Jordan Journal of Civil Engineering, Volume **13**, No. **1**, **2019**

Resistance to Degradation of Porous Asphalt Mixture Using Pine Resin As Asphalt Modifier

Ratna Yuniarti

Department of Civil Engineering, Faculty of Engineering, Mataram University,
Jl. Majapahit 62 Mataram 83125 Lombok, Indonesia.
E-Mail: ratna_yuniarti@unram.ac.id

ABSTRACT

Porous asphalt is an open graded mixture characterized by a very high air void content to provide high permeability in order to prevent aquaplaning. However, due to their high porosity, aggregates can be stripped easily from asphalt mixes. Applying asphalt modifier is expected to overcome this problem by increasing the binding of aggregate particles. This study aims to evaluate the resistance to degradation of porous asphalt mixture using crude pine resin from pine tree (*Pinus merkusii*) and gum rosin as modifier. In this study, specimens were prepared with different percentages of crude pine resin and asphalt content. The durability of porous asphalt mixture was assessed by Cantabro abrasion test on unaged and aged specimens. The susceptibility of the mixture to withstand disintegration against permanent contact with water is also included. It was found that the use of 2%-4% pine resin by weight of asphalt binder in porous asphalt mixture provides a better resistance to degradation after a heating period of 7 days at 60°C compared to the mixture containing asphalt 60/70. Results from this study show that the specimen formulated with 3% pine resin was the most effective one at increasing resistance to water damage. Therefore, pine resin as asphalt modifier has a great potential to improve the lifetime of porous asphalt mixture.

KEYWORDS: Pine resin, Asphalt modifier, Open graded mixture, Degradation, Water damage, Cantabro abrasion test.

INTRODUCTION

Porous asphalt is an open graded mixture predominantly made up of coarse aggregates, which allows water to drain quickly through its porous structure. Due to a very high void content, the mix is able to prevent aquaplaning during rainy days (Aman et al., 2014a). However, a high percentage of air void content provided in porous asphalt can cause the mixture to have stripping problems due to the movement of air and water. Moisture weakens the bond between asphalt and aggregate, leading to rapid aging of the binder and consequently to enhanced premature deterioration of asphalt pavement (Aman et al., 2014b).

Modifiers are believed to increase the lifetime of porous asphalt by increasing the cohesion and adhesion in the asphalt mixes. By applying such modifiers, the binder film thickness also can be increased without the risk of segregation of the binder (Nielsen, 2006). In addition, Potgieter et al. (2002) stated that aromatic oils as part of the modified binder make bitumen rubber binders ideally suited for use in porous asphalt mixes.

In recent years, there has been an increase of environmental awareness in issues related to the use of sustainable binder. Saving natural resources is one of the

Received on 18/7/2018.
Accepted for Publication on 21/10/2018.

main reasons for using this kind of binder as has been mentioned in a number of publications. Bio-binder, soybean oil, palm oil and vegetable oil are among common alternative binders. According to Huang et al. (2012), most of these alternative binders are of chemical compositions (hydrocarbons, aromatics, saturates, asphaltenes,… etc.) somewhat similar to those of conventional asphalt binders.

Bailey and Phillips (2010) in the UK patent application GB 2462322 stated that sesame oil, sunflower oil, soybean oil, corn oil, palm oil and peanut oil are suitable for the rejuvenating of asphalt. In addition, Laurens et al. (2011) disclosed that the binder composition comprises a resin of vegetable origin, an oil of vegetable origin and a polymer, while the polymer comprises functional groups chosen from carboxylic acid anhydride, carboxylic acid and epoxide groups. According to Nigen-Chaidron et al. (2010) in United States patent number 7,811,372 B2, rejuvenating agent comprising 10-90% weight palm oil and 90-10% weight asphalt is suitable for use in place and hot in plant recycling processes. Moreover, Caro et al. (2016) conducted research to examine the effects of adding biomodifiers produced by solvolysis from three different agroindustrial waste materials (sugarcane bagasse, corncobs and rice husk) on the adhesive-bond properties with aggregates in asphalt mixtures. This observation concluded that the use of biomodifiers showed positive results in terms of their rheological properties. However, moisture damage should be carefully evaluated in asphalt mixtures fabricated with these materials.

Yuniarti (2012a) stated that the properties of old asphalt can be restored by using oil extracted from oil nut tree (*Calophyllum inophyllum* L.) as rejuvenating agent in asphalt pavement recycling. In addition, *Calophyllum inophyllum* L.oil as part of bio-flux oil can improve the performance of hot mix asphalt containing granular asphalt (locally named as *asbuton*) from Buton island in Indonesia (Yuniarti, 2012b). Yuniarti (2015a) concluded that the application of bio-flux oil consisting of crude pine resin and other ingredients in a certain composition as modifier of *asbuton* has fulfilled the Indonesian specification of asphalt concrete-wearing course (AC-WC). Moreover, Yuniarti (2015b) concluded that 5% of crude pine resin and 2% of organic oils could be blended with asphalt of penetration grade 60/70 to produce bio-asphalt. Until recently, there has been no research conducted that studied the applicability of using bio-oils as 100% replacement of bitumen to be used in paving industry (Peralta, 2012).

From the description above, it can be seen that sustainable modifier is suitable to overcome some of the problems that were encountered with asphalt mixtures. Based on previous research, the aim of this study is to evaluate the resistance to degradation of porous asphalt mixture using crude pine resin from pine tree (*Pinus merkusii*) and gum rosin as asphalt modifier. Gum rosin is a solid form of resin obtained from pine trees, produced by heating fresh liquid resin to vaporize the volatile liquid terpene components. Crude pine resin is chosen because of its viscoelastic properties. Similar to asphalt, it becomes harder (more viscous) as temperature decreases and softer (less viscous) as temperature increases. In addition, pine resin was traditionally used to protect and preserve boats. Due to its waterproof characteristics, the potential of pine resin to make porous asphalt resistant to damages caused by moisture is promising.

MATERIALS AND METHODS

Materials

Coarse aggregate and fine aggregate were obtained from an asphalt mixing plant in Pringgabaya, East Lombok, Indonesia. Mineral filler used in this study is fly ash, which was supplied from a coal-fired power plant in West Lombok. The aggregates were washed, dried and sieved into a typical centre line target grading for open graded wearing course according to the Australian Provisional Guide as shown in Table 1. Aggregate impact value was measured according to BS 812, whereas specific gravity of coarse and fine aggregates was determined according to AASHTO T

85-88 and AASHTO T 84-88. The test of affinity to asphalt was conducted according to AASHTO T-182 and Indonesian National Standard SNI 03-2439-1991. Aggregate physical properties are shown in Table 2.

As shown in Table 2, aggregate impact value of 8.43% indicates that the aggregate is strong enough to withstand loads due to impact. In this study, affinity to asphalt of 100% indicates that surface area of aggregate can be well coated. Furthermore, bulk and apparent specific gravity of aggregates can be used to determine their compactibility. Since the results have qualified the specification, these aggregates have good compaction properties.

Table 1. Aggregate gradation

Sieve size (mm)	Percent passing	Production tolerance
13.2	100	± 6
9.5	90	± 6
6.7	40	± 6
4.75	20	± 5
2.36	12	± 5
1.18	8	± 5
0.6	6	± 5
0.3	5	± 3
0.15	4	± 3
0.075	3.5	± 1

Source: Austroads Technical Report, 2002.

Table 2. Properties of aggregates

Laboratory test	Testing method	Results		
		Coarse aggregate	Fine aggregate	Filler
Aggregate impact value (%)	BS 812	8.43	-	-
Bulk specific gravity Apparent specific gravity	AASHTO T 85-88 AASHTO T 84-88	2.645 2.771	2.64 2.84	2.69 2.72
Affinity to asphalt (%)	SNI 03-2439-1991 AASHTO T 182-84	100	-	-

Pine-asphalt used in this study consisted of crude pine resin and gum rosin which were blended with asphalt of penetration grade 60/70; namely, pine-asphalt A, pine-asphalt B, pine-asphalt C and pine-asphalt D. Pine-asphalt A, B, C and D consisted of 2%, 3%, 4% and 5% crude pine resin by weight of asphalt binder, respectively and 4% of gum rosin was applied for all the mixtures of pine-asphalt.

The properties of crude pine resin and asphalt cement of penetration grade 60/70 are presented in Tables 3 and Table 4. According to Table 4, the properties of asphalt cement of penetration grade 60/70 have satisfied the specification.

Coarse aggregate (percent of aggregate retained on 4.75 mm sieve), fine aggregate (percent aggregate passing 4.75 mm sieve and retained on 0.075 mm sieve) and filler (percent of aggregate passing 0.075 mm sieve) were used in this study based on Table 1; namely, with percentages of 80%, 16.5% and 3.5%, respectively. Three asphalt contents were applied for each type of asphalt mixture; namely, 4.5%, 5% and 5.5%. Aggregate and pine-asphalt were mixed at a temperature of 160ºC and compaction of 50 cycles of gyratory compactor was applied. The specimens were then left to cool down for 24 hours at ambient temperature.

Table 3. Properties of pine resin from *Pinus merkusii*

Laboratory test	Testing method	Results
Specific gravity	SNI 06-2441-1991 / AASHTO T 228-90	1.04
Viscosity, 60ºC, (cSt)	SNI 06-6721-2002 / AASHTO T 72-90	349.08
Loss on heating, 5 hours, 163ºC, (%)	SNI 06 2440-1991 / AASHTO T 179-88	16.98
Solubility in CCl_4	Gravimetry	94.1
Chemical properties:		
Carbon (%)	Spectrometry	80.15
Nitrogen (%)	Kjeldahl	0.03
Sulfur (%)	Spectrometry	0.14

Source: Yuniarti (2015)

Table 4. Properties of asphalt of penetration grade 60/70

Laboratory test	Testing method	Results	Specification*
Penetration, 25ºC, 5 sec. (0.1 mm)	SNI 06-2456-2011 AASHTO T 49	66	60-79
Softening point (ºC)	SNI 06-2434-2011 AASHTO T 53	48	minimum 48
Ductility (cm)	SNI 06-2432-2011 AASHTO T 51	131	minimum 100
Flash point (ºC)	SNI 06-2433-2011 AASHTO T 48-89	298	minimum 200
Specific gravity	SNI 06-2441-2011 AASHTO T 228-90	1.05	minimum 1.0
Loss on heating, 5 hours, 163ºC (%)	SNI 06-2440-1991 AASHTO T 179-88	0.64	maximum 0.8

* Department of Public Work (2003).

Laboratory Tests Procedure

Cantabro Abrasion Test

The purpose of Cantabro test is to evaluate cohesion, bonding properties between aggregate and bitumen for porous asphalt and its sustainability towards traffic abrasion. This test was conducted using Los Angeles abrasion machine with the number of revolutions fixed to 300 at 30 revolutions per minute without charge of steel balls according to ASTM D7064 as stated by Mallick et al. (2000). This test can be carried out on unaged and aged specimens. Aging was accomplished by placing Marshall specimens in a forced draft oven set at 60°C for 168 hours (7 days). The specimens were then cooled to 25°C and stored for 4 hours prior to Cantabro abrasion test. Meanwhile, the susceptibility of the mixtures to withstand disintegration against permanent contact with water was measured after immersion in water at 60°C for 24 hours. The result of Cantabro test was expressed as percentage of the weight loss relative to the initial weight based on Equation (1).

$$CL = 100 \left(\frac{P_1 - P_2}{P_1}\right) \quad ......\ldots\ldots\ldots\ldots\ (1)$$

where:
CL = Cantabro loss.
P1 = initial specimen weight.
P2 = final specimen weight.

Air Voids

Since the primary function of porous asphalt mixture is to drain surface water through the pavement structure, it needs to provide adequate air void structure for satisfactory water drainage. The air voids in the compacted specimens were calculated using Equation (2), derived from ASTM 3203 procedure as described by Aman et al. (2014c).

$$Va = 100 \left(1 - \frac{G_{mb}}{G_{mm}}\right) \quad \ldots\ldots\ldots\ldots...... (2)$$

where:
Va = air voids.
G_{mb} = bulk specific gravity of the compacted specimen.
G_{mm} = theoretical maximum density.

The results of each test were determined by calculating the average of three specimens.

RESULTS AND DISCUSSION

The properties of pine-asphalts are presented in Table 5. Accordingly, the less the amount of crude pine resin, the higher the stiffness of pine-asphalts. As stated earlier, pine-asphalt A, B, C and D consisted of 2%, 3%, 4% and 5% crude pine resin, respectively. The more the amount of crude pine resin, the lower the temperature of softening point. As can be seen in Table 3, viscosity of crude pine resin at 60°C is 349.08 cSt. According to Perhutani (2007), softening point of gum rosin is in the range of 78ºC-82ºC. Due to low viscosity of crude pine resin, it is needed to apply gum rosin to increase the stiffness of pine-asphalt.

Table 5. Properties of pine-asphalt

Laboratory test	Testing method		Results		
		Pine-asphalt A	Pine-asphalt B	Pine-asphalt C	Pine-asphalt D
Penetration, 25ºC, 5 sec. (0.1 mm)	SNI 06-2456-1991 AASHTO T 49	47.4	49.2	51.6	56.2
Softening point (ºC)	SNI 06-2434-1991 AASHTO T 53	54	52	51	50
Ductility (cm)	SNI 06-2432-1991 AASHTO T 51	142	145	153	155
Flash point (ºC)	SNI 06-2433-1991 AASHTO T 48-89	250	222	220	219
Specific gravity	SNI 06-2441-1991 AASHTO T 228-90	1.04	1.04	1.04	1.04
Loss on heating, 5 hours, 163ºC (%)	SNI 06-2440-1991 AASHTO T 179-88	0.09	0.17	0.24	0.32

Ductility of pine-asphalts tends to increase due to increasing percentage of crude pine resin, as shown in Table 5. It can be said that pine-asphalts are likely more adhesive than asphalt 60/70. However, flash point of pine-asphalt is lower than that of asphalt 60/70 and its specific gravity remains constant.

The loss on heating as measured by the volatility of the asphalts can be predicted by the hardening of asphalt during mixing and service life of pavement. As shown in Table 5, the loss on heating tends to increase in pine-asphalts containing higher crude pine resin. This is because pine resin is much more volatile than asphalt 60/70. According to Table 3, the loss on heating of pine resin is 16.98%, whereas the loss on heating of asphalt 60/70 is 0.64%.

The impact of different pine-asphalt combinations on the mixture resistance to degradation was evaluated using Cantabro test and is presented in Fig. 1. The result demonstrates that the abrasion loss generally increases following the increase percentage of the pine-resin for the sample made with 4.5% asphalt content. It can also be seen that the value of Cantabro loss tends to decrease as the content of asphalt in the mixture increases. This is because high amount of asphalt content improves the thickness of asphalt film. Thick asphalt film provides good durability due to sealing the pavement better than thin film asphalt and hence improves the resistance to degradation. Nevertheless, mixtures containing pine-asphalt B and C appear to give a better result compared to control mix (0% pine-resin) as shown by samples made with 5% and 5.5% asphalt contents. For the sample made with 5% asphalt content, the best resistance of abrasion is achieved by pine-resin content of 3% (pine-asphalt B). The corresponding resistance loss of samples made by 5.5% asphalt content was 10.28%, 12.53%, 9.65%, 8.98% and 10.99% for pine-resin content 0%, 2%, 3%, 4% and 5%, respectively. From these results, it is shown that incorporating pine resin in porous mixes improves the resistance to abrasion. Low amount of this modifier is needed to increase the resistance compared to control mix.

Fig. 2 shows the relation between voids in the mix and asphalt content. From this figure, it can be seen that for all of the mixtures, the value of VIM tends to decrease as increasing the content of asphalt. This is because the higher the asphalt content, the more voids are filled by asphalt. The value of VIM in the mixtures containing pine-asphalt is smaller than the value of VIM in the mixture containing asphalt 60/70. It is indicated that pine asphalt exhibits a stronger binding of aggregate particles. As a result, the mixture containing pine-asphalt becomes more dense and VIM value decreases. Voids in the mix also showed a direct relation with the Cantabro loss as presented in Fig. 3. The reduced Cantabro loss can be associated with higher work of adhesion between aggregate and asphalt in the mixtures which contain larger quantity of asphalt.

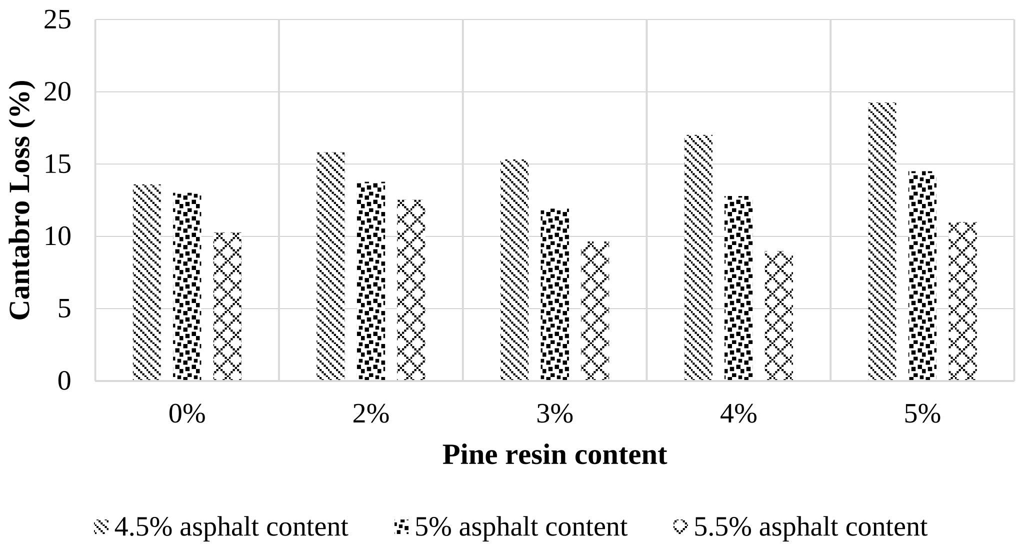

Figure (1): Cantabro loss *versus* pine-resin content

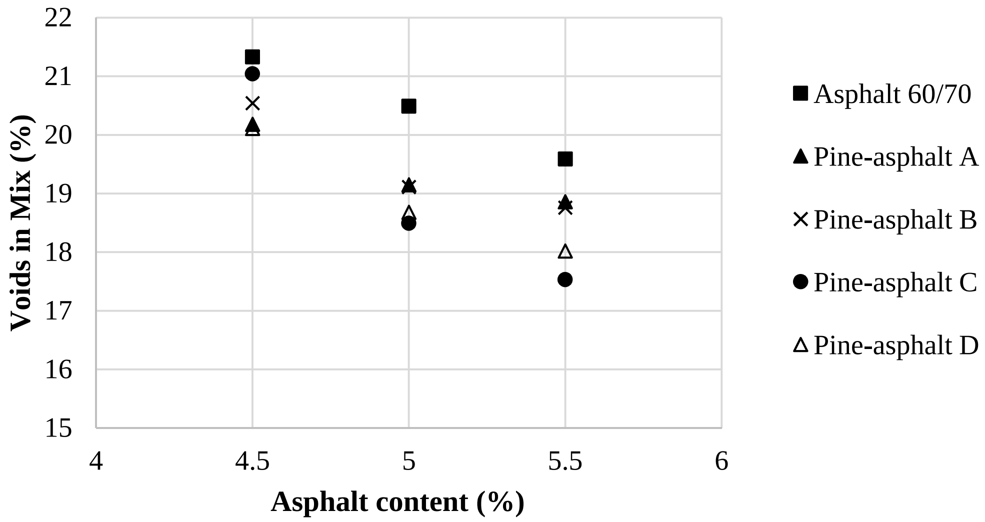

Figure (2): Voids in mix *versus* asphalt content

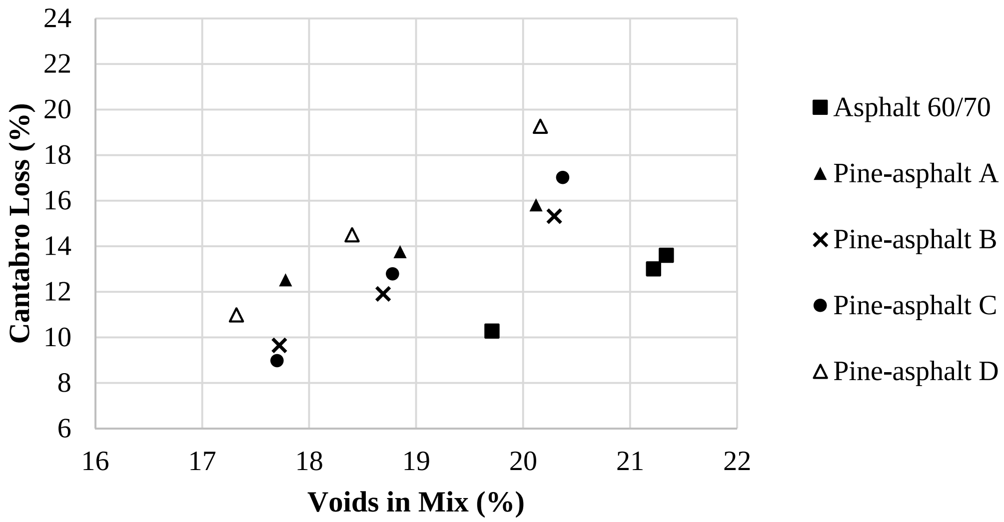

Figure (3): Voids in mix *versus* Cantabro loss

According to the National Asphalt Pavement Association (NAPA, 2002), the optimum asphalt content for porous asphalt can be determined by asphalt content that meets air voids greater than 18%. In addition, Australian standard of porous asphalt recommends that the provisional asphalt content of the porous asphalt mix used determined from the Cantabro test results must fulfil an abrasion requirement less than 20% (Austroads Technical Report, 2002). Based on these requirements, for the mixture containing asphalt 60/70, optimum asphalt content of 5.0% was chosen. Meanwhile, for the mixture containing pine-asphalt A, B, C and D, the optimum asphalt contents are 4.9%, 5.0%, 5.0% and 5.1%, respectively.

Moreover, the value of abrasion loss at the optimum asphalt content is presented in Fig. 4. The results of the age Cantabro test and immersion Cantabro test are presented in Fig. 5 and Fig. 6.

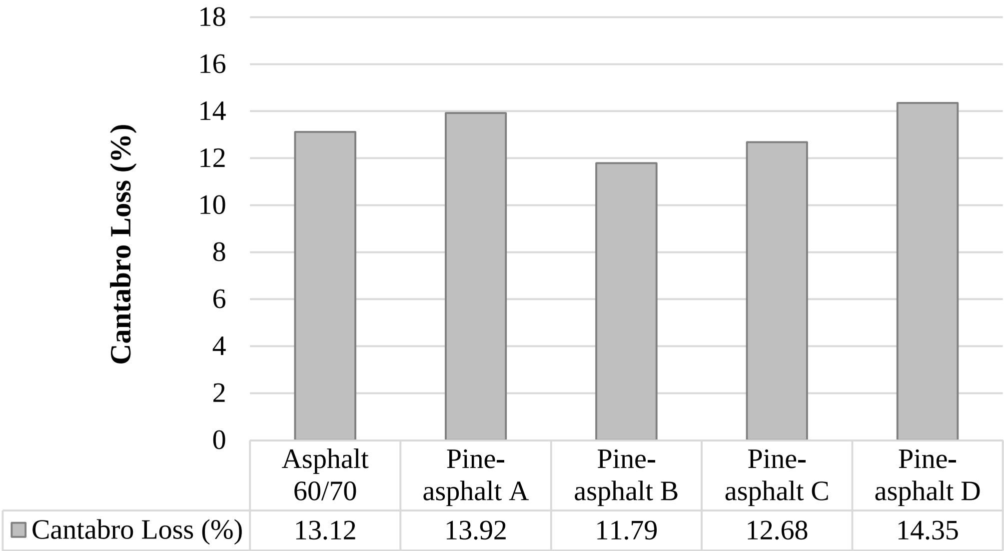

Figure (4): Cantabro loss at optimum asphalt content

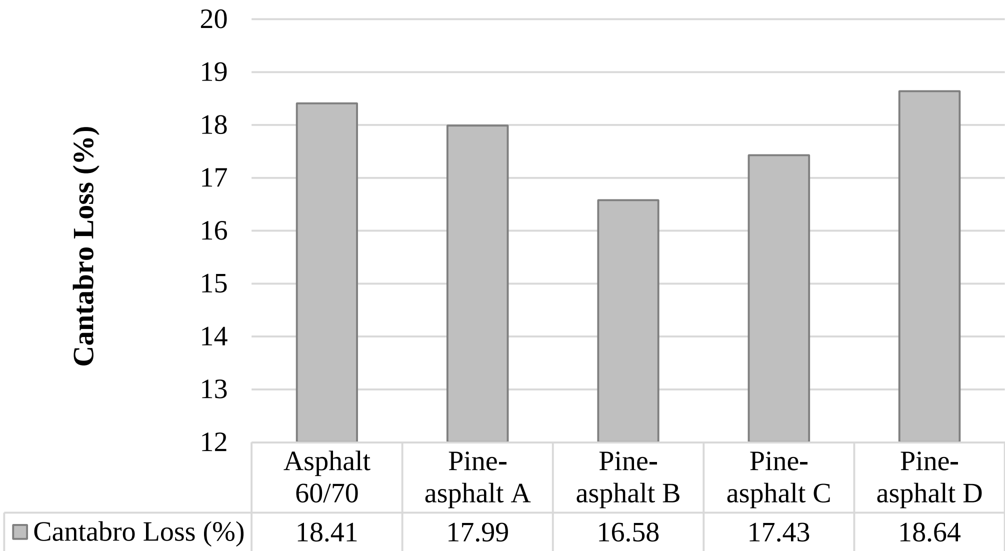

Figure (5): Age Cantabro loss at optimum asphalt content

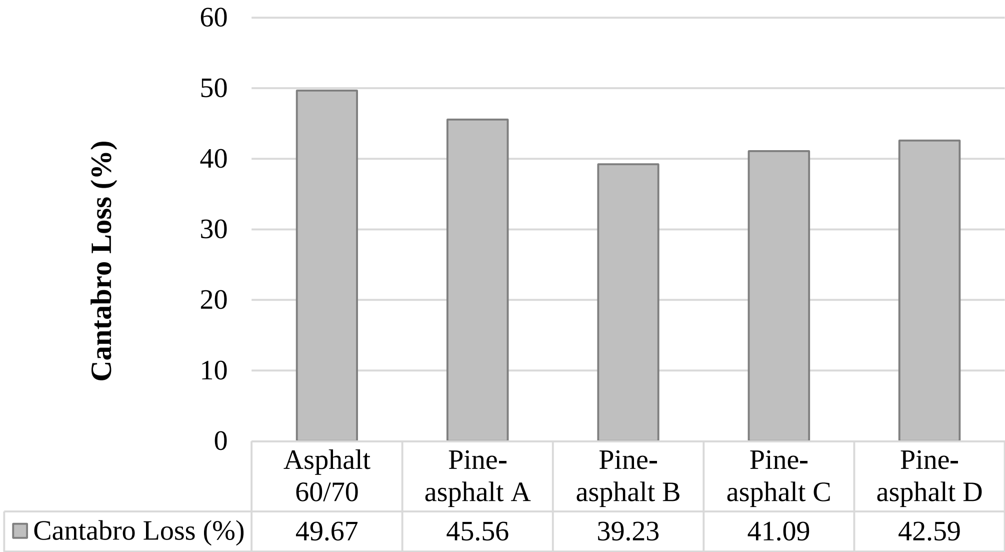

Figure (6): Immersion Cantabro loss at optimum asphalt content

Based on Fig.4, the abrasion loss obtained is between 11.79% and 14.35% and the mixtures containing pine-asphalt B and C exhibit better resistance to abrasion loss compared to the mixture incorporating asphalt 60/70. As stated by Kandhal and Mallick (1999), the abrasion loss of porous mixes should not exceed 20% of unaged specimens. Although the mixture containing asphalt 60/70 has satisfied this requirement, the use of pine-resin in asphalt binder in certain percentages is necessary to improve the performance of the mixtures.

The results of the age Cantabro loss test at the optimum asphalt content are presented in Fig. 5. From this figure, it can be seen that the resistance to disintegration of the mixture containing asphalt 60/70 is 18.41%. The use of pine resin as modifier of asphalt 60/70 between 2%-4% provides a better resistance to disintegration after a heating period of 7 days at 60°C. However, the particle loss resistance of mixture containing 5% pine resin (pine-asphalt D) is decreased when compared to unmodified specimen or control asphalt binder. Further, the value of the age Cantabro loss should not be more than 30%. Although this value has been fulfilled by all the specimens, the optimum content of pine-resin is 3% by weight of asphalt binder to obtain the best abrasion loss resistance.

The susceptibility of the mixture to withstand disintegration against permanent contact with water is measured after immersion in water at 60°C for 24 hours. The abrasion loss in the Cantabro test of the specimens after being subjected to this test should not exceed 40%. As shown in Fig. 6, the best performance is obtained in the mixture containing pine-asphalt B. Meanwhile, the mixture containing asphalt 60/70 is considered to be the worst among all the mixtures. This effect can probably be due to the use of pine-resin in an appropriate dosage, which improves the bond between bitumen and aggregate particles. As stated earlier, pine resin has been used to protect and preserve boats. This indicates that pine resin is an excellent material as glue and waterproofing. From Fig. 6, it can be seen that porous asphalt mixtures containing pine-asphalt exhibit better resistance to water damage compared to the mixture containing asphalt 60/70. Therefore, the use of pine resin as modifier of asphalt cement is recommended to enhance the performance of porous asphalt concrete.

CONCLUSIONS

Based on the results, the following conclusions are drawn:

- Pine-asphalt used in this study consisted of crude pine resin from pine tree (*Pinus merkusii*) and gum rosin which were blended with asphalt of penetration grade 60/70 with a value of penetration in the range of 47.4-56.2 (0.1 mm), a softening point between 50 and 54^{o}C, a ductility in the range of 142-155 cm, a flash point between 219 and 250^{o}C and loss on heating in the range of 0.09-0.32%.
- The use of pine resin between 2% and 4% by weight of asphalt binder in porous asphalt mixtures provides a better resistance to degradation after a heating period of 7 days at 60°C.
- The porous asphalt mixture containing pine-asphalt exhibits better resistance to water damage compared to the mixture containing asphalt 60/70.

ACKNOWLEDGMENT

The author gratefully acknowledges the support provided by Laboratory of Highway and Transportation Engineering, Faculty of Engineering, Mataram University, Indonesia. Thanks are also due to undergraduate students in the Department of Civil Engineering for preparing the samples for testing.

REFERENCES

Aman, M.Y., and Hamzah, M.O. (2014a). “Effects of anti-stripping additives on moisture sensitivity of warm porous asphalt mixtures”. International Journal of Construction Technology and Management, 1 (1), 10-16.

Aman, M.Y., Shahadan, Z., Radhwa, S., and Zawani, Z.E. (2014b). “Effects of anti-stripping agents in warm-mix asphalt incorporating Cecabase® against moisture damage”. Australian Journal of Basic and Applied Sciences, 8 (10), 447-456.

Aman, M.Y., Shahadan, Z., and Noh, M. Z. M. (2014c). ”A comparative study of anti-stripping additives in porous asphalt mixtures”. Journal Teknologi (Sciences and Engineering), 70 (7), 139-145.

Austroads Technical Report AP-T20/02. (2002). “Selection and design of asphalt mixes: Australian provisional guide”. APRG Report No. 18, Australia.

Bailey, H., and Phillips, P. (2010). “Asphalt rejuvenation”. United Kingdom Patent Application No. GB 2462322 A.

Caro, S., Vega, N., Husser, J., and Alvarez, A.E. (2016). “Studying the impact of biomodifiers produced from agro-industrial wastes on asphalt binders”. Construction and Building Materials, 126, 369-380.

Department of Public Work. (2003). “Hotmix asphalt specifications”. Public Work Publisher, Jakarta, Indonesia (in Indonesian).

Huang, S.C., Salomon, D., and Haddock, J.E. (2012). “Workshop introduction”. Paper from a Workshop on Alternative Binders for Sustainable Asphalt Pavements in Washington, D.C., January 22nd Transportation Research Circular E-C165, Transportation Research Board.

Kandhal, P.S., and Mallick, R.B. (1999). “Design of new-generation open-graded friction courses”. National Center for Asphalt Technology, Research Report 99-3, Auburn University, USA.

Laurens, C., Nadjar, H., Rebuffatti, A.C., Rodrigues, C., Wang, K., and Soubigou, C. (2011). “Binder composition and asphalt mixture”. Patent Number 8,076,399 B2, United States Patent and Trademark Office.

Mallick, R.B., Kandhal, P.S., Cooley, L.A., and Watson, D.E. (2000). “Design, construction and performance of new generation open-graded friction courses”. National Center for Asphalt Technology, Auburn University, USA.

National Asphalt Pavement Association. (2002). "Design, construction and maintenance of open-graded asphalt friction courses". Lanham, Maryland, USA.

Nielsen, C.B. (2006). "Durability of porous asphalt-international experience". Published by Road Directorate, Danish Road Institute, Denmark.

Nigen-Chaidron, S., and Porot, L. (2010). "Rejuvenating agent and process for recycling of asphalt". Patent Number US 7,811,372 B2, United States Patent and Trademark Office.

Peralta, J., Williams, R.C., Rover, M., and Silva, H.M.R.D. (2012). "Development of rubber-modified fractionated bio-oil for use as noncrude petroleum binder in flexible pavements". Transportation Research Board, Washington, D.C.

Perhutani, P. (2007). "Gum rosin and turpentine factory". Perum Perhutani Unit II, East Java.

Potgieter, C.J., Sadler, D.E., and de Villiers, E.M. (2002). "Bitumen rubber asphalt: report on the long-term performance in South Africa". Proceedings of the ISAP 9th International Conference on Asphalt Pavements in Denmark, August 7th-22nd. International Society for Asphalt Pavement.

Yuniarti, R. (2012a). "A change in physical properties of aged asphalt due to addition of rejuvenating agent of tamanu oil (*Calophyllum inophyllum* L.)". Research Journal of Mataram University, 2 (17), 24-33 (in Indonesian).

Yuniarti, R. (2012b). "Bio-flux oil performance in buton asphalt mixture". Proceedings of the Sixth National Conference on Civil Engineering in Jakarta, Indonesia. November 1st-2nd. The University of Trisakti, MB1-MB7 (in Indonesian).

Yuniarti, R. (2015a). "Performance of bio-flux oil as modifier of buton granular asphalt in asphalt concrete-wearing course". Journal of JSCE (Japan Society of Civil Engineers), 3 (1), 33-44.

Yuniarti, R. (2015b). "Modification of asphalt with pine resin and fly ash to produce bio-asphalt". Journal of Science, Technology and Environment, Mataram University, 1 (2), 1-8 (in Indonesian).