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DEVELOPMENT OF STIFFNESS MODULUS AND PLASTIC DEFORMATION CHARACTERISTICS OF POROUS ASPHALT MIXTURE USING TAFPACK SUPER™

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ABSTRACT : Porous Asphalt is a bituminous mix with very low sand contents resulting in a high air void content. It is promoted as being effective in enhancing traffic safety in rainy weather, decreasing hydroplaning tendencies, producing good skid resistance at higher speed of traffic and reducing also noise and glare at night.
Pursuing our previous research, the Tafpack Super; produced by Taiyu Kensetsu Co. Ltd, was used as an additive in a porous asphalt mix. It is expected to improve the mechanical properties of the mix, such as : increase the Resilient Modulus and Tensile Strength, and improve also its resistance to Permanent Deformation.
The percentages of Tafpack Super used in this research were 5%, 10%, and 15% of the total weight of bitumen, while the asphalt content varies from 4.5% to 6.5% with 0.5% increments. In order to determine the Optimum Asphalt Content, some preliminary laboratory tests were performed i.e. Marshall Standard test, Cantabro Loss test, and Asphalt Flow Down test.
The use of Tafpack Super in Modified binders seems to decrease its Penetration value, increase its Softening Point and increase its Viscosity, as the percentage of Tafpack Super increases. The Wheel Tracking test was conducted to determine the relation between Dynamic Stability of porous mix, to the "modified" bitumen viscosity and percentage of air voids (VIM). The equations obtained showed that Dynamic Stability increases if percentage of TPS increases. In order to determine the Bearing Capacity of porous asphalt mix, in terms of Tensile Strength and Resilient Moduli, the "static" and "dynamic" Indirect Tensile test were conducted. The results showed that the Resilient Modulus decreases and Tensile Strength increases, if percentage of TPS increases.
Generally all test results showed that the use of Tafpack Super^{TM} additive in Asphalt Concrete mix could give the better performance of porous mix, in line with all research's results for Tafpack Super, conducted in Japan.

Key Words: Porous Asphalt, Tafpack Super, Marshall Test, Cantabro Loss, Asphalt Flow Down.

1. INTRODUCTION

A porous asphalt pavement has some advantages for road users and road side environments, e.g. improving drainage function, driving safety function, and road noise reduction function. The application of porous asphalt is also to provide skid resistance, especially in the wet season, which is markedly better than that of dense graded asphalt. The potential of aquaplaning much reduced at normal driving speeds, and, together with improved visibility, may be the most important benefit for using this type of mix.
Originally, this porous asphalt pavement was developed in Europe and was commenced to be adopted in Japan since the beginning of 1990's (Nakanishi H. et al., 2001). However, the original method from Europe was not always satisfactory in the high temperature conditions, humid climate and traffic conditions in Japan. Some problems were raised such as: the pores were blocked at the early stages, durability of drainage function, rutting and scattering occurred by traffic loading at intersection. Large percentage of air voids of the mixture is adopted in order to maintain the drainage function. However, as the percentage of air voids increases, strength properties of the mixture decrease. This is the basic principle of asphalt mixture. In order to solve these problems, the high viscosity asphalt has been investigated to satisfy the road engineers facing the climate and traffic conditions.
In this research, the high viscosity asphalt could be obtained by using the asphalt modifier "TAFPACK-Super" (TPS) in the asphalt mix. TAFPACK-Super is an asphalt modifier, in the form of pellet with 2 ā 3 mm diameter. TAFPACK-Super contains a thermoplastic elastomer as main gradient, which, in general, is hard to dissolve in asphalt. However, carrying out a polymer blending together with an adhesion resin, a *plasticizer*, it becomes possible to be dissolved into straight asphalt and to modify it into high viscosity asphalt. (Taiyu Kensetsu Co. Ltd., 2001).
The objective of this research is to evaluate some "strength" performances of porous asphalt mixtures, using TAFPACK-Super i.e. Resilient Modulus, Indirect Tensile Strength and Permanent Deformation characteristics, and also to measure the durability of porous asphalt mixture using Marshall Immersion test.

2. LABORATORY TEST PREPARATIONS

The activities performed to achieve the objectives of this research were conducted in the Highway Engineering Laboratory, ITB, Bandung. Indonesia. Almost the entire test methods used in these preparations was those specified by the Japanese method and the Indonesian method. The other standard methods, i.e.: ASTM, AASHTO, and Australian method, were used when appropriate.

2.1 Bitumen Properties

Petroleum asphalt called "AC-20" (approximately equivalent to 60/70 pen was used in the porous asphalt mixture. The laboratory tests performed to evaluate the bitumen properties were: Penetration, Softening Point, Ductility, Flash Point, Solubility, Specific Gravity and Viscosity. The TAFPACK-Super added in the bitumen was 5%, 10% and 15% from the total weight of asphalt.

2.2 Aggregate Properties

The coarse and fine aggregates used were crushed rock imported from West Java, Indonesia and the filler used was Portland Cement (PC) type I. The laboratory tests performed for coarse aggregates were: Los Angeles Abrasion, Aggregate Impact Value, Aggregate Crushing Value, Water Absorption, Specific Gravity, Flakiness, Elongation and Angularity. The tests for fine aggregates were: Specific Gravity and Water Absorption, while for filler the test was Specific Gravity only.

2.3 Mix design of Asphalt Porous

In this research, mix design were prepared for four types of mixture i.e. type A – mixture without Tafpack Super(TPS), type B – mixture with 5% TPS and type C – mixture with 10% TPS and type D – mixture with 15% TPS. The mixing temperature and tamping temperature for type A were determined to obtain the viscosity of 170±20 cSt and 280±30 cSt, respectively, while for type B and type C, these temperatures were 180±5 ^{o}C and 165±3 ^{o}C, respectively, as proposed by Japanese method.

2.4 Marshall Test preparations

In order to determine the Optimum Asphalt Content (OAC) of porous asphalt mixture, the Japanese method was used. (Nakanishi H.,et al., 1985).This method required 3(three) experimental results i.e. Marshall Test, Cantabro Loss test, and Asphalt Flow Down test.
The specimens for Marshall Test were prepared at asphalt content ranging from 4.50% to 6.50% by weight, with 0.50% increment. The weight of each specimen was 1030 grams, tamped by 2x50 blows, and three specimens were tested for each asphalt content. The total specimens prepared for this test were 3x5x3 = 45 samples.
The purpose of Cantabro Loss test was to determine the abrasion resistance of Marshall compacted specimen. These specimens shall be tested in 7 days after compaction finished, and it was placed directly in the Los Angeles Abrasion Machine. The Asphalt Flow Down test was used to assess the amount of binder that is likely to drain down from a mix, during transport from mixing plant to project site. This method is suitable for asphalt mixes with aggregate having a nominal size of 20 mm or less.
The Marshall Immersion test was conducted for specimens prepared at OBC. The objective of this test was to measure the water resistance of the mixture after immersion for 24 hours at 60^{o}C. The specimens prepared for this test were 4x1x2 = 8 samples.
The Resilient Modulus of asphalt porous specimens, at OBC, was measured by using UMATTA equipment, at 3(three) temperature levels i.e. 30^{o}C, 40^{o}C and 50^{o}C. The total specimens prepared for this test were 3x3x1 = 9 samples (Tenrilangi, A.I.., 2004).
The purpose of Wheel Tracking test was to measure the resistance of porous asphalt mix on plastic deformation. This test was conducted for specimens at OBC, at 2(two) temperature levels i.e. 45^{o}C and 60^{o}C, and 4(four) types of specimen i.e. 0%, 5%, 10% and 15% TPS. Then the total specimens were 2x4x1 = 8 samples (Busnial, 2004).

3. LABORATORY RESULTS AND ANALYSIS

3.1 Bitumen

The laboratory tests data for bitumen properties, with and without TAFPACK-Super were shown in Table L1. The results on Penetration tests at 25°C, for bitumen with TFS 5%, 10% and 15% showed that bitumen becomes less susceptible, and the Pen-value will decrease as the percentage of TFS increases. Another test on Softening Point and Elastic Recovery show the same trend. Some relations obtained in these tests i.e. Pen-value vs. %TPS, Softening Point-value vs. %TPS and Compaction or Mixing temperature values vs. %TPS were presented herein.

a. Pen-value vs. %TPS: Pen-value = -97.6 (%TPS) + 64.02 …….. (1)

b. Softening Point-value vs. %TPS: SP-value = 138.5 (%TPS) + 47.30 …….. (2)

c. Compaction Temperature vs. %TPS: T_c = 266 (%TPS) + 140.80 ………. (3)

d. Mixing Temperature vs. %TPS: T_m = 330 (%TPS) + 148.50 ……... (4)

The viscosity tests were conducted to determine mixing and compaction temperatures and the results were given in Table 1. It is shown that the Kinematics Viscosity increases as the percentage of TFS increases. This result verifies that bitumen with TFS becomes more viscous.

Table - 1
Viscosity test results for Asphalt + TAFPACK-Super

No.	Temperature	0% - TPS	5% - TPS	10% - TPS	15% - TPS
1	120°C	811.0	-	-	-
2	140°C	404.4	466.9	861.4	-
3	160°C	159.5	146.6	388.7	535.0
4	180°C	61.2	102.6	202.2	285.6
5	200°C	-	-	89.0	149.8
6	210°C	-	-	-	109.8

3.2 Aggregates

All of the laboratory tests results of aggregates used in this research, could meet the Indonesian specification (SNI M-09-1989-F) and British Standard (BS 812: Part 3 : 1985). The aggregate grading used was conformed to Japanese Specification (Taiyu Kensetsu Co. Ltd., 2001) and was shown in Figure 1 and Table L2.

3.3 Marshall Test

The results of Marshall Test i.e. Stability, Flow, Marshall Quotient (MQ), Density, Voids in Mix (VIM) and Voids in Mineral Aggregate (VMA) are shown in Table 2. Regarding the Stability value, it seems that TPS 15% was the highest, but the MQ value shows that TPS 10% is the best. In fact, the VIM obtained was lower than the "target" value i.e. 20%. The reasons for this probably the grading should modify for Indonesian condition or the aggregates used are not properly conforming to the specification proposed.

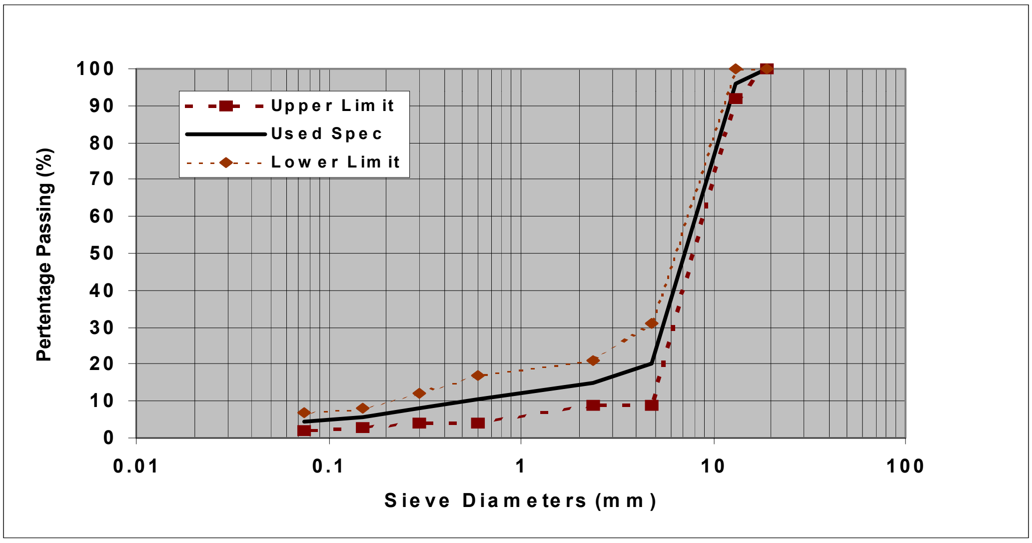

Figure 1
Aggregate Grading for Porous Asphalt Mixture

Table - 2
Marshall Test results for Asphalt + TAFPACK-Super

	0% - TPS	5% - TPS	10% - TPS	15% - TPS
Stability	381.24	443.38	491.78	536.97
Flow	3.22	3.12	3.33	4.14
MQ	119.10	142.05	147.91	129.83
Density	2.219	2.220	2.224	2.225
VIM	11.60	10.84	10.34	10.05
VMA	21.76	21.97	22.09	22.20

3.4 Cantabro Loss Test

The tendencies of the loss of particle in porous asphalt were observed and simulated in Cantabro Loss test and their results were given in Table 3. It is seen that, for all specimens, this value decreases as the asphalt content increases. It is confirmed also that the use of TAFPACK Super could decrease the Cantabro Loss value; the more TFS used the lower Cantabro Loss value obtained. The use of TAFPACK Super as additive in porous asphalt mix obviously improved its scattering resistance.

3.5 Asphalt Flow Down Test

The results of Asphalt Flow Down test were given in Figure 2. Similarly with Cantabro Loss value, for all specimens, this value decreases as the asphalt content increases. It is shown also that the higher TPS used the Asphalt Flow Down value will decrease. This result confirmed that the use of TAFPACK Super reduces the amount of asphalt loss and improve the workability of porous asphalt mixture.

Table - 3
Cantabro Loss Test results

No.	Asphalt Content (%)	5% - TPS (%)	10% - TPS (%)	15% - TPS (%)
1	4.5	10.80	9.26	6.96
2	5	6.61	5.05	3.19
3	5,5	5.27	4.51	2.18
4	6	4.87	3.99	2.01
5	6.5	3.61	2.20	1.12

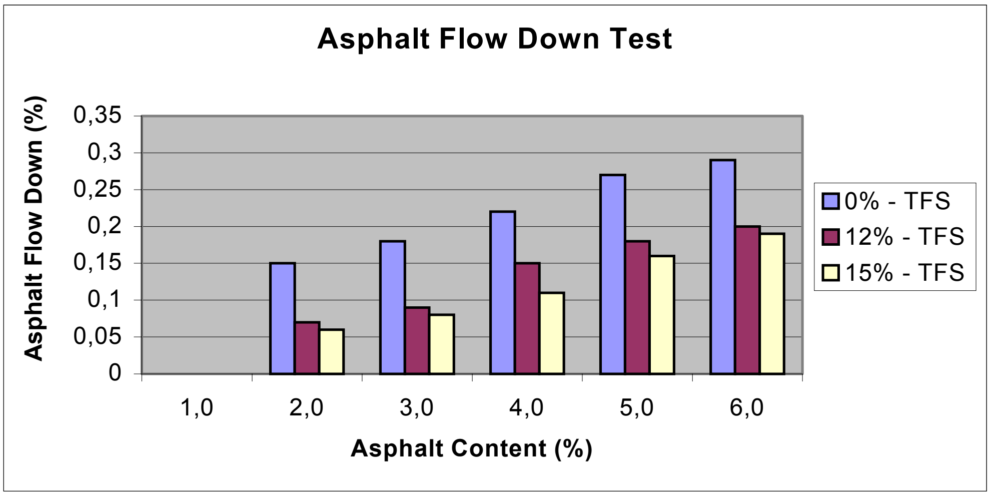

Figure 2
Results of Asphalt Flow down Test

3.6 Optimum Asphalt Content

As mentioned previously, the Japanese method was used to determine the Optimum Asphalt Content (OAC). This method required some following values i.e. Density, VIM, VMA, VFB, Cantabro Loss and Asphalt Flow Down. The procedure were shown in our previous paper and the results were same i.e. 5.50% for all percentages of TPS.

3.7 Marshall Immersion Test

The results of Immersion test were presented in Table 4. It is shown that the value of Index of Retained Stability (IRS) was relatively high, i.e. more than 70%. . Hence, it is concluded that the use of TPS in porous asphalt mix could improve its susceptibility of water damage.

Table – 4
Results of Marshall Immersion Test

No.	TPS Content (%)	Marshall Standard	Marshall Immersion	Index of Retained Stability
1	5.0	443.38	387.45	87.38
2	10.0	491.78	479.94	97.59
3	15.0	536.97	485.78	90.47

3.8 Resilient Modulus Test

The results of Resilient Modulus test using UMATTA equipment were given in Table 5. It is shown that the Resilient Modulus of porous asphalt mix using TPS decreases as the TPS-content increases and the highest value obtained for TPS 5%. It seems that the use of TPS will increase the "flexibility" of the mix and it is applicable for all temperatures.

Table – 5
Results of Resilient Modulus Test

Temperature	TPS – 5%	TPS – 10%	TPS – 15%
$30^{o}C$	798.30 MPa	694.50 MPa	621.30 MPa
$40^{o}C$	316.60 MPa	305.50 MPa	243.40 MPa
$50^{o}C$	196.30 MPa	113.30 MPa	127.00 MPa

3.9 Indirect Tensile Strength Test

The purpose of this test is to measure the tensile strength of porous asphalt mix, using the "modified" Marshall equipment, at 3(three) different temperatures i.e. $30^{o}C$, $40^{o}C$ and $50^{o}C$. The results of this test were shown in Table 6. It is shown that, contrary with the results of Resilient Modulus test, the Tensile Strength of mix increases as the TPS-content increases and the highest value obtained for 15% TPS content. It is assumed that the use of TPS additive could increase the mortar's strength, and then the tensile strength of porous asphalt would increase too.

Table – 6
Results of Indirect Tensile Strength Test

Temperature	TPS – 5%	TPS – 10%	TPS – 15%
30^{o}C	55.90 psi	57.30 psi	62.80 psi
40^{o}C	26.70 psi	28.40 psi	33.10 psi
50^{o}C	18.30 psi	19.80 psi	20.10 psi

3.10 Wheel Tracking Test

The resistance of plastic deformation was represented by 3(three) parameters i.e. Dynamic Stability (DS), Rate of Deformation (RD) and Total Deformation (D_o). The results of this test, at 2(two) temperatures i.e. 45^{o}C and 60^{o}C, were presented in Figure 7. It is shown that the Dynamic Stability (DS) of mix increases as the TPS content increases. Contrary with Dynamic Stability, the Rate of Deformation decreases as the TPS content increases. Hence, it can be concluded that the use of TPS additive in porous asphalt mix, would increase its resistance to plastic deformation.

TABLE – 7
Results of Wheel Tracking Test

Temperature	TPS 5%	TPS 5%	TPS 10%	TPS 10%	TPS 15%	TPS 15%
	(DS)	(RD)	(DS)	(RD)	(DS)	(RD)
45^{o}C	9000	0.0047	12600	0.0033	15750	0.0027
60^{o}C	2032	0.0207	3706	0.0113	3928	0.0107

4. CONCLUSIONS

Considering all results of laboratory test and analysis, some conclusions could be drawn:

a. The use of Tafpack Super in the “original” bitumen could modify some of their properties i.e. decrease its Pen-value, increase its Softening Point-value, and increase its Kinematics Viscosity. It means that the modified-bitumen becomes more stiff and durable.
b. The use of Tafpack Super in the porous asphalt mix give some advantages for the mix performances i.e. increase the Marshall Stability, decrease the Cantabro Loss value and decrease the Asphalt Flow Down value.
c. Another mix characteristic should be affected also by using the Tafpack Super. Those characteristics are : resistance to water immersion (indicated by the value

of IRS), Tensile Strength (indicated by Resilient Modulus and Indirect Tensile Strength), and resistance to plastic deformation (indicated by Dynamic Stability).

d. The “target” VIM (Voids in Mix) value of porous asphalt mix, i.e. greater or equal to 20%, according to the Japanese Specification, could not be achieved in this research. The reason would be come from either the grading curve chosen for this research or the formula to calculate VIM-value. We plan to check and re-check again that formula and the grading curve for porous asphalt mix.
e. The optimum value of percentage of Tafpack Super could not be determined precisely in this research. This is due to limited percentage value of TPS (5%,10% and 15%) and the trend of Resilient Modulus value would be doubtful. We plan to check again this value using another test e.g. fatigue test.
f. Nevertheless, considering some “positive” results of this research, the use of Tafpack Super in the porous asphalt mix could be recommended and the application in the pavement construction, especially in Indonesia, could be initiated by building the “trial pavement section” first.

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Table - L1
Test on Bitumen Properties & TAFPACK Super

No	Laboratory Test	Unit	TFS Percentage		
			5%	10%	15%
1	Penetration	0.1 mm	56.5	53.9	50.5
2	Softening Point	ºC	50.8	59.2	70.5
3	Ductility	cm	>100	>100	79.4
4	Specific Gravity	-	1.039	1.036	1.034
5	Penetration after TFOT	% orig.	92.0	95.9	90.9
6	Ductility after TFOT	cm	>100	85.4	64.9
7	Softening Point after TFOT	^{o}C	53.5	61.2	71.8
8	Flashing Point	ºC	331	327	323
9	Burning Point	ºC	337	330	327
10	Solubility	%	99.4	99.3	99.2
11	Elastic Recovery at 25^{o}C	% orig.	49	67	86.5

Table – L2
Aggregates Grading used for Porous Asphalt Mix

Sieve Size (mm)	% (percentage) Passing			% Retained Grading Combination
	Upper Limit	Lower Limit	Grading Combination	
19.00	100	100	100	-
13.20	100	92	97	3.0
4.75	31	9	21.7	75.3
2.36	21	9	16	5.7
0.60	17	4	11.2	4.8
0.30	12	4	9.3	1.9
0.15	8	3	6.8	2.5
0.075	7	2	4.1	2.7
Pan	-			4.1