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UTILIZATION OF POLYPROPYLENE TO SUBSTITUTE BITUMEN FOR ASPHALT CONCRETE WEARING COURSE (AC-WC)

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ABSTRACT: In this study, Polypropylene (PP) plastics waste with various concentrations of 0.5%, 0.8%, and 1% were investigated to substitute bitumen's mass. The mixing of plastics and asphalt was conducted by wet method, which added PP plastic into the asphalt when being heated so it produced a homogeneous mixture. Then, AC-WC mixture was made with bitumen contents of 5%, 5.5%, 6%, 6.5%, and 7%. Each mixture was carried out in triplicate for every plastic's concentrations. Five parameters of mixtures were tested by Marshall Method, as follows: VIM, VMA, VFA, stability, and flow. Then, all the parameters were plotted in bar chart to determine an OBC (optimum bitumen content). Changes in rheological properties after the addition of PP plastics occurs which indicates the increasing of viscosity, softening point, flash point, and the decreasing of density, penetration and solubility. Based on Marshall Test, the OBC for asphalt pen 60/70 was 5.4% while the OBC with PP plastic content of 0.5%, 0.8% and 1%, consecutively, were 5.41%, 5.43% and 5.45%. Despite the increasing of OBC, this substitution of bitumen to plastics has some advantages such as increasing stability and remaining strength index (RSI), reducing plastic waste generation and asphalt cost. However, it has disadvantages such as it consumes more energy and it increases gas emission.

Keywords: Asphalt, Bitumen, Polypropylene, Recycling, Plastic waste

1. INTRODUCTION

The development of plastic products in Indonesia had increased rapidly for the last two decades as it is widely used in almost all aspects of human's needs [1]. This occurred as a result of the increasing of humans' needs as the population also grew fast.

The increasing of plastic products will lead to the generation and accumulation of plastic wastes. Indonesia ranks the top two in producing plastic wastes into the ocean [2]. It produces 5.4 million tons of domestic plastic wastes every year or equals to 14% of the total wastes [3]. In Bandung, the composition of plastic wastes reached 10-11% of wet weight for low to middle-income communities [4].

Another impact of the growing population is the increasing of human's mobility and movement. Thus, high qualities of road infrastructures are needed. It can be fulfilled by providing high qualities of bitumen and aggregates to ensure the best mixtures. One method to improve the quality of mixtures is by modifying the asphalt using the plastic wastes. Modifying is aimed not only to strengthen the pavement structures, but also to reuse plastic wastes and to reduce pollution to the environment.

Several studies reported that the addition of polymer into asphalt will increase kinematic viscosity and will decrease penetration value [5], increase ductility [6,7].

2. MATERIALS AND METHODS

2.1 Research Materials

The materials used in this study are *polypropylene* (PP) plastic waste, asphalt pen 60/70 which is produced by Shell, aggregates which are collected from *PT Kadi Internasional*, and cement as filler is collected from *PT Sinar Tambang Arthalestari*. The characteristics of materials are shown in Table 1, Table 2, and Table 3.

2.2 Research Methods

2.2.1 Asphalt Pen 60/70 and PP Plastic Wastes Mixture

Asphalt pen 60/70 and PP plastic waste mixture was made from as much as 1800 grams for the both plastic content of 0.5% and 0.8%, and 2000 grams for the plastic content of 1%. The plastics wastes were re-weighted according to substitution variations, while the asphalt pen 60/70 was heated. Then, the heated asphalt Pen 60/70 was added gradually into the canister which was filled by plastic. Asphalt-plastics mixture was stirred until homogeneous and then, added the remaining of the asphalt Pen 60/70 if necessary.

2.2.2 PP-Modified Asphalt Characterization

PP - modified asphalt was characterized by using a specimen. The sample was weighted approximately 1.200 g. The mold shape is a cylinder with 0.1 m diameter and 0.64 m height. The variations of asphalt contents were respectively 5%, 5.5%, 6%, 6.5% and 7%. The mixture was made by mixing aggregates with the asphalt at a given temperature, then were compacted at a given temperature. Mixing and compaction temperature were determined based on the results of a viscosity test of PP-modified asphalt. The mixture was inserted into a mold, then was compacted as much as 75 times collisions per field (for roads with heavy traffic loads). Once compacted, the specimen was cooled for approximately 2 hours, then was removed from the mold and was allowed to stand for 24 hours at room temperature.

PP-modified asphalt was then characterized by testing penetration, softening point, density, flash point, ductility, viscosity and solubility. Table 4 showed the standard method used in those tests.

Table 1 Aggregate characteristics

No	Parameter	Result
Course Aggregate		
1	Absorption (%)	1.881
2	Bulk density	2.620
	SSD density	2.673
	Apparent density	2.767
	Effective density	2.694
3	Soundness (%)	4.90
4	Abrasion (%)	21.07
5	Angularity	99.97/99.93
6	Spherical and oval (%)	1.00
7	Passing through sieve No.200 (%)	1.85
Fine Aggregate		
1	Absorption (%)	1.253
2	Bulk density	2.535
	SSD density	2.589
	Apparent density	2.678
	Effective density	2.607
3	Sand equivalent test (%)	70.18
4	Angularity (%)	54.70
Filler		
1	Density	3.220
Mix Aggregate		
1	Bulk density	2.615
	SSD density	2.663
	Apparent density	2.745
	Effective density	2.680

Table 2 PP Plastics waste characteristics

Parameter	Standard	Result
Water content	ASTM D 2216-98	0.57%
Dry content	ASTM D 2216-98	99.43%
Volatile content	Gravimetric SNI 01-2891-1991 point 6.1	96.26%
Ash content	Gravimetric SKSNI M-36-1991-103	3.74%
Density	ASTM C 128-93	0.96
Calorific value	Bomb calorimeter	44.23 MJ/Kg
Melting point	-	142℃

Table 3 Asphalt pen 60/70 characteristics

Parameter	Result
Penetration	65.4
Viscosity (cst)	421
Melting point (°C)	49.8
Flash point (°C)	339
Solubility (%)	99.640
Density	1.040
Ductility	100

Table 4 Standard methods for asphalt characterization

No	Parameter	Standards
1	Penetration at 25^0C (0.1mm)	SNI 06-2456-1991
2	Softening point (^{0}C)	SNI 2434-2011
3	Ductility at 25^0C (cm)	SNI 2432-2011
4	Flash point (^{0}C)	SNI 2433-2011
5	Solubility in Trichloroethylene (%wt)	AASHTO T4403
6	Density (g/cc)	SNI 2442-2011
7	Kinematic viscosity 135^0C	SNI 06-6441-2000

SNI is Indonesian National Standards

2.2.3 Optimum Bitument Content (OBC) Determination

Optimum Bitumen Content (OBC) was determined by reviewing the parameter VIM (void in mixture), VMA (void in the mineral aggregate), VFA (voids filled with asphalt), stability and flow. To determine the value of VIM, VMA, and VFA, measuring the dry weight, weight in water and weight at SSD condition (saturated surface- dry) were conducted. To determine the value of stability and flow, the measurement of height for four sides of specimen were conducted. Then, the specimen was immersed for 30 minutes in a water bath at 60^0C. When the specimen changed shape, the reading value of stability and flow was conducted.

3. RESULTS AND DISCUSSION

3.1 Marshall Analysis

3.1.1 PP-modified Asphalt Characteristics

The mixtures of asphalt and PP plastic shows the dcreasing in penetration value, solubility, and density. Based on the result, it is known that penetration value of asphalt pen 60/70 is 65.4, while the penetration value of PP-modified asphalt with plastic content of 0.5%, 0.8% and 1% consecutively are 62, 60, and 59. It can be concluded that the higher plastic content is added, the lower penetration will be or asphalt becomes rougher. The decreasing penetration occurs since the addition of solid phase in asphalt, while the liquid phase was the same, so the asphalt becames stiffer. Penetration value determines the penetration index (PI). PI is a parameter which indicates asphalt sensitivity to temperature so the age when asphalt gets cracked can be evaluated. The closer penetration value to minimum specification, the better asphalt will be since it indicates that asphalt can be used in hot climate and can hold heavy loads of traffic.

Solubility test was conducted to find out the purity level of asphalt. Based on the result, PP plastic wastes addition which consists of 0.5%, 0.8%, and 1% decrease solubility of asphalt from 99.64% to 99.49%, 99.34%, and 99.23% consecutively. The decreasing solubility demonstrates the increasing contents of materials other than asphalt, in this case plastics, thus, it reduces the purity.

Density showed comparison between asphalt weight and water weight towards the same volume at room temperature. The density of asphalt was directly proportional to its quality. Based on the result, it can be concluded that PP plastic addition will decrease asphalt density value. It is because plastic density is lighter than asphalt density. Asphalt pen 60/70 density is 1.04 g/cc while density of PP-modified asphalt with plastic content of 0.5%, 0.8% and 1%, respectively, are 1.038, 1.036, and 1.025 g/cc.

The value of viscosity, softening point, and flash point of the PP-modified asphalt increase. Based on the result, asphalt pen 60/70 viscosity is 421 cst, while PP-modified asphalt viscosity which plastic content 0.5%, 0.8%, and 1% respectively are 462 cst, 473 cst, and 530 cst. It can be concluded that PP addition cause asphalt more viscous. Asphalt and polymer mixing will form multi-phase system, a phase that rich of asphalt which is not absorbed by polymer [8]. It causes increasing of viscosity since it is formed a more complex asphalt structure [9]. The asphalt viscosity is concerned because if it is too high, the asphalt will be too viscous and thus, it is difficult to bind aggregates. *Vice versa*, if the viscosity is too low, the asphalt will be diluted so that the mixture is flaccid and wet. This condition will lead the mixture to be difficult to solidify and can cause instability.

Softening point value is used as reference to know the ability of asphalt to resist the surface temperature. Softening point needs to be higher than surface temperature so asphalt will not melt. Softening point value is inversely proportional to penetration value. The higher softening point, the lower penetration value or asphalt was rougher. This phenomenon suggested that higher concentration of PP plastic wastes in the mixture will cause the asphalt be less sensitive to temperature variation since plastic has high temperature resistance. Therefore, it takes higher temperature for the asphalt to start melting.

Based on the result, it is known that asphalt pen 60/70 softening point is 49.8℃, while PP-modified asphalt softening point with plastic content 0.5%, 0.8%, and 1% respectively are 50.25℃, 51℃, and 51.5℃. The increasing of softening point occurs since plastic has high temperature resistance characteristic. However, softening point value did not comply with the standard specifications. Softening point which do not comply with the standard specifications did not affect the mixture quality as long as it meets the softening point requirements for asphalt pen 60/70. Softening point value for polymer-modified asphalt is set higher than softening point for asphalt pen 60/70 for economical reason. When asphalt is modified using polymer (PP waste), it is more expensive. Therefore, the asphalt is expected to last longer by increasing its softening point.

Flash point is temperature when the flame is passed across the cup. The higher flash point, the better quality of asphalt will be. The high value of flash point do not affect the quality of pavement, but instead, it affects the fire hazard when mixing the asphalt. Based on the result, it is known that asphalt pen 60/70 flash point is 339℃, while PP-modified asphalt flash point with plastic content 0.5%, 0.8%, and 1% respectively are 340℃, 341℃, and 345℃.

Ductility value is the value of asphalt elasticity and asphalt resilience against crack. The low value of ductility shows that the asphalt is more brittle and is easy to crack. Based on the result, the ductility of asphalt pen 60/70 and PP-modified asphalt are more than 100. However, as the maximum scale of instrument is 100 cm, the change of ductility can not be measured.

3.1.2 Optimum Bitumen Content (OBC)

Optimum Bitumen Content (OBC) is asphalt content which will be used as mixture in real field condition. OBC needs to be determined in order to make high durability and economical pavement mixture. Too low asphalt content will reduce its binding power toward aggregates, while too high asphalt content will produce sticky mixture which is difficult to be compacted and have less stability.

The OBC of mixture was determined by Marshall Method by checking several parameters, such as VIM, VMA, VFA, stability, and flow. Marshall test shows the results of minimum and maximum asphalt content which meets specifications of each parameter.

As shown in Figure 1, OBC increases when PP plastic content increases. The higher OBC might not show the higher asphalt content used. In this experiment, PP plastics were used to substitute one part of asphalt mass to reduce the asphalt content. Therefore, there is possibility that the amount of asphalt used is less for higher OBC. Table 5 shows that the asphalt weight used in each mixture. Table 5 also shows that using PP plastic as asphalt substitution would indicate mass reduction of asphalt used. The percentage of asphalt mass reduction with the increase of PP plastic concentration 0.5%, 0.8%, and 1% consecutively are 0.316%, 0.249%, and 0.083%. PP plastic concentration of 0.5% gave the best mass reduction.

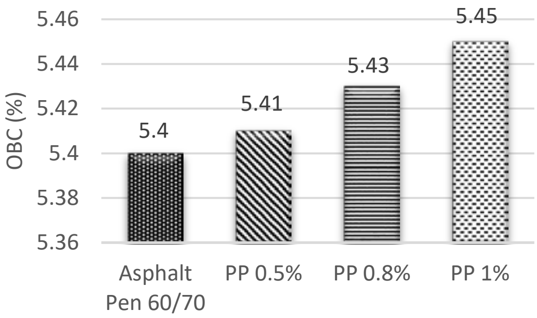

Fig. 1 OBC for each asphalt mixture

3.1.3 Stability and Remaining Strength Index (RSI)

After OBC was determined, the specimens were re-made by using OBC for each asphalt mixture. Then, Marshall immersion test was conducted. The test was conducted to understand the mixture durability under the effects of water and temperature change. The effects of water and temperature was shown by the loss of asphalt and aggregates bond. The mixture durability was expressed by Remaining Strength Index (RSI). RSI was equal to the ratio of the specimen stability after immersion for 24 hours to 30 minutes soaking at 60̊C. The results of stability are reported in Figure 2 and the value of RSI is shown in Figure 3.

Table 5 The amount of asphalt needed for each content of PP plastic

Parameter	Asphalt Pen 60/70	PP 0.5%	PP 0.8%	PP 1%
OBC	0.054	0.0541	0.0543	0.0545
Asphalt mass in mixture (g)	64.8	64.92	65.16	65.4
Plastic mass (g)	0	0.3246	0.52032	0.654
Asphalt mass (g)	64.8	64.5954	64.63	64.746

It could be concluded from the test that the addition of PP plastics will increase stability and tend to increase RSI. This phenomenon occurs as a result of the increasing interlocking between asphalt and aggregates in the mixture and the thickness of asphalt's cover caused by the high OBC which made it is difficult for water to pass through the aggregates. The highest increment was given by 0.1% plastics-modified asphalt, which was 12.93%.

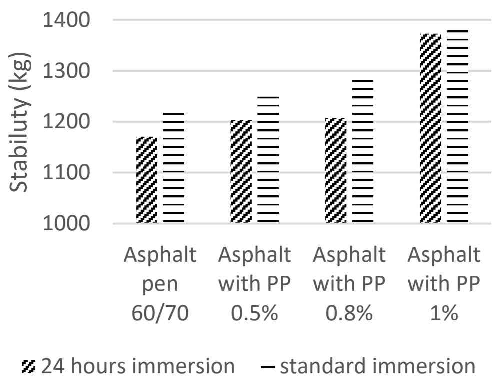

Fig. 2 Stability for each asphalt mixture

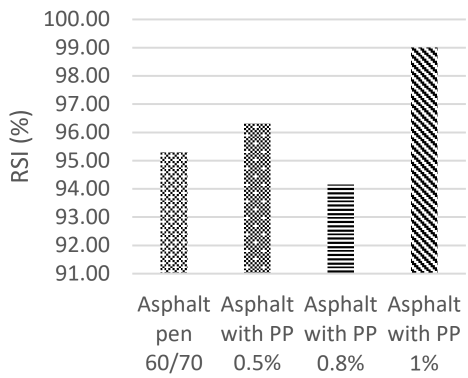

Fig.3 The value of RSI

3.2 Environmental Analysis

3.2.1 Potential use

Potential use of PP plastic wastes as asphalt substitutes were calculated for 10 m length of road. The volume of AC-WC layer was determined by assuming that road thickness was 0.05 m and the width was 3.5 m. Based on the calculation, it was shown that potential use of PP plastic wastes was 23.46 kg/meter for one line of AC-WC layer.

3.2.2 Gas emission

Gas emission from heating asphalt and plastic mixture was also measured, as shown in Table 6. It was reported that the longer the heating, the more gasses would be emitted. The result also showed that CO emission did not meet standard requirement, which was 1801 mg/Nm^3. The high CO emission was from asphalt heating, because according to [10], the melting of *Polyethylene* (PP), *Polypropylene* (PP), and *Polystyrene* (PS) will emit CO and CO_2 at temperature above 700°C.

Table 6 Gas Emission

Para-meter	Result (mg/Nm^3) Asphalt Pen 60/70	Result (mg/Nm^3) Asphalt Modified	Standard (mg/Nm^3)	Note
CO	1.790	1.801	500	Doesn't meet the standard
NO_x	27	36	400	Meet the standard
SO_2	3	3	1.200	Meet the standard

3.2.3 Energy usage

The energy was measured based on the heating time needed, as shown in Table 7. Gas consumed depends on the fire used, which is in this study was 2.9 kW/hour. The longer the heating, the more energy was used.

Table 7 Energy Used

PP content	Heating time (hour)	Energy used (kW)
0.5%	1.033	3
0.8%	1.100	3.19
1%	1.217	3.53

3.2.4 Cost reduction

The economical aspect was reviewed in terms of reducing asphalt-making cost. The calculation was conducted for each PP content by assuming road dimension 100 m x 3.5 m x 0.05 m and specific gravity 2.47. The result showed that cost reduction for PP content 0.5%, 0.8%, and 1%, respectively, were 0.316%, 0.248%, and 0.083%. Thus, asphalt with PP content 0.5% shows the highest cost reduction and the most economical.

4. CONCLUSIONS

The addition of PP plastic concentration of 0.5%, 0.8%, and 1% affect the rheological properties, which increase viscosity, flash point, softening point, and decrease density, penetration and solubility. The change in rheology, especially penetration, increases the value of OBC. The Marshall test demonstrates that the value of OBC of Asphalt Pen 60/70 was 5.4%. The OBC with PP plastic variation of 0.5%, 0.8% and 1%, respectively, were 5.41%, 5.43% and 5.45%. The results indicate that OBC increases with the increases of PP plastics. The increasing OBC does not always show the increasing content of asphalt used. The least amount of asphalt used was when the PP plastic concentration was 0.5%. From technical and environmental aspect, PP plastic content of 1% is the most optimum since it reachs the highest stability and RSI and also indicates more potential use. However, from economical aspect and energy use point of view, PP plastic content of 0.5% is the most optimum since it shows the highest reduction cost while using the least energy.

5. ACKNOWLEDGMENT

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