Research Article

Performance of Recycled Porous Hot Mix Asphalt with Gilsonite Additive

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The objective of the study is to evaluate the performance of porous asphalt using waste recycled concrete material and explore the effect of adding Gilsonite to the mixture. As many as 90 Marshall specimens were prepared with varied asphalt content, percentage of Gilsonite as an additive, and proportioned recycled and virgin coarse aggregate. The test includes permeability capability and Marshall characteristics. The results showed that recycled concrete materials seem to have a potential use as aggregate in the hot mix asphalt, particularly on porous hot mix asphalt. Adding Gilsonite at ranges 8–10% improves the Marshall characteristic of the mix, particularly its stability, without decreasing significantly the permeability capability of the mix. The use of recycled materials tends to increase the asphalt content of the mix at about 1 to 2% higher. With stability reaching 750 kg, the hot mix recycled porous asphalt may be suitable for use in the local roads with medium vehicle load.

1. Introduction

In the recent years, as the Indonesian economy improves, the need for additional infrastructure tends to increase. In most cities, areas which used to be residential ones have been converted into commercials. Many 2- or 3-story buildings mostly built in 1980s have been demolished and rebuilt into 8–12-story buildings, hence leaving a large amount of waste material as by-product of demolition.

In the same time, as the need for infrastructure to support the economic activities increases, many agricultural fields have also been converted into residential areas, hence decreasing the open land area. Consequently, the amount of rain water being infiltrated into underground has also decreased. ICPI [1] has perspicuously illustrated this phenomenon, as shown in Figure 1.

These two phenomena need to be addressed in all aspects of civil infrastructures since in the long run it will affect the human life. As for the transportation infrastructure, the construction of roads should also consider these aspects, as part of the road sustainability. When waste materials are available in the area, they should be utilized as part of the construction materials. However, until recently, only few countries have implemented such concept [2]. Studies

investigating the effect of recycled concrete aggregate (RCA) use on the mechanical properties of asphalt mixtures are limited and governed by the availability of waste concrete in each country and the imposed restrictions in the design specifications and environmental regulations [3]. In addition, most researches that have been conducted on the subject are usually concerned with using recycled aggregate from recycled asphalt pavements not from recycled concrete from building demolition. In other words, extensive researches are still needed to come up to a better performance of hot mix asphalt using waste materials from building demolition [4].

Another potential application for sustainable highway system is the use of the porous pavement system. Porous pavement has been practiced since the 1960s in Europe for the construction of airport runway [5]. About 90% of the construction of new road network in Netherlands has adopted porous pavement [6]. The road rehabilitation policy in Japan is directed toward the use of porous pavement [7]. A study by Collins et al. [8] found that the use of porous pavement reduces peak flow rate of runoff (peak flow rate) from 52% to 81%. In addition, the use of porous pavement has also reduced the volume of tracks that vary from 38% to 78%. Djakfar et al. [9] studied the base course gradation scenario that provides the best performing for use in the road base

FIGURE 1: Effect of built areas on the amount of water infiltration (ICPI, 2009).

material. Raab and Partl [10] and Cerezo et al. [11] studied the use of porous pavement to increase the safety for driver during rainy season by reducing the splashing effect of water.

However, one of the disadvantages of porous asphalt pavement is its performance. Previous research showed that the Marshall stability of porous asphalt specimens usually fell below 500 kg. This is unfortunate since to be able to be used in the arterial or collector road systems, pavement should have Marshall stability at least 750 kg. Therefore, efforts should be pursued to increase the Marshall stability of the porous asphalt so that it can be applied on arterial or collector road systems.

Reviewing the nature of the porous asphalt, in which its strength and performance were influenced by the internal force among coarse material and the bonding contributed by asphalt, increasing the bonding capability of asphalt may improve the performance of the mixture. This can be done by adding additive to the mixture. Previous research by Ameri et al. [12] shows that adding Gilsonite as an additive to asphalt binder increases its viscosity and reduces its penetration. A study by Kök et al. [13] observed that increasing Gilsonite content provokes better rutting performance of modified asphalt binders. Bahia et al. [14] found that Gilsonite can be used as a modifier to improve the performance of asphalt binder and mixture.

Therefore, in this research, the effect of Gilsonite on the performance of porous asphalt using recycled concrete material was investigated to explore whether it contributes to the improvement of the mixture performance.

The objective of the study is to evaluate the performance of porous asphalt using waste recycled concrete material.

2. Material and Methods

Figure 2 presents the steps in doing the research.

2.1. Materials

2.1.1. Asphalt. Asphalt used in this research was AC 60/70. This is the most commonly used asphalt in Indonesia with respect to weather and conditions. Tables 1–3 present the asphalt and the Gilsonite HMA modifier grade characteristics used in the research.

2.1.2. Coarse and Fine Aggregates. Two coarse aggregates are used in the research: common and concrete waste recycled

FIGURE 2: Steps of the research.

TABLE 1: Properties of AC 60/70.

Number	Description	Unit	Specifications*		Test results
			Min	Max	
1	Penetration	mm	60	79	61.778
2	Softening point	°C	48	58	49
3	Ductility	mm	100	—	>1500
4	Flash point	°C	200	—	320
5	Burning point	°C	200	—	346
6	Specific gravity		1	—	1.061

* IDGH Specification (Indonesian Directorate General of Highway).

materials. Tables 4–6 present the characteristics of the coarse and fine materials, respectively.

The common material was acquired from quarry commonly used in East Java, Indonesia, while the concrete waste was acquired from concrete testing by-products.

Before being used, the concrete waste was crushed using crusher to obtain the required gradation.

The fine aggregate was acquired from Lumajang, the largest sand quarry in East Java. As can be seen from the tables, the materials conform to the Indonesia specification, except the specific gravity and the water absorption of the waste materials, which have lower values than the specs.

TABLE 2: Properties of asphalt AC 60/70 mixed with Gilsonite additive.

Number	Properties	Unit	AC 60/70 specifications		Gilsonite additive (%)				
			Min	Max	0	2	4	6	8
1	Penetration	0.1 mm	60	79	62	53.4	45.8	44	41
2	Softening point	°C	48	58	54	56	57	61	65
3	Flash point	°C	100	—	321	336	342	342	342

TABLE 3: Properties of Gilsonite HMA modifier grade [15].

Number	Properties	Values
1	Softening point (ASTM E28-92)	160–185°C
2	Ash (ASTM D-271-70 M)	≤1.0% 2% maximum
3	Moisture (AGC method)	<0.5% 1.0% maximum
4	Penetration (25°C, 100 gm, 5 sec.)	0
5	Flash point (COC)	316°C
6	Nitrogen	3%
7	Sulfur	0.3%
8	Specific gravity	1.06
9	Color in mass	Black

2.2. *Experimental Design.* Once the materials were tested, the next step was to prepare the Marshall specimens. The experimental design for this purpose is presented in Table 7.

90 Marshall specimens were prepared using proportioned coarse aggregate and asphalt content as shown in Table 6. The goal of this step was to obtain the optimum asphalt content and optimum coarse aggregate proportion. The 5 to 9 percent asphalt content range was selected since most asphalt mix design has optimum asphalt content in this range when using local materials. The proportion of regular and recycled coarse aggregate (as shown in Table 6) was selected to cover all the possible outcomes, from 0/100 to 100/0 of common/recycled coarse aggregate proportion. Procedures to obtain the optimum asphalt content followed the Asphalt Institute's [15]. Once the asphalt content was determined, the related Marshall characteristics could be determined.

All Marshall specimens were mixed at 145°C, following the standard procedure, except for those containing Gilsonite HMA modifier, which were heated to about 175°C, to ensure that Gilsonite mixes properly with asphalt. The compaction was conducted at 135°C.

The next step was to determine the optimum Gilsonite additive percentage when added to the mix. This was done by preparing the Marshall specimens using the optimum asphalt content obtained from the previous step and mixed with Gilsonite additive with proportion and number of samples as shown in Table 8. The results of this step should be able to determine the optimum mixture.

2.3. Specimens Tests

2.3.1. *Permeability Test.* A falling head permeability test was conducted to measure the permeability capability of the

mixture. The permeability capability is expressed in terms of permeability coefficient (k), which is calculated as follows:

$$k = 2.3 \frac{aL}{At} \left[\log \left(\frac{h_1}{h_2} \right) \right], \quad (1)$$

in which a is area of the tube (cm^2), L is thickness of the specimen (cm), A is area of the specimen cross section (cm^2), t is time measured to flow water from h_1 to h_2 (s), and h_1 and h_2 are height of water (cm).

2.3.2. *Marshall Test Stage 1.* This test was conducted to determine the Marshall characteristics which includes stability, flow, voids in mineral aggregate (VMA) and void in the mix (VIM), and the optimum asphalt content. The specimens for the test were shown in Table 6. The procedure for performing the test can be found elsewhere [14].

2.3.3. *Marshall Test Stage 2.* This test was conducted to determine the amount of optimum Gilsonite additive. The procedure follows the Marshall procedure as Marshall test stage 1 except that the amount of asphalt in the mix uses the optimum asphalt content obtained from Marshall test stage 1. The specimens for the test were shown in Table 7.

2.4. *Analysis of Test Results.* The last step of the research was to analyze the results of the test and provide plausible analysis of the phenomenon.

3. Results and Discussions

Figures 3–7 present the results of the permeability test and Marshall test stage 1.

Figure 3 shows that the higher the asphalt content the lower the k value. The table also shows that specimens with about 50/50 regular/recycled aggregate proportion tend to have higher k value.

Figures 4–7 were used to obtain the optimum asphalt content. Using the Asphalt Institute procedure (AI, 2009), the asphalt optimum for each coarse aggregate proportion can be determined. From the analysis, it was determined that the optimum asphalt content was 7% for 100/0, 80/20, and 0/100 regular/recycled aggregate proportion, 7.5% for 40/60 and 20/80 proportion, and 8.5% for 60/40 proportion. Based on the optimum asphalt content, the estimated Marshall characteristics of the mix at the optimum asphalt content can then be determined. Table 9 presents the summary of the optimum asphalt content for each coarse aggregate proportion and their corresponding Marshall characteristics.

TABLE 4: Properties of regular coarse aggregate.

Number	Properties	Unit	Specifications*		Test results	Notes
			Min	Max		
1	Specific gravity	—	2.5	—	2.642	OK
2	SSD specific gravity	—	—	—	2.690	OK
3	Specific gravity	—	—	—	2.776	OK
4	Water absorption	%	—	3	1.818	OK
5	Los Angeles	%	—	40	12.748	OK
6	Impact value	%	—	30	12.186	OK

*IDGH Specification (Indonesian Directorate General of Highway).

TABLE 5: Properties of concrete waste aggregate.

Number	Properties	Unit	Specifications*		Test results	Notes
			Min	Max		
1	Specific gravity	—	2.5	—	2.45	Not OK
2	SSD specific gravity	—	—	—	2.56	OK
3	Specific gravity	—	—	—	2.74	OK
4	Water absorption	%	—	3	4.8	Not OK
5	Los Angeles	%	—	40	27.36	OK
6	Impact value	%	—	30	20.42	OK

*IDGH Specification (Indonesian Directorate General of Highway).

TABLE 6: Properties of fine aggregates.

Number	Properties	Unit	Specifications*		Test results	Notes
			Min	Max		
1	Specific gravity	—	2.5	—	2.733	OK
2	SSD specific gravity	—	2.5	—	2.770	OK
3	Specific gravity	—	—	—	2.839	OK
4	Water absorption	%	—	3	1.359	OK

*IDGH Specification (Indonesian Directorate General of Highway).

TABLE 7: Proportion of the aggregate, asphalt content, and number of samples.

Common and recycled materials proportion (%)	5	Asphalt content (%)				9
		6	7	8	9	
		Number of samples				
100/0	3	3	3	3	3	
80/20	3	3	3	3	3	
60/40	3	3	3	3	3	
40/60	3	3	3	3	3	
20/80	3	3	3	3	3	
0/100	3	3	3	3	3	

As can be seen from Table 9, the optimum asphalt content at any coarse aggregate proportion ranges from 7% to 8.5%. These values are a bit higher when compared to commonly optimum asphalt content when using the regular coarse aggregate, which typically ranges from 5.25 to 6.5%. That may be due to the effect of the recycled materials in the mix.

TABLE 8: Design of experiment to obtain optimum Gilsonite content.

% Gilsonite additive	Number of samples
7%	3
8%	3
9%	3
10%	3

Another point that can be explained from the table is that none of the mixes meets the VIM requirement. As the Australian standard requires that the VIM should be in the range of 18 to 25%, all mixes fall below the range. The plausible explanation on this phenomenon is that higher asphalt content in the mix fills void, causing reduced void area.

Table 9 also shows that stability increases as the proportion of recycled aggregate increases. That brings to an early conclusion that recycled material has positive effect on increasing mix stability. In addition, higher recycled material proportion decreases the asphalt content as well. This is due to the fact that recycled materials have less pores compared with

TABLE 9: Summary of optimum asphalt content and its Marshall characteristics.

Marshall characteristics	Coarse aggregate proportion						Australian specifications
	100/0	80/20	60/40	40/60	20/80	0/100	
	Optimum asphalt content						
	7%	7%	8.5%	7.5%	7.5%	7%	
VIM	13.0	12.9	12.3	12.4	13.2	15.6	18%–25%
Stability	342.3	454.5	520.6	528.3	559.3	560.9	>500 kg
Flow	3.1	3.4	3.5	3.8	3.9	4.2	2–6 mm
MQ	113.3	130.1	149.4	136.4	145.3	137.3	<400 kg/mm

TABLE 10: Marshall characteristics at different percentage of Gilsonite additive.

Asphalt content	% recycled materials	% Gilsonite additive	VIM	Stability	Flow	MQ
7.5%	100%	7%	20.0	653	5	131
			21.0	707	5.5	129
			21.6	623	4.5	138
			22.3	718	5.5	130
			21.5	675	5.8	116
		8%	19.8	621	5.8	107
			20.6	868	5.4	161
			21.9	771	5.5	140
			21.0	825	4.2	196
			20.3	707	5.6	126
		10%	20.3	743	5.6	133
			21.8	686	5	137

FIGURE 3: Permeability coefficient (k) at each asphalt content and coarse aggregate proportion.

the natural materials. When one looks to the stability value, except at the 100/0 and 80/20 proportions, all mixes conform to the specification of the porous asphalt mix. However, when referred to regular hot mix asphalt specification, which requires that the minimum stability of a mix should be 800 kg, the stability value in Table 9 is a bit low. In other words, the mix may not be suitable to be implemented in the arterial or collector road system.

In order to increase the stability, one may need to add some additives, as previous researches have shown. This was

FIGURE 4: Marshall stability of specimens (kg) at each asphalt content and coarse aggregate proportion.

accomplished by the Marshall test stage 2 as explained above. Using Table 7 as the experimental design, the tests were conducted to the specimens and the results are shown in Tables 10 and 11.

An analysis of variance was performed to the data to determine the effect of adding Gilsonite to each Marshall characteristic. The summary of the analysis is presented in Table 12.

As can be seen from Table 12, Gilsonite additive affects the Marshall characteristics and permeability capability of the mix, except for the VIM. That means that Gilsonite did not significantly affect the existence of void in the mix; even at

FIGURE 5: Marshall flow of specimens (mm) at each asphalt content and coarse aggregate proportion.

FIGURE 6: Marshall VIM of specimens (%) at each asphalt content and coarse aggregate proportion.

TABLE 11: Results of permeability test on specimens with Gilsonite additive.

Asphalt content	% recycled concrete	% Gilsonite	Permeability coefficient
7.5%	100%	7%	0.41
			0.35
			0.36
		8%	0.40
			0.42
			0.44
		9%	0.31
			0.34
			0.34
		10%	0.31
			0.36
			0.30

some point this gives an advantage for the mix, since adding Gilsonite increases the performance of the mix.

Using the standard procedure for Marshall analysis, it was found that the optimum Gilsonite content was 9%. Furthermore, the related Marshall characteristic is presented

FIGURE 7: Marshall VMA of specimens (%) at each asphalt content and coarse aggregate proportion.

TABLE 12: Summary of effect of Gilsonite additive on the Marshall characteristics and permeability capability.

Marshall characteristics	Gilsonite effect	
	<i>p</i> value	Remarks
VIM	0.937	Not significant
Stability	0.007	Significant
Flow	0.007	Significant
MQ	0.032	Significant

TABLE 13: Effect of Gilsonite additive on Marshall characteristic.

Marshall characteristics	Test results at 9% Gilsonite	Specifications	Remarks
VIM	21.2	18%–25%	OK
Stability	761	>500 kg	OK
Flow	5.4	2–6 mm	OK
MQ	144	<400 kg/mm	OK
Permeability	0.327 cm/sec	0.2–0.5 cm/sec	OK

in Table 13. It shows that adding Gilsonite gives positive effect to the mix since all mix requirements were met by doing that.

4. Conclusion

Based on the above discussions, the following conclusions can be drawn:

- (1) Recycled concrete materials seem to have a potent to be used as aggregate in the hot mix asphalt, particularly on porous hot mix asphalt.
- (2) Adding Gilsonite additive at ranges 8–10% improves the Marshall characteristic of the mix, particularly its stability, without decreasing the permeability capability of the mix.
- (3) The use of recycled materials tends to increase the asphalt content of the mix, from the range 5–6% to 7–8%.
- (4) With stability reaching 750 kg, the hot mix recycled porous asphalt may be suitable for use in the local roads with medium vehicle load.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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