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STRENGTH AND TOUGHNESS CHARACTERISTICS OF AC-WC MIXTURE CONTAINING PET AND PP PLASTIC WASTE UNDER STATIC COMPRESSION

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ABSTRACT: The use of plastic waste as an asphalt-concrete mixture in road construction with flexible pavements can overcome chemical waste. Many studies have been carried out on plastic waste used as an aggregate material for road construction with flexible pavements, including this research. This paper discusses polyethylene terephthalate (PET) and polypropylene (PP) plastic waste as an additive for the modification of the asphalt-concrete mixture. The sample was made using a cylindrical mold with 10 cm height and diameter of 10 cm. Asphalt Buton type Retona Blend 55, fine and coarse aggregates and fillers are mixed at a mixing temperature of 160 ± 0.5 ° C, with a total mixture weight of 1,600 grams. The compressive strength test was carried out on the asphalt-concrete combination using Modified Buton Asphalt (MBA) as a binder with PET and PP Processed and has not been processed based on Indonesian test standards (SNI 03-6758-2002). Comparison of 3% asphalt binder mixture to total aggregate and the ratio of adding PET and PP (100: 0%, 0: 100%, and 50: 50%). The results showed that the compressive strength of the AC-WC treatment was higher than without treatment. Also, PET and PP can mix with an MBA as a better binder and result in higher strength. The pavement analysis's important elasticity parameter is the Poisson ratio, where the test results show that the modulus of elasticity and the Poisson ratio follow the standard, namely 80% of the peak load.

Keywords: Compressive strength, PET, PP, MBA, AC-WC mixture

1. INTRODUCTION

Currently, the use of plastic in modern lifestyles has reached almost all parts of life. Plastics can be used for packaging, protective materials, and serving nearly all types of consumer goods. The use of plastics begins with a change in the progress of the industry, which uses cheaper raw materials with more reserves. Today, many important economic sectors, from the agricultural sector to the packaging, building materials, and communications sectors, have used plastics materials. The use of these non-biodegradable products (according to recent research, plastics can remain unchanged for 4,500 years on earth) becomes a problem as waste. Therefore, this problem needs to be resolved by making innovations in plastic waste as a material that can be used as a construction material, especially road infrastructure [1-4].

One of the additives that are often used to improve the pavement quality is adding polymer to the asphalt mixture [5]. The plastics polymers with suitable *plastomeric* properties use to enhance the performance of the asphalt mixture. The use of recycled polymers also shows the same performance results compared to natural polymers when carried out with a strict selection of plastic waste and production conditions [6-9]. The mixing of the polymer into the asphalt mixture can be done in two ways: a wet mixture and a dry mixture. However, dry mix is the method most widely applied in field use [10-12]. The reason for using polyethylene terephthalate (PET) and Polypropylene (PP) plastic waste as an added material is that the two types of plastic dominate the plastic waste that is disposed of into the sea as waste. This study will combine the two types of plastics as an additive to the asphalt mixture [13].

Asphalt rock is available in abundance on Buton Island, Southeast Sulawesi, Indonesia, and is widely studied for its sedimentation. In recent years it has been known that the value of moisture content, asphalt content, and penetration of Buton Buton Asphalt (BGA) obtained from the refining process of asphalt rock meets the material requirements for road surface coating. From several research results, natural Buton asphalt can be used as a pavement mixture because rock asphalt has similar properties to oil asphalt [14-19]. The Buton asphalt type that has undergone a modified process and is widely used as a binder is Asphalt Buton Retona Blend 55, a semi-extracted

Buton asphalt processed from natural Buton asphalt [20].

Two critical parameters of the characteristics of an asphalt concrete mixture used to assess the mixture's performance are strength and toughness. Generally, toughness is the capacity of a combination to absorb energy (called energy toughness) determined based on the area of coverage of the stress-strain curve due to compressive loads. This total energy represents the amount of energy absorbed by the mixture before the complete collapse. The mixture's additional load-bearing capacity is directly proportional to the toughness that the plastic waste added to the Asphalt mixture. The increase in the residual asphalt concrete's strength also shows the ability to withstand more loads, even after damage occurs.

The asphalt concrete layer located at the top is the asphalt concrete Wearing Couse (AC-WC). This surface pavement structure will receive axial compressive loads from vehicle tires that are then passed on to other layers so that this layer is the most frequently damaged. Maintaining the pavement surface's continuity without reducing undue compressive strength is an essential parameter of the AC-WC mixture's top layer, as shown in Figure 1. This study used modified Buton Asphalt (Asbuton) as a binder to produce the AC-WC mixture. This study aims to determine the relationship between stress and strain in the AC-WC mix, which has been added with processed plastic waste (PET and PP as a 3% asphalt binder to total aggregate weight) by performing monotonic compressive loading in a short time.

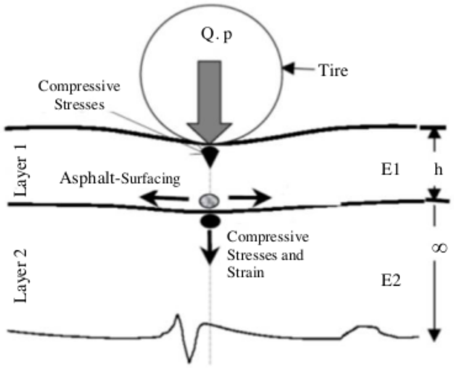

Fig 1. The compressive strength parameter of AC-WC based top layer

This paper will discuss the relationship between stress and strain on the AC-WC asphalt pavement layer with plastic waste added in the composition of 3% plastic waste using a ratio of 100: 0%, 0: 100%, and 50: 50% of PET and PP plastic waste at short-term monotonic compressive load. Besides, the value of the modulus of elasticity, Poisson's ratio, and the toughness index will be calculated for the mixture without additional plastic waste or using plastic waste.

2. MATERIALS AND METHOD

2.1 Plastic Waste added Mateials PET and PP

PET and PP plastic waste is a thermoplastic polymer material produced by chemical companies and is widely used in everyday human life. This plastic's physical properties have a high melting point of 260^{o}C for PET and 190-200^{o}C for PP. These two types of plastic, respectively obtained in disposable bottles and cups, are collected from domestic waste. The plastic bottles and cups are then crushed using a coconut shredder machine, modified to get the material with a size that passes the No.50 sieve and is stuck on the No.100 sieve to make it easier for the mixing process. The differences in the physical properties of the two types of plastic waste are shown in Table 1, while the plastic waste used in the asphalt mixture is shown in Figure 2.

Table 1. The difference between PET and PP

Difference	Waste plastic PP	Waste plastic PET
Chemical	$(C_3H_6)_x$	$C_{10}H_5O_4$
Characteristics	Soft and waxy, lighter in quality and has a certain transparency	High chemical stability, good hygienic property, and high heat resistance
Basic material	Polymer	Polyester
Melting point	160 ^{0}C	260 ^{0}C
Density	0,855 g/cm^3	1,4 g/cm^3

Fig 2. (a) Waste plastic PP; (b) Waste plastic PET

2.2 Modified Buton Asphalt (MBA)

The characteristics of Modified Buton Asphalt (MBA), namely Retona Blend 55, is the type of MBA used in this study and is shown in Table 2. MBA is a combination of Asbuton granules partly extracted with hard asphalt Pen 60 or Pen 80, produced in Indonesia.

Table 2. The MBA Retona Blend 55 characteristics

Properties	Testing result
Penetration before weight loss (mm)	78.6
Softening point (°C)	52
Ductility in 25°C, 5cm/minutes (cm)	114
Flashpoint (°C)	280
Specific gravity	1.12
Weight loss	0.5
Penetration after weight loss (mm)	86

2.3 Aggregates

In this study, they were using coarse aggregate taken from crushed river rock. The first is aggregates with a diameter of 5-10 mm and aggregates with a diameter of 10-20 mm. Sand and rock ash as fine aggregate and filler are taken from the processing of stone crusher. The aggregates used in this study as fine and coarse aggregates as asphalt mix aggregates are shown in Tables 3, 4, and 5.

Table 3. Coarse aggregate properties

Properties	(Crushed stone)	
	5 - 10 (mm)	10 - 20 (mm)
Water absorption, %	2.07	2.08
Bulk specific gravity	2.62	2.63
Saturated surface dry specific gravity	2.68	2.68
Apparent specific gravity	2.77	2.78
Flakiness index, %	20.10	9.38
Abrasion aggregate, %	25.72	24.36

Table 4. Fine aggregate properties

Water absorption, %	2.729	
Sand equivalent, %	89.66	
Bulk specific gravity 2.449	Saturated surface dry specific gravity 2.518	Apparent specific gravity 2.629

Table 5. Filler properties

Water absorption, %	2.283	
Sand equivalent, %	69.57	
Bulk specific gravity 2.595	Saturated surface dry specific gravity 2.654	Apparent specific gravity 2.758

2.4 Combined Aggregate Gradation

The AC-WC top layer pavement mix requirement must use a tightly graded aggregate between the upper and lower limits as required in the 2010 Bina Marga specification book, as shown in Figure. 3.

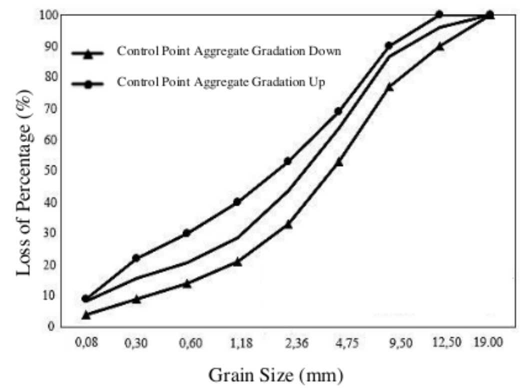

Fig 3. Combined aggregates gradation

2.5 Compressive Strength

Starodubsky et al. (1994) have reported stress and strain relationship tests for stress-induced asphalt concrete mixtures to describe their elasticity limit values [21]. The free compressive strength test using the Universal Testing Machine shows the maximum stress value applied to the test object until it cracks. The test object will also experience a change in length, obtained from the deflection value reading from the LVDT tool. The test was carried out to determine the material's ability to compressive forces using the Indonesian test standard SNI 03-6758-2002 [22]. The compressive strength test in the laboratory is shown in Figure 4.

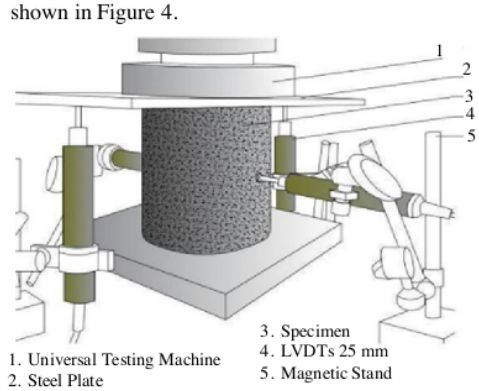

Fig 4. The laboratory compressive strength testing

2.6 Compression Toughness Factor

The Association of Japanese Civil Engineers (JSCE) issued the SF-5 standard [23], the compression toughness is in the area under the load-deflection curve until deformation occurs. AC-WC mixed cylindrical sample measuring 100 mm x 100 mm, as shown in Figure 5. The compression toughness factor shows the compressive strength of the post-matrix cracks of Ultra-High-Performance Concrete (UHPC) without distinguishing the same pre-peak and post-peak behavior. With 0.075 cm. The compression toughness factor is shown in equation 1.

$$\sigma = \frac{T_c}{A.\delta_{tc}} \quad (1)$$

Where:

σ = Compression toughness factor
Tc = Compression toughness (Nm)
δ_{tc} = Deformation corresponding to 0.75 percent converted to strain (mm)
A = Surface of a specimen

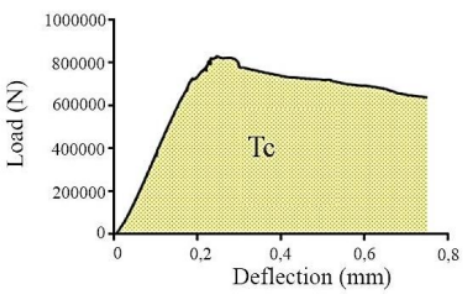

Fig 5. Load-deformation curve of the sample

3. RESULTS AND DISCUSSIONS

3.1 Mixtures Design of AC-WC Treated and Untreated Plastic Waste

AC-WC Asphalt Mixture with 3% added material content of PET and PP plastic waste using variations in the weight ratio of PET: PP (100: 0%, 0: 100%, and 50: 50%), as shown in Table 6. Asphalt mixing process retona, coarse and fine aggregates, and fillers are mixed at a mixing temperature of 160 ± 0.5 ° C and compacted in a cylindrical mold with a height of 10 cm and a diameter of 10 cm with a mixture weight of 1,600 grams [22]. The mixture was compacted using a Marshall Compactor with 75 collisions on each side. After that, the solidified mixture was removed from the mold and stored at the laboratory room temperature of 27°C.

3.2 Stress-Strain Curve of Asphalt Concrete

The horizontal and vertical strain is measured to the peak stress. The sample's stress and strain relationship are subject to a short-term monotonic compressive load for AC-WC without PET, and PP is shown in Fig. 6. While Fig. 7-9 shows the stress-strain relationship of AC-WC with PET and PP with a ratio of 100:0%, 0:100%, and 50:50%, respectively.

Figure 6-9 shows three loading conditions of vertical strain (V1, V2, and V3) and three horizontal strain (H1, H2, and H3). The whole stress-strain relationship (Fig. 6-9) shows that the three behavior zones, such as the bottom zone, reflect sample settlement, arise from approximately 0.35 MPa. Another section shows the linear zone representing the mixture's elasticity occurring up to about 70% of the peak stress. The next section shows the nonlinear zones appearing up to the peak stresses.

Also, it appears that all specimens have elasticity. It is because after mixing Retona Asphalt with added material, PET plastic waste occurs brittle, and PP remains in the elasticity of the sample. After reaching the maximum stress, the strength will decrease, but the strain will continue to increase. It shows that the AC-WC Asphalt mixture, although it behaves brittle but does not fail suddenly.

The AC-WC mixture's voltage value that uses plastic waste added material is higher than the stress value in the mix that does not use plastic waste (Figure 7-9). It is shown that the mixture of asphalt and plastic waste is more resistant to deformation due to short-term monotonic compressive loads. The compressive strength value of the AC-WC asphalt mixture that was not added with plastic waste was 1.26 MPa (Figure 6). While the mix that uses plastic waste with the addition of 3% in the composition ratio of PET: PP (100: 0%, 0: 100%, and 50: 50%) has a compressive strength of 3.70, 3.82, and 5, respectively. 23 MPa (Figure 7). The ratio sample (100: 0% and 0: 100%) and the untreated sample in Figure 7-8 - all samples failed when the vertical and horizontal strains reached 0.005 and 0.01, respectively (Figure 7-9).

The application of plastic waste as additional material in this study is based on differences in characteristics. In its original state, PET is a semi-crystalline resin, with a transition temperature (Tg) of about 70^{0}C. After heating, its properties will change to less crystalline material. Therefore, if this result is related to PET plastic waste as a semi-crystalline asphalt mixture, it will make the mixture stiff.

Table 6. The weighted mixture of the AC-WC mixture with waste plastic PET and PP

No	Description			Unit	Waste plastic content (%)			
					0.0	3.0 (PET: PP)		
					0.0	100 : 0	0: 100	50: 50
A	Waste plastic waste weight (PET + PP)			gr	0.00	45.00		
B	Modified Asbuton weight (6.25%)			gr	75.00			
C	Combined aggregates gradation				Weight of Aggregate by Number of Sieve			
	Number of sieves	% Getaway	% Restrained					
1	3/4"	100.00	0.00	gr	-	-	-	-
2	1/2"	96.00	4.00	gr	60.04	55.54	55.54	55.54
3	3/8"	86.93	9.07	gr	136.05	131.55	131.55	131.55
4	No. 4	63.90	23.03	gr	345.38	340.88	340.88	340.88
5	No. 8	43.56	20.34	gr	305.06	300.56	300.56	300.56
6	No. 16	28.62	14.94	gr	224.13	219.63	219.63	219.63
7	No. 30	20.76	7.87	gr	118.00	113.50	113.50	113.50
8	No. 50	15.60	5.16	gr	77.40	72.90	72.90	72.90
9	No. 100	10.79	4.80	gr	72.02	67.52	67.52	67.52
10	No. 200	8.43	2.37	gr	35.53	31.03	31.03	31.03
11	PAN	6.06	0.00	gr	126.39	121.89	121.89	121.89
12	PET (100%)	-	-	gr	-	45.00	0.00	22.50
13	PP (0%)	-	-	gr	-	0.00	45.00	22.50
	Total		100.00	gr	1,525	1,525	1,525	1,525
D	Total Weight of Test Piece (A + B + C)			gr	1,600	1,600	1,600	1,600

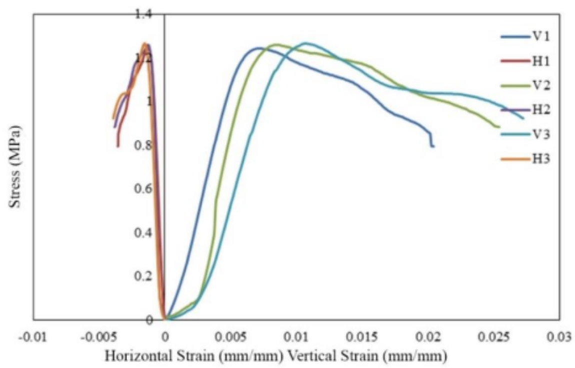

Fig 6. Stress-strain curve of AC-WC mixture without waste plastic

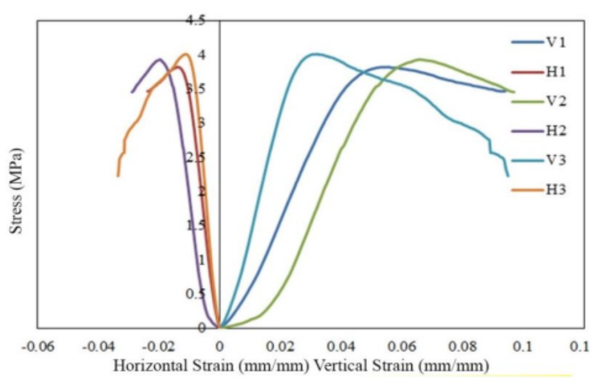

Fig 7. Stress-strain curve of AC-WC mixture with 3% waste plastic (PET: PP = 100: 0%)

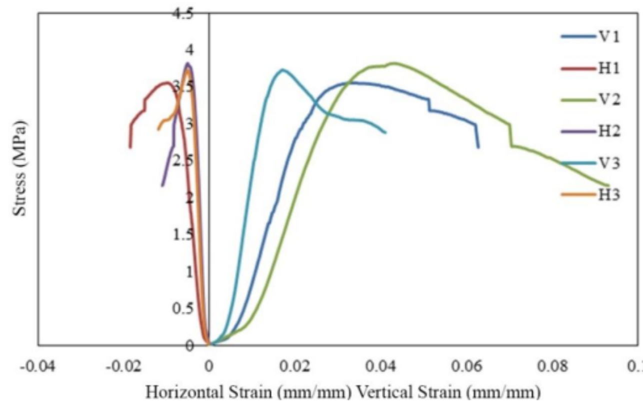

Fig 8. Stress-strain curve of AC-WC mixture with 3% waste plastic (PET: PP = 0:100%)

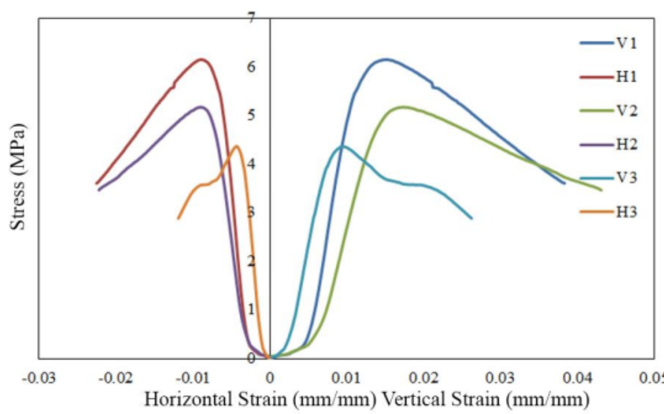

Fig 9. Stress-strain curve of AC-WC mixture with 3% waste plastic (PET: PP = 50%:50%)

However, the high melting point of PET (250°C) while the maximum temperature for hot asphalt mixing occurs at 180°C. The high melting point of PET in this study does not preclude its use as a hot asphalt mixture. A study conducted by Casey et al. (2008) showed that the use of PET, which has a high melting point, is not a problem in the mixing process because the plastic waste which does not melt after passing the mixing temperature will mix with the filler filling the cavities in the asphalt mixture [24].

As previously mentioned, this study used dry mixing, where the addition of PET was carried out in the final mixing process. The reason is to maintain semi-crystalline resin with minimal deformation and its main characteristics. Meanwhile, PP plastic waste that will melt at mixing temperature will cover the aggregate to increase the adhesion of the asphalt and protect the aggregate from temperature and water disturbances.

As shown in Figure 6, Figure 9 AC-WC asphalt mixture containing PET and PP plastic waste and Retona asphalt has sufficient stability with resistance to deformation and enough strength to withstand compressive loads.

3.3 Elastic Modulus, Poisson Ratio, and Toughness Index

The elastic modulus (E), Poisson's ratio, and toughness index values measured at short-term monotonic compression loads are presented in Table 7. The elastic modulus of AC-WC asphalt added with plastic waste was higher than AC-WC asphalt which was not given plastic waste. . The test results conducted show that there is no significant difference in the Poisson ratio and toughness index values for all test objects.

Table 7. Elastic modulus, Poisson's ratio and toughness index of the AC-WC mixture with waste plastic PET and PP

Type asphalt	Type asphalt	σ_{max} (MPa)	Elasticity (MPa)	Poisson ratio	Toughness index
Without waste plastic	0%	1.26	74.985	0.229	2.347
With waste plastic 3%	PET : PP (100: 0%)	3.70	86.047	0.329	2.528
	PET : PP (0: 100%)	3.82	113.074	0.416	2.675
	PET : PP (50: 50%)	5.23	258.674	0.512	3.011

The modulus of elasticity and Poisson's ratio follow the established standards, namely 80% of the maximum load. An important elastic parameter for the response analysis of the pavement system is the Poisson's ratio. The Poisson ratio is the main parameter of inelastic analysis of asphalt mixtures and is used in viscoelastic and elasto-viscosity studies [25]. The stiffness of the asphalt mixture is related to stability and flow value. Asphalt mixtures, mostly AC-WC asphalt, have low stability with high flow values; this makes the mixture stiffer. As previously described, the increased stability is due to the low penetration of Asbuton bitumen [26].

4. CONCLUSION

The compressive strength test results showed an increase in the compressive strength value with the increase in PET and PP plastic waste compared to a mixture that did not use plastic waste. The primary use of PET and PP plastic waste contributes to an increase in the compressive strength of the AC-WC asphalt mixture at a 3% composition with a variation in the weight ratio of PET and PP 50.%: 50%. Besides, an increase in compressive strength can also occur due to the modification of Asphalt Buton type Retona Blend 55, which integrates with PP plastic waste and the reduced cavity in the mixture because it is filled with PET plastic waste. Therefore, PET plastic waste combined with PP plastic waste with a 50: 50% composition can be used as an additive to the AC-WC asphalt mixture.

This study's results contribute to the road construction infrastructure based on the utilization of Indonesia's natural potentials of Buton asphalt and reduce the environmental impact of plastic waste, especially PET and PP plastics, which are expected to create an environmentally friendly environment right development.

5. ACKNOWLEDGMENTS

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