorption value has poor porosity, low specific gravity and high aggregate degradation. Aggregates with low porosity produce high effective bitumen content (Yuniarti et al., 2023b), however aggregates with high absorption and porosity values produce low effective bitumen content. High water absorption in aggregates affects the durability of the asphalt mixture, including moisture resistance due to temperature and water (Apeagyei et all., 2015). Low effective bitumen content results in the binding capacity of the asphalt mixture not performing well enough, which can cause stripping, besides that it can affect damage due to moisture and the ease of water and air entering the asphalt mixture (Airey and Choi, 2002). Specific gravity and aggregate absorption can affect the void value in the mixture/VIM (Waani, 2013), the use of aggregate material with high absorption value creates high voids in the mixture (Taringan, 2019). The specific gravity of the aggregate used in the asphalt mixture will affect the density of the asphalt mixture (Gashi et all., 2017). Aggregates that have high wear values have low specific gravity values (Rondonuwu et al., 2013).

Due to the nature of tabas stone aggregate which has a low specific gravity, high absorption and wear values used for asphalt mixtures, it is necessary to test the characteristics of the asphalt mixture, especially its mechanical properties. The low specific gravity of aggregate will affect the volumetric properties of asphalt mixtures, including VMA (Hall, 2004). Aggregates that have high water absorption will influence the need for sufficient bitumen content. According to (Minhas, 2019) the percentage of bitumen content is a sensitive parameter influencing the volumetric properties of the asphalt mixture. The use of PP plastic is aimed at reducing the high absorption and wear properties of coarse aggregate. The aim of this research is to analyze the mechanical properties of asphalt mixtures using PP plastic coated aggregates.

2. Literature review

2.1 Tabas stone

Basalt stone (Fig. 1) or what Balinese people often call tabas stone is a type of scoria basaltic rock sourced from frozen volcanic lava containing glass, plagioclase and pyroxene minerals which are chunks in ancient lava flows (Sunartha, 2004). If we look at the compounds that make up tabas stone, it turns out that they are very similar to those contained in several cementitious materials such as: fly ash, silica fume and slag (Intara et all., 2013). Tabas stone is used as a filler or filling material to help the performance of asphalt concrete mixtures, improve road quality and guarantee the impact of environmental damage due to waste that is not processed optimally (Wijaya et all., 2019). The waste resulting from processing tabas stone is in the form of stone pieces as in Fig. 2.

2.2 Polypropylene (PP)

Polypropylene (PP) plastic is a crystalline form that is thermoplastic and hard and has a melting point of 160^{o}C - 165^{o}C (Tokoplas, 2020). PP plastic has the characteristics of being flexible, strong, clear, transparent, odorless and very resistant to chemical reactions, so it is very commonly used as disposable packaging plastic. PP plastic waste as in Fig. 3.

Fig. 1. Tabas stone.

Fig. 2. Tabas stone waste.

Fig. 3. PP plastic waste.

2.3 Hot Rolled Sheet (HRS)

Hot Rolled Sheet (HRS) is a type of asphalt mixture that functions as a cover layer or wear layer, has a minimum thickness of 3 cm or 3.5 cm. HRS is a mixture of graded aggregate with the largest aggregate size of 19 mm, and filler in a certain ratio, mixed, spread and compacted hot conditions (Kementerian PUPR, 2020). Due to the gap grade, the voids in the HRS mixture are quite large, bitumen absorption is high (7-8%) without bleeding so that HRS has high flexibility and durability. (Rahmawati, 2017).

2.4 Stiffness test/ Indirect Tensile Stiffness Modulus (ITSM)

Asphalt mixtures are sensitive to tensile stress rather than compressive stress, so it is necessary to test the tensile stiffness modulus of the asphalt mixture. Asphalt mixture stiffness is one of the mechanical properties of the asphalt mixture which influences the performance of the asphalt mixture's ability to withstand and distribute loads. Stiffness shows the ability of a solid asphalt mixture to withstand and distribute loads expressed by the elastic modulus. The high stiffness of the asphalt mixture under the influence of repeated loads will cause cracking. Stiffness testing is carried out using the BS EN 12607–26:2012 method.

2.5 Fatigue test/Indirect Tensile Fatigue Test (ITFT)

Fatigue is defined as cracking in the asphalt mixture due to repeated loading, the magnitude of the load is usually smaller than the tensile strength. Resistance to fatigue is greater at low temperatures because at low temperatures the asphalt mixture is stiffer (Whitoeak, 1991). Fatigue life is determined by the magnitude of the strain and the stiffness of the asphalt mixture determining the relationship between stress and the number of load applications until failure. Fatigue testing is carried out using the BS EN 12697–24:2012 method.

2.6 Deformation Resistance Test / Creep Test

Deformation resistance is defined as the ability of an asphalt mixture to accept repeated loads within a certain period of time. Factors that influence creep performance are bitumen penetration, aggregate gradation, aggregate texture, aggregate locking, and compaction level. There are two types of creep testing, namely static creep testing and dynamic creep testing, the main difference is the load application system applied. Fatigue testing is carried out using the BS EN 12697–25:2005 method. The slope of the creep curve is depicted in a graph of the relationship between cumulative constant strain and loading cycle. Typical slope values obtained from testing asphalt concrete mixtures from dynamic creep tests are in Table 1.

Table 1. Typical minimum slope of dynamic creep testing (Aderson 1995).

Avg. annual temperature of road pavement (°C)	Heavy traffic load >10^6 ESA	Medium traffic load $5x10^5$ - 10^6 ESA	Light traffic load <$5x10^5$ ESA
> 30	<0.5	0.5 - 3	>3 - 6
20 - 30	<1	1 - 6	>6 - 10
10 - 20	<2	2 - 10	-

3. Material and methods

This research began with the preparation of materials and tools, such as coarse aggregate (tabas stone waste), fine aggregate (tabas stone waste), filler (tabas stone ash), 60/70 penetration bitumen, and used PP plastic additives. Tabas stone waste is obtained from tabas stone craftsmen in the Sebudi Village, The used PP plastic is cleaned and then chopped manually using scissors with a chipped area of ± 1 cm^2. Materials such as aggregate and bitumen used in asphalt mixtures will be tested for their material properties. The aggregate and bitumen that will be used in the mixture are tested according to SNI procedures. Tabas stone aggregate material will only be investigated based on specifications because there is a possibility that aggregate properties will not meet specifications.

The gradation used in the mixture is the middle limit of the HRS-WC gradation range specifications as in Table 2 Kementerian PUPR (2018). The selection of the HRS WC middle limit gradation is used as an aggregate gradation for asphalt mixtures as a gradation that represents the middle limit between the lower limit and upper limit gradations that meet specifications. The aggregates are proportioned proportionally as in Table 3 to obtain a mixed gradation that meets the HRS-WC gradation specifications as in Table 2. Proportional aggregate gradation mixing is carried out by mixing each aggregate size according to the proportion of aggregate weight to the aggregate composition in the asphalt mixture. Proportional aggregate gradation mixing has advantages, including the aggregate gradation being closer to the planned gradation because each aggregate size has a proportion in the aggregate gradation composition as in Table 4.

Table 2 HRS aggregate gradation size (Kementrian PUPR, 2018).

Sieve size (mm)	HRS Gradation	
	WC	Base
3.75		
25		
19	100	100
12.5	90-100	90-100
9.5	75-85	65-90
4.75		
2.36	50-72	35-55
1.18		
0.6	35-60	15-35
0.3		
0.15		
0.075	6-10	2-9

After determining the proportion of aggregate based on the aggregate weight of the planned gradation based on the middle limit gradation specifications, the next step is to determine the initial planned bitumen content. The initial planned bitumen content will be used as a reference for variations in bitumen content to determine the optimum bitumen content Based on the consideration that the absorption rate for coarse aggregate is 2.7 times the maximum limit and fine aggregate is 1.86 times the maximum limit required by Bina Marga, a constant value (k) of 4 is used to obtain an initial bitumen content value of 9.28 ≈ 9.5%. The draft proportion of aggregate material requirements can be shown in Table 4. The initial plan bitumen content based on the results of formula calculations will be varied by ±0.5% and ±1% of the lower and upper limits of the initial plan bitumen content.

Table 3 . HRS-WC aggregate proportions (Kementrian PUPR, 2018).

Sieve size (mm)	Middle limit plan gradation	
	Cumulative pass (%)	Retained (%)
37.5	100	-
25	100	-
19	100	-
12.5	95	5
9.5	80	15
4.75	70	10
2.36	61	9
1.18	54.5	6.5
0.6	47.5	7
0.3	38	9.5
0.15	20	18
0.075	8	12
Filler		8

Table 4. Aggregate material requirements for HRS-WC.

Material	Aggregate size (mm)	Proportion (%)	1 Sample (gram)	2 Sample (gram)	3 Sample (gram)
Coarse Agg. 30%	19-12.5	5.00	40.00	80.00	12.,00
	12.5-9.5	15.00	120.00	240.00	360.00
	9.5-4.75	10.00	80.00	160.00	240.00
Fine Agg. 62%	4.75-2.36	9.00	72.00	144.00	216.00
	2.36-1.18	3.00	24.00	48.00	72.00
	1.18-0.6	10.50	84.00	168.00	252.00
	0.6-0.3	14.00	112.00	224.00	336.00
	0.3-0.15	13.50	108.00	216.00	324.00
	0.15-0.075	12.00	96.00	192.00	288.00
Filler 8%	0.075	8.00	64.00	128.00	192.00
Total		100.00	800.00	1600.00	2400.00
Bitumen requirement (% to the total weight of the mixture)					
8.50 % =	8.5/(100 – 8.5) x Agg. weight			74.3	148.6
9.00 % =	9/(100 - 9) x Agg. weight			79.1	158.2
9.50 % =	9.5/(100 – 9.5) x Agg. weight			84.0	168.0
10.00 % =	10/(100 - 10) x Agg. weight			88.9	177.8
10.50 % =	10.5/(100 – 10.5) x Agg. weight			93.9	187.7

Table 5. Requirements for properties of HRS mixtures (Kementrian PUPR, 2010; Kementrian PUPR, 2018).

Properties of Mix.		HRS		
		WC		Base
Effective bitumen content (%)	Min.	5.9		5.5
Number of impacts per field			50	
VIM (%)	Min. Max.		4 6	
VMA (%)	Min.	18		17
VFB (%)	Min.		68	
Marshall stability (kg)	Min.		600	
Marshall Quoetient (kg/mm)	Min.		250	
Retained Marshall stability (%)	Min.		90	
Flow (mm)	Min.		3	

The test specimens were made according to the design (Table 4) compacted with 2 x 50 impacts (Table 5), and continued with Marshall testing to determine the Optimum Bitumen Content (OBC) which was determined from the middle value of the maximum and minimum bitumen content range which met the stability, flow, Marshall Quotient/MA, VMA, VFB and VIM. Marshall characteristic and volumetric values will be assessed based on table 5. OBC was determined using the Barchart Method Pustran-Balitbang PU (2003) in RSNI M-01-2003, and then used as a reference in making the HRS-WC mixture using tabas stone aggregate coated in used PP plastic.

The coating is only carried out on coarse aggregate by drying at a plastic content of 5% and 10% of the total weight of coarse aggregate, and is followed by testing the characteristics of specific gravity, absorption, aggregate wear and aggregate adhesion to bitumen. Based on consideration of the results of the absorption value of coarse aggregate coated with PP plastic which decreased significantly, the test objects were made at OBC-0.5%, OBC-1% and OBC-1.5% with the aim of preventing bleeding in the test objects. After knowing the OBC value and the proper bitumen content with optimal plastic coating on the aggregate, the ITSM, dynamic creep, and ITFT value will be found.

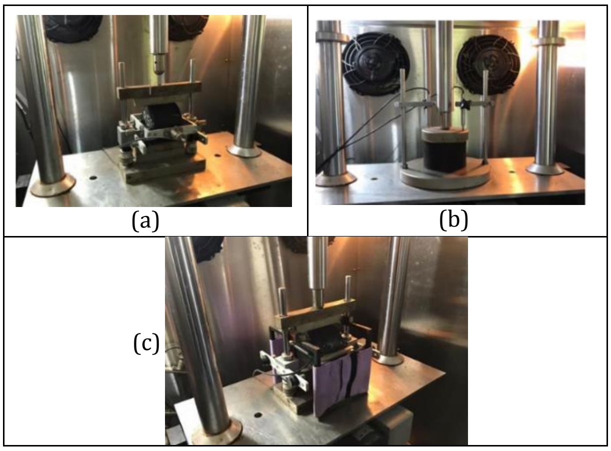


Fig. 4. (a) ITSM test, (b) Dynamic creep test, (c) ITFT test.

ITSM, dynamic creep and ITFT testing using the Dynapave Universal Testing Material test equipment. The elastic modulus of the asphalt mixture was tested using Indirect Tensile Stiffness Modulus (ITSM) Fig.4 (a), testing carried out according to the BS EN 12697-26: 2012 method. The deformation resistance properties of the asphalt mixture due to loading were tested using dynamic creep Fig. 4 (b), testing according to the BS EN 12697-24: 2012 method. Indirect Tensile Fatique Test (ITFT) is carried out to analyze the nature of cracks due to fatigue of asphalt mixtures due to the number of repeated loads Fig 4. (c), referring to the BS EN 12697-24: 2012 method.

4. Result and discussion

4.1 Characteristics of aggregate of tabas stone and Plastic

Table 6. Results of investigation of the coarse aggregate of tabas stone.

Type of testing	Result			Spec.
	Bulk	SSD	App.	
Specify gravity	1.82	1.97	2.13	
Absorption		8.11%		≤ 3%
Angularity		100%		≥ 95%
Clay content		0.84%		≤ 1%
Soundness test		1.25%		≤ 12%
Aggregate abrasion		52.64%		≤ 40%
Aggregate adhesiveness to bitumen		99%		≥ 95%

Table 6 and Table 7 are a summary of the test results for tabas stone aggregate, the specific gravity of the coarse aggregate is relatively small with absorption of 8.11% while the fine aggregate is 5.85% (specifications ≤ 3%) and the abrasion of the coarse aggregate is 52.64% specifications ≤ 40% Kementerian PUPR (2018). Investigation results the specific gravity filler is 2.53 and plastic is 1.37 (Table 8 and Table 9). The results of the investigation the aggregate properties of tabas stone material do not have to meet the specification requirements but are only a review of the characteristics of the aggregate used.

Table 7. Results of investigation of the fine aggregate of tabas stone.

Type of testing	Result		Spec.
	Bulk	SSD	App.
Specify gravity	2.14	2.27	2.45
Absorption	5.85%		≤ 3%
Angularity	53.09%		≥ 45%
Clay content	0.58%		≤ 1%
Sand equivalent	100 %		≥ 50%

Table 8. Results of investigation of the filler of tabas stone.

Type of testing	Result	Spec.
Specify gravity	2.53	-

Table 9. Results of investigation of the PP plastic.

Type of testing	Result	Spec.
Specify gravity	1.37	-

4.2 Determine Optimum Bitumen Content (OBC)

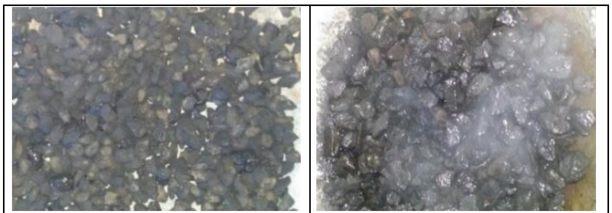
OBC is determined using the Barchart Method and is set at 10%. Marshall characteristics for each variation of initial bitumen content can be seen in Table 10. All asphalt mixture levels provide stability ≥ 800 kg, for flow, VIM and VFB characteristics, the bitumen content range is 9.5% – 10.5% which meets specification

Table 10. Results of HRS-WC mixture characteristics on bitumen variations.

Properties of Mix.	Bitumen content (%)					Spec.
	8.5	9	9.5	10	10.5	
Marshall stability (kg)	1049.73	1234.97	1320.83	1236.88	1182.18	≥ 800
Flow (mm)	2.54	2.88	3.30	3.89	4.15	≥ 3
MQ (kg/mm)	418.73	430.25	403.56	318.31	284.76	≥ 250
VIM (%)	9.78	7.33	5.77	5.56	5.37	4 - 6
VMA (%)	20.01	18.70	18.19	18.88	19.56	≥ 18
VFB (%)	51.12	60.83	68.31	70.56	72.61	≥ 68

4.3 Coarse aggregate coating with PP plastic

Visual observation shows that a 5% plastic coat is able to coat around 50% of the aggregate and a 10% plastic coat 100% of the aggregate surface (Fig. 5 (a) and Fig. 5 (b)). The plastic requirement for one test sample is 12 grams (5% content) or 24 grams (10% content). The higher the composition of the plastic content used to coat the aggregate, the more evenly the aggregate will be coated with the plastic. The aim of coating the aggregate with plastic is to coat the tabas stone aggregate which has high absorption properties and a high abrasion rate so that the absorption value and abrasion value rate can be reduced. Under certain conditions, a high plastic content for coating the aggregate can affect the mechanical properties of the mixture. Apart from that, the higher the plastic content coating the aggregate will affect the effective asphalt content.



(a) (b)

Fig. 5. (a) Coating aggregate with 5% plastic content, (b) Coating aggregate with 10% plastic content.

4.4 Characteristics of tabas stone aggregate coated in PP Plastic

Based on Table 11, the results of the investigation of the absorption of coarse aggregate coated with plastic at 5% and 10% plastic content were 3.73% and 2.5% respectively. This value decreased by 8.11% compared to those not coated by plastic. This is because the surface pores of the aggregate are coated by a layer of plastic. The airtight nature of plastic prevents air from seeping into the pores of the aggregate, thereby reducing the level of aggregate absorption. Aggregate coated with 10% plastic meets the Kementerian PUPR (2018) specification requirements, namely a maximum of 3%.

The results of the wear inspection of aggregates coated with plastic with levels of 5% and 10% showed wear values of 26.20% and 19.63% respectively. Plastic that coat the surface of the aggregate and plastic that is absorbed into the pores of the aggregate reduces the breakdown of aggregate particles when exposed to mechanical loading. This shows that the coarse aggregate coated in plastic has met the specifications required by the Kementerian PUPR (2018), namely a maximum of 40%.

Visual observation of the aggregate adhesion value to bitumen is 99% > 95% of the specifications required by the Kementerian PUPR (2018). This shows that coating the aggregate surface with plastic does not weaken the aggregate's adhesion to bitumen.

Table 11. Average results of investigation of coarse aggregate coated in plastic.

Type of testing	Result									Spec.
	No plastic			Plastic content 5%			Plastic content 10%			
	Bulk	SSD	App.	Bulk	SSD	App.	Bulk	SSD	App.	
Specify gravity	1.82	1.97	2.13	1.79	1.86	1.92	1.78	1.82	1.86	
Absorption (%)		8.11			3.73			2.50		≤ 3
Aggregate abrasion (%)		52.64			26.20			19.63		≤ 40
Aggregate adhesiveness to bitumen (%)		99			99			99		≥ 95

4.5 Marshall characteristics of HRS-WC mixtures with PP plastic coated aggregates

The Marshall characteristics test of the mixture was designed for variations in bitumen content of 8.5%; 9%; and 9.5% on coarse aggregate with a plastic content of 5%, 10%, and the characteristics can be seen in Table 12 and Table 13. The higher the plastic content used to coat the aggregate, the reduced the absorption and wear value of the aggregate (Table 11). A high aggregate absorption value will affect the amount of bitumen content and the level of aggregate abrasion will affect the durability of the asphalt mixture. Marshall test specimens for samples coated with plastic and uncoated with plastic visually do not look much different (Fig. 6 (b) and Fig. 6 (c)).

(a) (b) (c)

Fig. 6. (a) Marshall Stability test, (b) Marshall test specimens, the aggregate uncoated with the plastic, (c) Marshall test specimens, the aggregate coated with the plastic.

Table 12. Characteristics of the HRS-WC aggregate mixture coated with plastic with a 5% content.

Properties of Mix.	No plastic in bitumen content (%)			With 5% plastic content in bitumen content (%)			Spec.
	8.5	9	9.5	8.5	9	9.5	
Marshall stability (kg)	1049.73	1234.97	1320.83	1127.99	1260.43	1352.72	≥ 600
Flow (mm)	2.54	2.88	3.30	2.96	3.30	3.39	≥ 3
MQ (kg/mm)	418.73	430.25	403.56	404.40	413.99	402.23	≥ 250
VIM (%)	9.78	7.33	5.77	8.54	6.79	5.23	4.0-6.0
VMA (%)	20.01	18.70	18.19	19.67	18.97	18.46	≥ 18
VFB (%)	51.12	60.83	68.31	56.60	64.23	71.67	≥ 68

Table 13. Characteristics of the HRS-WC aggregate mixture coated with plastic with a 10% content.

Properties of Mix.	No plastic in bitumen content (%)			With 5% plastic content in bitumen content (%)			Spec.
	8.5	9	9.5	8.5	9	9.5	
Marshall stability (kg)	1049.73	1234.97	1320.83	1214.21	1370.06	1456.21	≥ 600
Flow (mm)	2.54	2.88	3.30	3.64	3.81	3.98	≥ 3
MQ (kg/mm)	418.73	430.25	403.56	334.18	365.31	370.06	≥ 250
VIM (%)	9.78	7.33	5.77	7.90	5.75	4.87	4.0-6.0
VMA (%)	20.01	18.70	18.19	19.11	18.07	18.15	≥ 18
VFB (%)	51.12	60.83	68.31	58.66	68.16	73.15	≥ 68

From Table 12, the plastic-coated aggregate mixture at 5% plastic content for each bitumen content does not have a significant effect. Only 9.5% bitumen content meets the HRS-WC mixture specifications. At 10% plastic content (Table 13), each bitumen content has a significant influence on changes in the characteristic values of the HRS-WC mixture until it approaches and reaches specifications. The HRS-WC aggregate mixture coated in plastic with a plastic content of 10% at an bitumen content of 9% and 9.5% meets the specifications for the HRS-WC mixture.

According to Waani (2013) the high VIM in the mixture in terms of aggregate properties is influenced by the specific gravity and aggregate absorption. Based on the results of aggregate coating, the higher the plastic content used for aggregate coating will reduce the aggregate absorption value. A high VIM value indicates that the mixture is porous (Putra et al., 2018) and the use of aggregate material with a high absorption value results in a high VIM value (Taringan, 2019). Aggregates with high porosity absorb more bitumen, have less effective bitumen content and bitumen film thickness than aggregates with low values (Yuniarti et al., 2023a; Yuniarti et al., 2023b). Low effective bitumen content will affect the thickness of the bitumen film thickness which is influenced by bitumen content, aggregate type and aggregate surface area (AIKofahi and Khedaywi (2019). According to the results of Table 12 and Table 13, the VIM value will decrease according to the proportion of added PP plastic. The more PP plastic added to the asphalt mixture causes the stability value to increase, the VIM value to decrease, the VMA value to decrease and the VFB value to increase.

4.6 ITSM test result

ITSM testing of a mixture of variations in bitumen content of 8.5%; 9%; and 9.5% on the coarse aggregate coated with plastic with plastic content of 5% and 10%, the characteristics of which can be seen in Table 14 and Fig. 7.

Table 14. The results of the average ITSM value of the HRS-WC mixture with variations in plastic coated aggregate and variations in bitumen content.

Bitumen content (%)	ITSM (MPa) Plastic content 5%	Plastic content 10%
8.5%	4433	3806
9%	3113	2765
9.5%	2462	2128

Based on Table 14, the highest ITSM value was obtained with a mixture of variations in bitumen content of 8.5% with a plastic content of 5% with an ITSM value of 4433 MPa, while the lowest ITSM value was obtained with a mixture of variations in bitumen content of 9.5% with a plastic content of 10% to ITSM value is 2128 MPa. The graph in Fig. 7 for variations in plastic content of 5% and plastic content of 10% shows that the ITSM value has decreased from bitumen content of 8.5% to an bitumen content of 9.5%. This is because the bitumen content value of 8.5% has the maximum ITSM value because the mixture with a plastic content of 5% has high stiffness properties, while the mixture with an bitumen content of 9.5% has a higher bitumen content, causing the mixture to be more elastic and reduce stiffness. The higher the bitumen content results in the stiffness value of the asphalt mixture decreasing because increasing the bitumen content causes the asphalt mixture to become more plastic, the density decreases and the stiffness of the mixture becomes lower. The asphalt mixture stiffness value in the 10% plastic content mixture is lower due to the high percentage of plastic coating the coarse aggregate so that the bitumen absorption in the aggregate is lower causing the effective bitumen content to be higher and the bitumen film thickness to be higher, the stiffness of the asphalt mixture is lower due to the nature of the mixture. Bitumen is more plastic than a mixture with a plastic content of 5%.

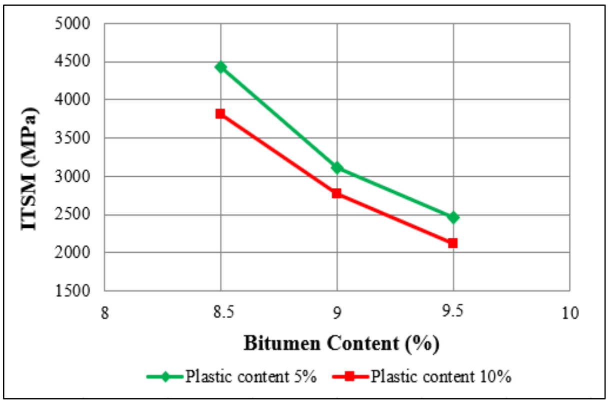


Fig. 7. The relationship between bitumen content and ITSM value on variations in plastic content coating coarse aggregate.

4.7 Creep test result

Creep testing of mixed bitumen content variations of 8.5%; 9%; and 9.5% on plastic-coated coarse aggregate with plastic content of 5% and 10%, can be seen in graphs Fig. 8 and Fig. 9.

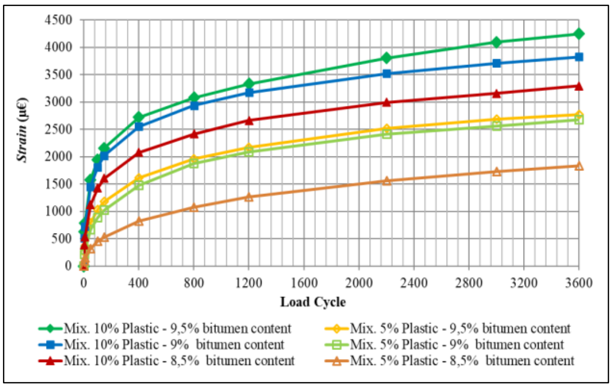


Fig. 8. The relationship between loading cycles and strain values on variations in plastic content coating coarse aggregate.

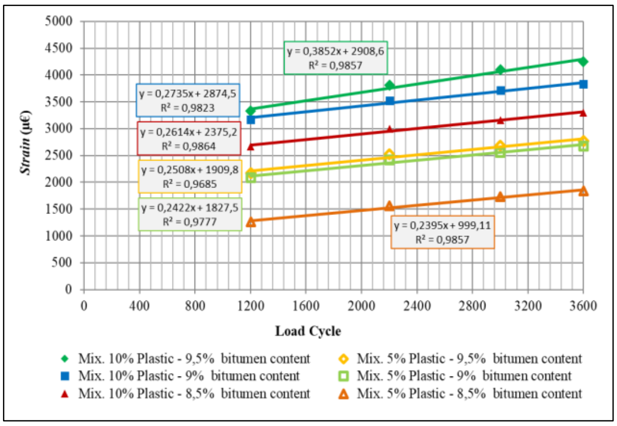


Fig. 9. The slope value in the relationship between loading cycles and strain values.

Based on the graph in Fig. 8, a mixture with a plastic content of 10% and a variation of bitumen content of 9.5% has a high strain value in the creep test. Based on the graph in Fig. 9, a mixture with a plastic content of 10% and a variation of bitumen content of 9.5% has a high slope value in line with the high strain value in the creep test. Asphalt mixtures with a plastic content of 10% have a higher strain value compared to mixtures with a plastic content of 5% because the mixture is more flexible and has a lower stiffness modulus value. A high percentage of plastic content coating the coarse aggregate causes lower bitumen absorption in the aggregate and a higher effective bitumen content as well as a higher value bitumen film thickness which causes the mixture to become more flexible and soft. When compared with Table 1 for typical dynamic creep slopes, asphalt mixtures with plastic content of 5% and 10% for each variation in bitumen content are included in the type of mixture that can be used for heavy traffic, ESA >10^6 (Anderson, 1995). This is in accordance with the behavior of the asphalt mixture stiffness value which is higher with a greater ITSM value. The higher the plastic content can cause the strain to be higher and the mixture to be more flexible and have a lower stiffness of the asphalt mixture. Deformation resistance can be influenced by aggregate properties and asphalt properties such as asphalt viscosity and bitumen content (Ferreira et al., 2020). Deformation resistance, which affects rutting properties is also influenced by the level of asphalt penetration (Kok and Kuloglu, 2007).

4.8 ITFT test result

ITFT testing of a mixture of variations in bitumen content of 8.5%; 9%; and 9.5% on coarse aggregate coated with plastic with plastic content of 5% and 10%, can be seen in the graph Fig. 10. The results of the ITFT values are depicted in the form of a graph of the relationship between bitumen content with the number of repetitions of the load until failure/ NF.

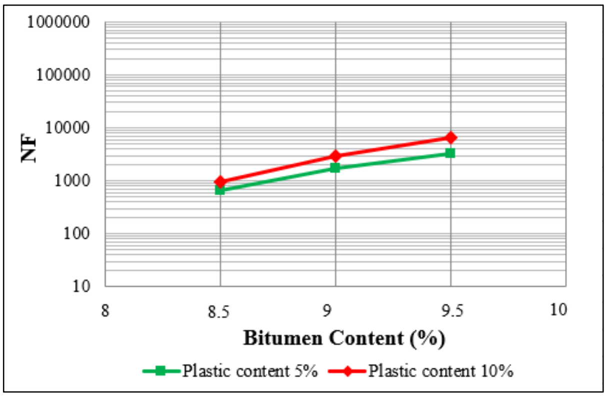


Fig. 10. The relationship between bitumen content and NF.

The amount of stress applied to the test specimen is 500 kPa. The applied stress of 500 kPa is the maximum value used when testing the sample when it receives a load before the sample collapses (the sample does not collapse quickly at the beginning of the test). For each type of asphalt mixture, a mixture of 5% and 10% plastic content was made with variations in the bitumen content of 8.5%; 9%; and 9.5%. Based on the graph in Fig. 10, a mixture with a plastic content of 5% collapses more quickly than a mixture with a plastic content of 10% at a certain strain. Resistance to high fatigue is assessed from the value of the number of repetitions of the load until high failure under certain stress conditions.

Asphalt mixtures with a plastic content of 10% have a higher number of repetitions of load to failure than mixtures with a plastic content of 5% (Fig. 10). This is because asphalt mixtures with a plastic content of 10% are more flexible and have lower stiffness than mixtures with a plastic content of 5%. A high percentage of plastic coating the coarse aggregate causes bitumen absorption in the aggregate to be lower and the effective a bitumen content to be higher and the bitumen film thickness being higher, the stiffness of the asphalt mixture being lower. The higher the bitumen content in the variation 8.5%; 9%; and 9.5% mixture with 5% and 10% plastic content causes the asphalt mixture to be more resistant to fatigue and has a higher number of repetitions of load to fail.

5. Conclusion

Characteristics of tabas stone that does not meet specifications for coarse aggregate, its absorption and wear values, while for fine aggregate its absorption value. The characteristics of tabas stone in a coat with a plastic content of 5%, the wear value meets the specifications but the absorption value does not meet the specifications. Aggregate coating with a plastic content of 10% wear value and aggregate absorption meets specifications. The characteristics of the HRS-WC mixture with aggregate coated in used PP plastic show that increasing the plastic content coating the aggregate and bitumen content in the mixture results better stability, flow, MQ, VIM, VMA, VFB. The stiffness value of the asphalt mixture in a mixture with a plastic content of 10% is lower than that of a plastic content of 5% due to the high percentage of plastic coating the coarse aggregate so that the absorption of bitumen in the aggregate is lower causing the effective bitumen content to be higher and bitumen film thickness to be higher, the stiffness of the asphalt mixture becomes lower with the properties of the asphalt mixture being more plastic. The higher the bitumen content in the variation 8.5%; 9%; and 9.5% mixture with 5% and 10% plastic content causes the asphalt mixture to be more resistant to fatigue and has a higher number of repetitions of load to fail. The higher the plastic content value causes the strain value to be higher so that the mixture has a higher deformation value. The higher the plastic content can cause the strain to be higher and the mixture to be more flexible and have a lower stiffness of the asphalt mixture.

The recommended mixture composition using plastic to coat the aggregate is a mixture with a plastic content of 5%. It was chosen as a recommendation based on the HRS-WC requirements meeting specifications, and in terms of mechanical properties, deformation resistance is better than a mixture with a plastic content of 10%. Suggestions for further research in terms of the use of plastic to cover aggregates, the use of plastic to coat aggregates that have high absorption and abrasion values can be applied. Future research can also apply the composition of the HRS WC mixture using plastic coated aggregates on paving blocks.

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