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AGING SIMULATION OF HOT MIX ASPHALT MIXTURES UTILIZING RECLAIMED ASPHALT PAVEMENT

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ABSTRACT: The utilization of reclaimed asphalt pavement (RAP) has become more popular due to increasing concerns of sustainability, environmentally and economically. The research was to investigate the effect of simulated aging to the characteristics of two types of pavement layer, Asphalt concrete-Wearing Course (AC-WC) comprising considerable portion of reclaimed asphalt pavement or bituminous waste materials. Aging simulation includes Short Term Oven Aging (STOA) and Long Term Oven Aging (LTOA) method. The research included determination of the appropriate composition of RAP and new materials, determination of Optimum Asphalt Content (OAC) and production of specimens for the two type of asphalt pavement. Three types of specimen were control condition (non aged), STOA and LTOA specimens. All of specimens are tested to determine the Marshall Properties, effect of immersion and Indirect Tensile Strength (ITS) test. Indirect Tensile Strength, Retained Marshall Stability and Tensile Strength Ratio, have shown decreasing value while the Marshall Stability and Flow have shown incremental value.

Keywords: *Asphalt Recycling Pavement, Aging, Marshall Properties, Durability, Indirect Tensile Strength.*

INTRODUCTION

Background

Nowadays, the conservations of materials, environmental issue, and costs effective are three major issues in pavement construction, rehabilitation and maintenance. Especially for flexible pavement utilizing asphalt cement that comes from natural resources. Asphalt pavement recycling is one of procedure that eminently and realistically meets these concerns because of the economical in terms of energy and materials usage.

In asphalt pavement recycling, materials reclaimed from old pavement structures are reprocessed along with some new materials to produce asphalt mixtures meeting all normal specification requirements (Asphalt Institute, 1983). The asphalt contained in old pavements is an additional valuable resource. Because of factors such as oxidation, the aged asphalt may have lost some of its original properties, but when combined with new asphalt it can again serve as an effective binder. The reuse of aged asphalt may reduce the amount of new asphalt required for pavement reconstruction.

Asphalt pavement materials consists of aggregate and asphalt cement. Asphalt cements are composed of organic molecules that react with oxygen from environment. This reaction is called oxidation and it changes the structure and composition of asphalt molecules. Oxidation causes asphalt cement to harden. Because asphalt cement exists in thin films covering the aggregate, the oxidation reaction occurs at a faster rate. “Short term aging” is used to describe the aging that occurs in this stage of the pavement life. Oxidative hardening also occurs because of exposure to air and water. “Long term aging” happens at a relative slow rate in a pavement, although it occurs faster in warmer climates and during warmer seasons. Because of this hardening, old asphalt pavements are more susceptible to cracking. Improperly compacted asphalt pavements may exhibit premature oxidative hardening because of a higher percentage of interconnected air voids. This allows more air to penetrate into the asphalt mixture, increasing oxidative hardening (Asphalt Institute, 2001).

Research Objectives

1. To perform AC Wearing Course (AC-WC) hot recycling asphalt utilizing bituminous waste materials (RAP) and new materials (aggregates and asphalt cements) and to conduct performance tests by determine the Marshall characteristics, failure plane by Indirect Tensile Strength (ITS) test and durability of the mixture.
2. To determine the effects of aging to the hot recycling asphalt by using short and long term aging procedures which were developed at Oregon State University under the Strategic Highway Research Program (SHRP) A-003A project.

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LITERATURE REVIEW Asphalt

Recycling Pavement

Asphalt pavement recycling is not a new development. Used to called reconstruction, it has been in use for more than 5 decades. In asphalt pavement recycling, materials reclaimed from old pavement are reprocessed with addition some new materials to produce new asphalt mixtures meeting all normal specification requirements. The asphalt contained in old pavements is an additional valuable resource. Because of factors such as oxidation, the aged asphalt may have lost some of its original properties, but when combined with new asphalt it can again serve as an effective binder. The reuse of aged asphalt may reduce the amount of new asphalt required for pavement reconstruction. Recycling can correct many types of pavement distress. By reusing aggregate and asphalt from deteriorated pavements, the need for new materials is appreciably reduced and the overall cost of the improved pavement will be less. The addition of asphalt to existing granular base materials during recycling increases structural strength without adding to pavement thickness, thereby preserving roadway geometrics. Since the pavement thickness is not increased, drainage problems are avoided. Adding asphalt also helps waterproof the base and renders it less susceptible to moisture damage. (Asphalt Institute, 1983)

Asphalt Aging Behaviour

As stated in Asphalt Institute (2001) asphalt cements are composed of organic molecules, because of that they react with oxygen from the environment. This reaction is called oxidation and it changes the structure and composition of asphalt molecules. Oxidation causes asphalt cement to harden. In practice, some oxidative hardening occurs before the asphalt is placed. Because asphalt cement exists in thin films covering the aggregate, the oxidation reaction occurs at a faster rate. “Short term aging” is used to describe the aging that occurs in this stage of the asphalt’s life. Oxidative hardening also occurs during the life of the pavement because of exposure to air and water. “Long term aging” happens at a relative slow rate in a pavement, although it occurs faster in warmer climates and during warmer seasons. Because of this hardening, old asphalt pavements are more susceptible to cracking. (Whiteoak et. al., 2003)

According to Kliewer et. al. (1995), the development and validation of laboratory aging procedures to simulate short and long term aging for asphalt-aggregate mixtures was undertaken as part of the Strategic Highway Research Program (SHRP) project A-003A at Oregon State University (OSU). The laboratory procedure for short term aging is to heat loose mix in a forced draft oven for 4 hours at a temperature of 135°C. This short term oven aging (STOA) simulates the aging of the mixture during the construction process. The laboratory procedure for long term aging of the compacted mixture is to heat the compacted specimens in a forced draft oven at 85°C. This long term oven aging (LTOA) simulates the aging of the mixture in service. An aging period of 4 or 5 days is recommended to simulate project about 10 years old.

Asphalt Mixture Testing

Asphalt mixture testing conducted to determine the quality of AC Wearing Course must meet the requrements as stated on Indonesian Directorate General of Highway (2007). There are two types of mixture properties that will obtained in this research are volumetric and Marshall properties. According to Asphalt Institute (2001), the test are :

1. Volumetric Properties
   a. Bulk specific gravity of aggregate
   b. Effective specific gravity of aggregate
   c. Maximum specific gravities of mixtures
   d. Asphalt absoption
   e. Effective asphalt content
   f. Percent VMA in compacted paving mixture
   g. Calculation of air voids in compacted mixture
   h. Percent VFA in compacted paving mixture
2. Marshall Properties
   a. *Stability*, the Marshall Stability value is the maximum load before the specimen yields or fails. Marshall stability test provides the performance prediction measurement for the Marshall Mix design method. The primary use of Marshall stability is to evaluate the change in stability with increasing asphalt content to aid in selecting of the optimum asphalt content.
   b. *Flow*, Marshall Flow, measured in units equal to 0.25 mm, represents the total deformation of the specimen. The deformation is a measure of a decrease in the vertical diameter of the specimen.
   c. *Marshall Quotient* (MQ), is Marshall Stability divide by Flow. Mixes that have very low flow values and abnormally high Marshall stability values are considered too brittle and rigid for pavement service. Those with high flow values are considered too plastic and have tendency to distort easily under traffic loads.

Indirect Tensile Strength (ITS)

According to AASHTO T 283, HMA made from certain materials are sensitive to the presence of water in the pavement. Water will cause the binder to not adhere to the aggregate. Since the binder is the "glue" that holds the pavement together, rapid failure of the pavement can be expected if the binder cannot adhere to the aggregate. This is often referred to as stripping. To help prevent stripping, additives such as hydrated lime or liquid anti-stripping chemicals may be required. Indirect Tensile Strength (ITS) test is a test method that can be used to determine if the materials may be subject to stripping and also to measure the effectiveness of additives. The specimens are tested for indirect tensile strength by loading the specimens at a constant rate and measuring the force required to break the specimens. The tensile strength of the conditioned specimens is compared to the control specimens to determine the tensile strength ratio (TSR).

METHODOLOGY

Research procedure consists of preparation, where Reclaimed Asphalt Pavement (RAP) materials were dried before used as material for specimens. Three types of materials that used in this study they are RAP, new aggregate and asphalt concrete have to be tested before used as composition of mixtures. Tests include extraction test for RAP, Los Angeles test, specific gravity test, sieve analysis, absorption to water test, sand equivalent test for new aggregate. Tests for bituminous material include Penetration test, flash point test, softening point test, loss on heating test, ductility test, penetration test after loss on heating and specific gravity. There are four types of specimens design in this research:

a. Specimen design for determining the composition of RAP and new aggregate without adding asphalt concrete. The variation of the specimens are : 100% RAP, 80% RAP : 20% new aggregate and 75% RAP : 25% new aggregate.
b. Specimen design for determining asphalt content design. The variation of added asphalt content is by 0.3% from 0.6% until 1.5% asphalt content addition to the chosen composition from 1.
c. Specimen design with asphalt content design as control specimens that use for testing on Marshall properties, ITS test.
d. Specimen design with condition Short Term Oven Aging (STOA) and Long Term Oven Aging (LTOA) for testing on Marshall properties, immersion, and ITS test.

Test specimens preparation were :

a. Number of specimens – At least three specimens were prepared for each combination of RAP, aggregates and asphalt content.
b. Preparation of RAP and aggregates – RAP and aggregates dried to constant weight at 105°C to 110°C.
c. Mixing and compaction temperature determination.
d. Mixture preparation – Each test specimen is weighed into separate pans for of each size fraction and percentage of RAP required to produce a batch that will result in a compacted specimen 63.5±1.27 mm in height. This will normally be about 1.2 kg.
e. Compaction of specimens – 75 blows are applied to compact the specimens to each side using compation hammer. After compacting, remove the specimens from mold and cool overnight until ready for testing.
f. For STOA specimens, the procedure is similar but after the specimens mixed, it must placed on oven for 4 hours at temperature of 135°C before compaction.
g. For LTOA specimens the procedures is similar with STOA procedures but after placed on oven for 4 hours at temperature of 135°C and compaction, the specimens must placed again in oven for 5 days at temperature of 85°C before ready for testing.

Specimens testing follows the procedures :

a. Marshall Properties Testing
1) Bulk specific gravity determination – This test is performed according to ASTM D2726.
2) Stability and flow tests – After the bulk specific gravity of the test specimens have been determined, the stability and flow tests are performed.

b. Indirect Tensile Strength testing
1) Height, dry height, submerged weight and surface dry weight of the specimens are measured and the air voids is determined.
2) Each specimen placed in water bath at 25° C and vacuum saturate for 45 minutes, then the wet conditioned specimens placed in a 60°C water bath for 48 hours.
3) The specimen is removed from the bath and then placed on its side between the bearing plates of the testing machine. A load is applied to the specimen by forcing the bearing plates together at a constant rate of 2 in. (50 mm) per minute.
4) The maximum load is recorded, and the load continued until the specimen cracks.

RESULTS AND DISCUSSION

Laboratory Results

1. Material Testing Result

Asphalt mixture consists of fresh aggregate and RAP. For new aggregate and asphalt cement, physical testing is conducted and the result is shown in Table 1.

Table 1. Material testing result

No	Test Type	Specification	Result	Unit
	Aggregate			
1.	Abrassion	Max. 40	24,4	%
2.	Bitumen adhesivity	> 95%	98	%
3.	Bulk Specific Gravity Coarse Aggregate	>2,50	2,729	gr/cc
	Bulk Specific Gravity Fine Aggregate	>2,50	2,868	gr/cc
4.	Coarse Aggregate absorption	<3	2,480	%
	Fine Aggregate absorption	<3	2,564	%
5.	Sand Equivalent	Min. 50	85	%
6.	Soundness Test	Max. 7%	1,57	
	Asphalt AC 60/70			
1.	Penetration at 25° C	60 - 79	62,2	0,1 mm
2.	Softening Point	48 – 58	48	° C
3.	Flashing Point	>200	347	° C
4.	25° C Ductility	>100	>100	cm
5.	Loss on heating (163°C, 5 hours)	<0,4	0,050	%
6.	CCl_4 solutibility	99	99,317	%
7.	Penetration after loss on heating	75	82,0	% of original
8.	Specific Grafity	1	1,030	gr/cc

The result of material testing for aggregate and asphalt cement were passed all the specifications in AASHTO 1982. The existing asphalt content in the mixture of RAP is 5.9% and in the mixture with addition of new asphalt cement is 4.4%, it is decreasing from original asphalt content which was 6 to 7 percent because the effect of oxidation.

2. Composition determination of the mixture

The mixture that tested for the effect of aging are consists of RAP and new aggregate with the addition of asphalt cement. To determine the best proportion of RAP and new aggregate, this research has trial 3 different proportion (100% RAP, 80% RAP : 20% new aggregate, and 75% RAP : 25% new aggregate) without any asphalt cement addition to determine the Marshall Properties. The result of the test is shown in the Table 2.

Table 2. Composition determination of the mixture

Marshall Properties	Specification	Proportion (RAP : New Aggregate)		
		100 : 0	80 : 20	75 : 25
Density (gr/cc)	-	2.199	2.178	2.184
VMA (%)	min. 15	16.29	16.14	15.94
VFB (%)	min. 65	67.46	52.44	51.04
VITM (%)	3.5 - 5.5	5.30	7.68	7.81
Stability (kg)	min. 800	2687	2668	2630
Flow (mm)	min. 3	2.17	2.33	3.03
MQ (kg/mm)	min. 250	1239	1147	907

From Table 2., for 100% RAP composition is passing all the specification except flow and gradation. The mixture is brittle because aging process makes the flow become low and the gradation not meet the requirement for AC-WC gradation because during the service life, the asphalt pavement experiencing degradation by traffic loading and milling process. For 80% RAP :
20% fresh aggregate composition, there are some items that not passed the specification, those are flow, VITM and VFB. But for 75% RAP : 25% fresh aggregate composition, although there are some items that not passed the specification (VITM and VFB), considering the gradation of this mixture is the gradation of AC-WC mixture and the flow are meet the requirements comparing with others composition, hence the choosen composition for this reasearch is 75% RAP : 25% fresh aggregate. With the prediction that is if some percentage of new asphalt is added to this composition, will make the mixture pass all the specification especially VITM and VFB.

3. Determination of Optimum Asphalt Content (OAC)

The OAC of recycled AC-WC mixture was obtained by preparing chosen specimens with five variation of asphalt content addition with the interval of 0.3% and testing those specimens with Marshall Testing method. The analysis to determine the OAC is shown in Table 3.

Table 3. Optimum Asphalt Content determination

Marshall Properties	% Bitumen (Addition to 4.4% existing) 0.6%	0.9%	1.2%	1.5%	1.8%
Density (gr/cc)	2.200	2.216	2.219	2.218	2.233
VMA (%)	15.82	15.68	15.69	15.94	16.36
VFB (%)	59.68	64.77	69.19	71.85	77.97
VITM (%)	6.40	5.52	4.85	4.49	3.45
Stability (kg)	1748	2027	1789	1876	2059
Flow (mm)	3.17	3.70	3.47	3.77	4.13
MQ (kg/mm)	560	548	517	498	499

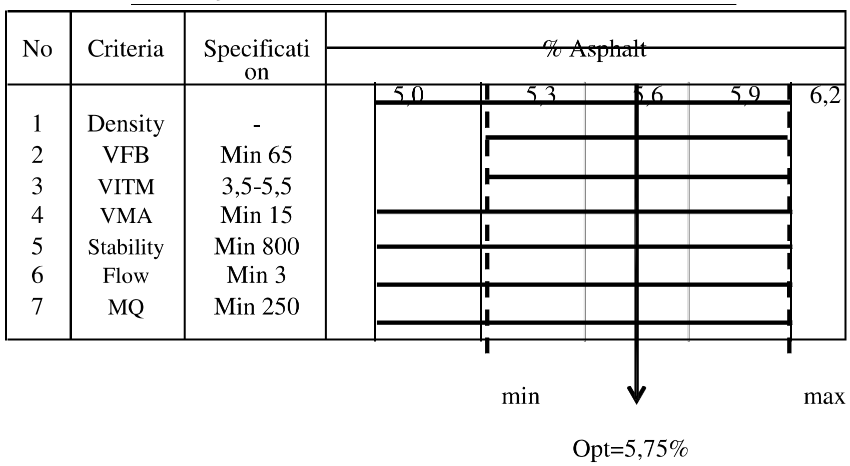

Fig. 1. Optimum Asphalt Conten Determination

From test result, the OAC of the mixture is 5.75% from the total of mixture. Therefore, to determine the effect of aging to the recycled asphalt pavement, 5.75% total asphalt content or 1.35% of asphalt addition to 75% RAP : 25% fresh aggregate mixture is used.

4. Specimens Testing Result In Optimum Asphalt Content Condition

To determine the effect of aging to the recycled AC-WC hot mixture, three specimens that are Control, STOA, and LTOA specimens are tested. The control specimen is the specimen that made by standard prochedure in Optimum Asphalt Content, the STOA and LTOA specimens is made by prochedure that adopted from Strategic Highway Research Program (SHRP) A-003A project. There are two major testing prochedure that conducted to all specimens in this research :

a. Marshall testing

There are two major result in Marshall testing, that are volumetric properties (density, Voids in Mineral Aggregate, Voids Filled with Bitumen, Voids In The Mix) and Marshall Properties (Stability, Flow, Marshall Quotient). The Marshall testing result for all specimens are shown in the Table 4. As control parameter, Indonesian Directorate General of Highway Specification year 2007 is used to determine the condition of the mixtures whether it confirms the requirements.

Table 4. Marshall Testing result for Control, STOA, and LTOA condition

Marshall Properties	Specification	Specimens Control	STOA	LTOA
Density (gr/cc)		2.217	2.223	2.181
VMA (%)	min. 15	15.48	15.26	16.84
VFB (%)	min. 65	69.47	70.68	64.77
VITM (%)	3.5 - 5.5	4.73	4.48	6.26

Stability (kg)	min. 800	1930	1943	1977
Flow (mm)	min. 3	3.17	3.50	3.60
MQ (kg/mm)	min. 250	617	555	549

b. Indirect Tensile Strength (ITS)

ITS test is used to determine the potential crack and indirect tensile strengths of asphalt mixtures at low and intermediate pavement temperatures. There are two types of specimens in this research those are unconditioned and conditioned. For unconditioned, the specimens are tested in standard condition and for the conditioned, the specimens ares tested after placed in a 60°C distilled water bath for 48 hours. The result of the test is shown in Table 5. The major item that measured in this test is the maximum loading number (P max) for each specimen to determine the ITS value and Tensile Strength Ratio. Asphalt Institute SP-2 (1996) is used as minimum requirements for this test.

Table 5 ITS test result for Control, STOA, and LTOA condition

Specimens		P max (N)	ITS (kPa)	TSR (%)
Control	Unconditioned	56.33	5161	79.25
	Conditioned	44.67	4090	
STOA	Unconditioned	53.00	4723	76.38
	Conditioned	40.67	3608	
LTOA	Unconditioned	50.33	4517	66.04
	Conditioned	33.67	2983	

DISCUSSION

Effect of aging to Indirect Tensile Strength (ITS)

Indirect Tensile Strength (ITS) test is used to indicate crack potential of the mixture and evaluates susceptibility from effect of water. Figure 2 and Figure 3 shows the effect of aging to Indirect Tense Strength (ITS) and Tensile Strength Ratio (TSR) of the mixtures.

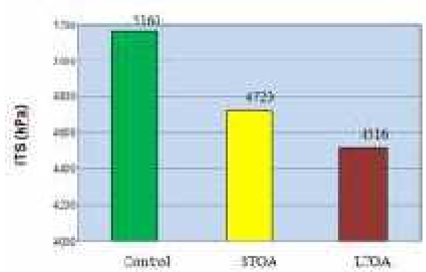

Figure 2. Effect of aging to ITS

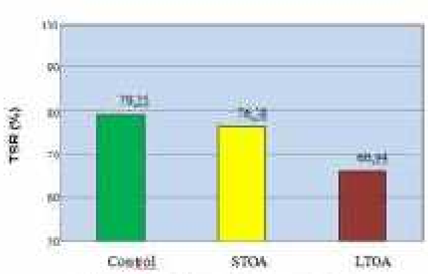

Figure 3. Effect of aging to TSR

The result of testing are ITS for Control specimen is 5160 kPa, for STOA is 4723 kPa and for LTOA specimen is 4516 kPa. It is indicates that effect of aging process will make the value of ITS decreasing because the mixture will be more brittle by the effect of aging or oxidation process.

Tensile Strength Ratio (TSR) is strength decreasing rate of the mixture that can effect the resistance of moisture damage and crack potential. TSR is obtained by dividing average tensile strength of the dry subset with average tensile strength of the conditioned subset. The acceptable resistance to moisture damage (TSR) based on Asphalt Institute SP-2 (1996) is 80%. From Figure 3., the TSR for Control specimen is 79.25%, for STOA specimen is 76.38% and for LTOA specimen is 66.04%. The results show that all the specimens cannot fullfill the requirement. Can be concluded that the effect of aging to the recycled AC-WC hotmix asphalt mixture make the resistance of moisture damage decreasing. Aging process in the mixture caused by asphalt cement oxidation will accelerate the asphalt cement hardening. Thus, the ability of asphalt cement as bonding agent weaker. As the result, the resistance of moisture damages become lower and crack potential will be higher.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

1. AC-WC asphalt hot mix recycled can be used as material for new AC-WC asphalt hot mix with addition of new aggregates and asphalt cements. Composition that selected for this research is 75% RAP : 25% new aggregates with Optimum Asphalt Content is 5.75% of total mixture. The properties of mixture in OAC condition are : density

2.217 gr/cc, VMA 15.48%, 69.47%, VITM 4.73%, stability 1930 kg, flow 3.17 mm, and MQ 617 kg/mm which all of those properties can fulfill the specification.

2. Effect of aging process to AC-WC asphalt hot mix recycled using short and long term aging procedures is The Indirect Tense Strength (ITS) for Control, STOA, and LTOA specimens are 5160 kPa, 4723 kPa and 4516 kPa respectively. The effect of aging process will make the value of ITS decreasing because the mixture will be more brittle by oxidation process. The Tensile Strength Ratio (TSR) for Control, STOA and LTOA specimens are 79.25%, 76.38% and 66.04% respectively. Can be concluded that the effect of aging to the recycled AC-WC hotmix asphalt mixture made the resistance of moisture damage become lower and crack potential will be higher.

Recommendations

Based on the result of the research, there are some recommendation for further research to make the better analysis in effect of aging to hot mix asphalt recycling :

1. The mixture of hot mix asphalt recycling using 75% RAP and 25% fresh aggregates with asphalt cement addition of 1.35% has no problem with the Tensile Stress Ratio (TSR) value that is very low. There are several methods to correct the poor TSR, those are : using different properties of asphalt cement, liquid anti-stripping additives, hydrated lime and change of aggregate or mix design.
2. Effect of aging process using short and long term aging procedures which were developed at Oregon State University under the Strategic Highway Research Program (SHRP) A-003A project must be validate with field experiment to determine exactly the effect of aging to the mixture by actual condition. It will become problem because to conduct the research needs long time and high budget.
3. To have better analysis in effect of aging to the hot mix asphalt recycling, it is recommended that the mixture have a simulation for loading test, for example Wheel Tracking Test because we will have not only effect of oxidation or weather to the mixture, but also the loading from vehicles to the pavement.

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