UTILIZATION OF TORAY FLY ASH AS FILLER SUBSTITUTION IN THE HOT ROLLED SHEET-WEARING COURSE (HRS-WC) MIXTURE

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ABSTRACT

In road construction materials, the utilization of fly ash as additive materials is limited and also small in quantity, while the disposal of fly ash is quite high. An abundance of fly ash can be found at PT Toray Company in Jakarta and Surabaya. Toray fly ash is disposed coal ash resulting from coal-fired electricity generating power plants. Toray fly ash in this research is used as substitute mineral filler in asphalt paving mixtures. Research on utilization of Toray fly ash as filler is conducted in the Hot Rolled Sheet – Wearing Course Mixture. Filler content in the HRS –WC mixture is 9%. Variations of Toray fly ash in the mixture tested are 0%, 25%, 50%, 75%, 100% and the variations of asphalt content are 6%, 6.5%, 7%, 7.5%, 8%. Marshall test is performed to determine the Optimum Asphalt Content and Marshall Stability, Indirect Tensile Strength (ITS) test and Tensile Strength Ratio (TSR) to select the optimum Toray fly ash utilization in the mixture based on the moisture susceptibility of specimens. The research results show that in variations of 0%, 25%, 50%, 75% and 100% Toray fly ash in the HRS-WC Mixture, the Optimum Asphalt Contents are at 6.8%, 7.0%, 7.0%, 7.1% and 7.6% and Marshall Stability values of the variations are 1649 kg, 1541 kg, 1568 kg, 1678 kg, 1718 kg respectively. TSR values in variations of Toray fly ash are 98.32%, 90.28%, 89.38%, 87.62%, 64.71% respectively, with Minimum TSR value required is 80%. Based on the overall parameters, the optimum Toray fly ash utilization in the HRS-WC Mixture recommended is 75% of Toray fly ash at 7.1% Optimum Asphalt Content.

Keywords: Toray fly ash, filler, HRS-WC, Marshall Test, Marshall Stability, OAC, ITS, TSR.

INTRODUCTION

A. Background
In road construction materials, the utilization of fly ash as additive materials is limited and also small in quantity, while the disposal of fly ash is quite high. An abundance of fly ash can be found at PT Toray Company in Jakarta and Surabaya. Facing the fact, it is necessary to consider a research on utilization of Toray fly ash, used as filler in the Hot Rolled Sheet – Wearing Course (HRS-WC) Mixture.

B. Research Objective
Research was conducted in laboratory to study the influence of utilization of Toray fly ash as filler substitution in the hot rolled sheet - wearing course (HRS-WC) mixture, particularly replacing the volcanic fly ash/stone dust with *Toray* fly ash. To identify the influence of Marshall Characteristic stability-flow, VITM, VFWA, VMA, and Marshall Quotient, durability, Indirect Tensile Strength and Tensile Strength Ratio on Optimum Asphalt Content.

LITERATURE REVIEW

A. Asphalt (Bitumen)

Asphalt is of particular interest to the engineer because it is strong cement, readily adhesive, highly waterproof, and durable. The primary use of asphalt (Bitumen) is in road construction, where it is used as the glue or binder for the aggregate particles. According to ASTM-D8 (1997), "Asphalt is a dark brown to black cementitious material in which predominating constituents are bitumens which occur in nature or are obtained in petroleum processing".

B. Asphalt Pavements

Asphalt Pavement is a construction above the prepared subgrade to resist the repetition of traffic vehicular loads and distribute the loads over the subgrade. An asphalt pavement structure consists of surface course, base course, sub base course, subgrade.

C. Hot Rolled Asphalt Surface

Hot rolled asphalt surface course is dense mixture of mineral filler, sand and bitumen into which a coarse aggregate is added. It is *gap-graded* material, the mechanical properties of which are dominated by the mortar.

D. Component Materials

1. Aggregates

The amount of mineral aggregate in asphalt paving mixture is generally 90 to 95 percent by weight or 75 to 85 percent by volume. Mineral aggregate is primarily responsible for the load supporting capacity of pavement.

  a) Coarse aggregate
     Coarse aggregate is defined in this research as that substantially retained on the 8 (2.36 mm) sieve. Specification for coarse aggregate used is based on The Ministry of Public Works (2007)
  b) Fine aggregate
     Fine aggregate is defined as that 'shall substantially' pass an 8 (2.36 mm) sieve. Specification for fine aggregate used is based on the Ministry of Public Works, Institute of Road Engineering (2007)

2. Filler

Filler desirable were aggregate passing the No. 200 sieve and non-plasticity. Filler must be dry and clean from clay lumps and friable particles appropriate SNI 03-6723-2002 (Ministry of Public Works, IRE 2007)

3. Asphalt

Asphalt used is asphalt cement ex PERTAMINA penetration 60/70.

4. Fly Ash

Fly ash produced from the burning of pulverized coal in a coal-fired boiler is a fine-grained, powdery particulate material that is carried off in the flue gas and usually collected from the flue gas by means of electrostatic precipitators, baghouses, or mechanical collection devices such as cyclones.

  a) Class F fly ash
     The burning of harder, older anthracite and bituminous coal typically produces Class F fly ash.
  b) Class C fly ash
     Fly ash produced from the burning of younger lignite or subbituminous coal, in addition to having pozzolanic properties, also has some self-cementing properties.

THEORETICAL APPROACH

A. Hot Rolled Sheet-Wearing Course (HRS-WC)

Hot rolled sheet in the basic is a surface course with mortared sand asphalt that may divide in two types of mixture, HRS-Base and HRS-Wearing Course (HRS-WC) which maximum aggregate size is 19-mm. Hot rolled sheet are *gap-graded* predominantly sand mixed with asphalt cement, layered and compacted in a particular temperature.

B. Marshall Test

The Marshall method seeks to select the asphalt binder content at a desired density that satisfies minimum stability and range of flow values (White, 1985).

1. Stability

The Marshall Stability test provides the performance prediction measure for the Marshall Mix design method.

$$S = O \times R \times T \tag{1}$$

Where,
O = stability timepiece reading on marshall test (lbs)

S = stability numeral (kg)
R = Proving ring calibration (kg)
T = the matter test correction factor

2. Flow
The flow is measured at the same time as the Marshall stability. The flow is equal to the vertical deformation of the sample (measured from start of loading to the point at which stability begins to decrease) in hundredths of an inch (Roberts et al, 1991).

3. Marshall Quotient (MQ)
Marshall Quotient (MQ) is the ratio of stability over flow, which indicates mixture stiffness.

The Marshall Quotient is calculated from the following equation.

$$MQ = \frac{\text{stability}}{\text{flow}} \quad \text{(kg/mm)} \tag{2}$$

4. Volumetric Properties of specimen
The volumetric properties of a compacted asphalt mixture provide indications of the potential performance of the mixture as a pavement. Volumetric properties are used in the two most common laboratory design procedures Marshall and Super Pave, Patrick G. Lavin (2003).

5. Voids in the Mineral Aggregates (VMA)
Voids in the Mineral Aggregate (VMA) are the total volume of voids within the mass of the compacted aggregate.

$$VMA = 100 - \frac{Gmb \times Ps}{Gsb} \tag{3}$$

6. Voids in the Total Mix (VITM)
A Voids In the Total Mix (VITM) expressed as a percent of in mixture that affects the stiffness and durability.

$$VITM = 100 \times \frac{Gmm - Gmb}{Gmm} \tag{4}$$

7. Voids Filled with Asphalt (VFWA)
Voids Filled with Asphalt calculated from VMA and air void content.

$$VFWA = 100 \times \frac{VMA - VITM}{VMA} \tag{5}$$

8. Indirect Tensile Strength Test
Suparma (2001), in Indirect Tensile Strength (ITS) test cylindrical specimens are subjected to compressive loads, which act parallel to and along the vertical diametrical plane using the Marshall loading Machine.

$$ITS = \frac{2.Pmaks}{\pi.t.d} \tag{6}$$

RESEARCH METHODOLOGY

A. Research Material
Research materials used in this research are as follow:

1. Aggregates and filler
Aggregate used in this research are coarse aggregate, fine aggregate from Clereng Kulon Progo district, Jogjakarta, Toray fly ash as filler and Stone dust filler.

2. Asphalt
Asphalt 60/70 penetration grade (ex. PERTAMINA) is used in the research based on Ministry of Public Works, Institute of Road Engineering (2007) specification.

B. Research Apparatus
1. Asphalt test apparatus
The apparatus used for physical properties test of asphalt, are asphalt Penetration test apparatus, Softening point, Flash point, lost on heating, Solubility, Ductility, apparatus, and Specific gravity.

2. Aggregate test apparatus
The apparatus used for quality of an aggregate, are Los Angeles Abrasion Machine, Density, Sand equivalent equipment

C. Marshall Test Apparatus
The apparatus used to conduct Marshall test are Flat bottom metal pans, Round metal pans, Oven and hot plate, Scoop, Thermometers, Balances, Mechanical mixture, Compaction pedestial, Compaction mold, Compaction model, Mold holder.

D. Indirect Tensile Strength Test apparatus
Loading press is capable in applying a compressive load at a controlled deformation rate of 51 mm (2 in) per minute. Loading strips

consisting of 13 x 13 mm (0.5 x 0.5 in) square steel bars for 102 mm (4 in) diameter specimens and 19 x 19 mm (0.75 x 0.75 in) square steel bars for 152 mm (6 in) diameter specimens. Machine the surface in contact with the specimen to the curvature of the test sample.

E. Research Location

The research was conducted in the Transportation Laboratory, Department of Civil and Environmental Engineering, Universitas Gadjah Mada, Yogyakarta.

F. Research Procedure

1. Preparation Phase

In this phase, materials and laboratory apparatus were prepared and checked. Apparatus check up was conducted for its functions, in respect of all the research methods used.

2. Material Preparation Phase

Materials prepared are those that fulfill the specification of the Ministry of Public Works, Institute of Road Engineering (2007) for Hot Rolled Sheet-Wearing Course (HRS-WC) Mixture.

3. Aggregates Gradation

Aggregate grading specification for Hot Rolled Sheet-Wearing Course (HRS-WC) is based on the Ministry of Public Works, Institute of Road Engineering (2007) specification. Gradation used in this research is shown in Table 1.

Table 1. Aggregate gradation for HRS-WC mixture

Sieve size (ASTM)	Percentage of weight passing sieve	
	Specification	Target
¾	100	100
½	90 – 100	95
3/8	75 – 85	80
No. 8	50 – 72	61
No. 30	35 – 60	49
No. 200	6 – 12	9

Source: Ministry of Public Works, Institute of Road Engineering (2007)

4. Asphalt Content Estimate

In Indonesia, asphalt content estimate is calculated based on the Ministry of Public Works, Institute of Road Engineering (2007).

$$Pb = 0.035 \times (\% \ CA) + 0.045 \times (\% \ FA) + 0.18 \times (\% \ \text{Filler}) + C$$

5. Sample Design properties

The Sample design properties can be seen at Table 2.

Table 2. Sample design properties

No	Samples	Toray fly ash (TFA) and stone dust (SD) content variation (triplo/variation)		Number of sample
		TFA (%)	SD (%)	
1.	Marshall Test to identify Optimum Asphalt Content (5 Variation)	100	0	5 x 5 x 3 = 75
		75	25	
		50	50	
		25	75	
		0	100	
2.	Marshall Test on Optimum Asphalt Content	100	0	5 x 1 x 3 = 15
		75	25	
		50	50	
		25	75	
		0	100	
3.	ITS Test on Optimum Asphalt Content Dry-conditioned specimen (ITS$_I$)	100	0	5 x 1 x 3 = 15
		75	25	
		50	50	
		25	75	
		0	100	
4.	TSR Test on Optimum Asphalt Content wet-conditioned specimen (ITS$_{II}$)	100	0	5 x 1 x 3 = 15
		75	25	
		50	50	
		25	75	
		0	100	
Total Samples				120

TEST RESULTS AND DISCUSSIONS

A. Laboratory Test Result

Here is the result of HRS-WC Material Components Tests

Table 3. Coarse aggregate test result

No	Type of Test	Unit	Requirement	Result	Remark
1	Los Angeles abrasion test	%	Max 40	29.5	qualify
2	Asphalt absorption	%	Min 95	98	qualify
3	Water Absorption	%	Max 3	1.6	qualify
4	Bulk specific gravity	gr/cm^3	2.5	2.6	qualify
5	Apparent specific gravity	gr/cm^3	2.5	2.7	qualify

Table 4. Fine aggregate test result

No	Type of Test	Unit	Require-ment	Result	Remark
1	Water Absorption	%	Max 3	1.635	qualify
2	Bulk Specific gravity	gr/cm³	Min 2.5	2.650	qualify
3	Apparent specific gravity	gr/cm³	Min 2.5	2.770	qualify
4	Sand equivalent	%	Min 50	80.40	qualify

Table 5. Fillers test result

No	Type of Test	Unit	Require-ment	Result	Remark
1	Specific gravity of stone dust	gr/cm³	Min 2.5	2.722	qualify
2	Specific gravity of Toray fly ash	gr/cm³	Min 2.5	2.770	qualify

Table 6. Test result of asphalt AC 60/70 ex PERTAMINA

No	Type of Test	Unit	Require-ment	Result	Remark
1	Penetration test (25°C, 5 sec)	0.1 mm	60 - 79	63.80	qualify
2	Softening point *(ring & ball)*	°C	48 - 58	48.25	qualify
3	Flash point *(cleveland open cup)*	°C	Min 200	340	qualify
4	Ductility (25°C, 5 cm/mnt)	cm	Min 100	> 100	qualify
5	Loss on heating (163 °C, 5 hour)	%	Max 0.4	0.0834	qualify
6	Solubility in CCL4	%	Min 99	99.455	qualify
7	Penetration after loss on heating	%	Min 54	92.50	qualify
8	Specific gravity	gr/cm³	Min 1	1.030	qualify

B. Analysis Test Results

1. Marshall Test for Optimum Asphalt Content (OAC) Determination.

Table 7. Optimum asphalt content

No	Toray fly ash variation in the HRS-WC Mixture	OAC
1	0% Toray fly ash – 100% Stone dust	6.8%
2	25% Toray fly ash – 75% Stone dust	7.0%
3	50% Toray fly ash – 50% Stone dust	7.0%
4	75% Toray fly ash – 25% Stone dust	7.1%
5	100% Toray fly ash – 0% Stone dust	7.6%

2. Analysis of the Marshall Test Result
   a) Density in the variations of Toray Fly ash to the Stone Dust filler

Density value shows the density of the compacted mixture and results from the ratio of the weight of a mixture to the weight of a unit volume of a mixture.

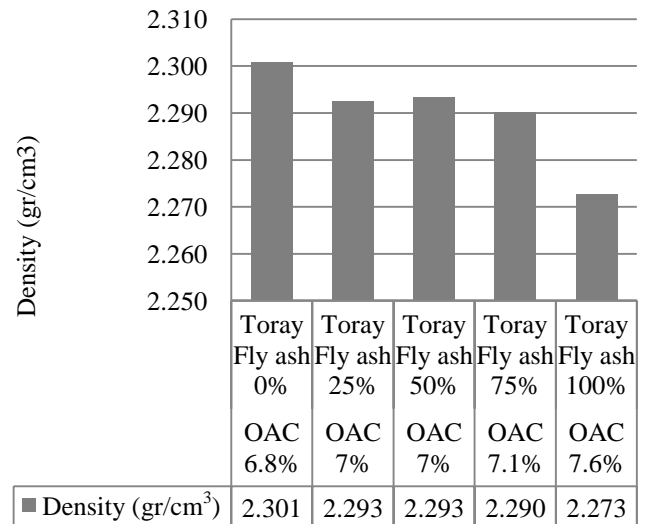|	Toray Fly ash 0% OAC 6.8%	Toray Fly ash 25% OAC 7%	Toray Fly ash 50% OAC 7%	Toray Fly ash 75% OAC 7.1%	Toray Fly ash 100% OAC 7.6%
Density (gr/cm³)	2.301	2.293	2.293	2.290	2.273

Figure 1. Density in the variations of Toray fly ash percentage

As shown in Figure 1, density in variations of 0%, 25%, 50%, 75% and 100% Toray fly ash on optimum asphalt content have the tendency to decrease with the increasing of Toray fly ash percentage in the mixture. Toray fly ash has 2.770 of specific gravity whilst stone dust 2.722. The differences in specific gravity value influence the average specific gravity of mixture variations. Specific gravity of Toray fly ash is higher than stone dust and it generates higher volume in the mixture.

Toray fly ash tends to create mortar with asphalt due to the higher effective asphalt content in a compacted mixture and the increasing of asphalt content will increase the inter-granular voids space between the aggregate particles which is not occupied by aggregate, hence decreasing the density value.

b) VMA in the variations of Toray Fly ash to the Stone Dust filler

Voids in the Mineral Aggregate in a compacted asphalt mixture is defined as the inter-granular void space between the aggregate particles in a compacted asphalt mixture that includes the air voids and the effective asphalt content (Lavin, 2003).

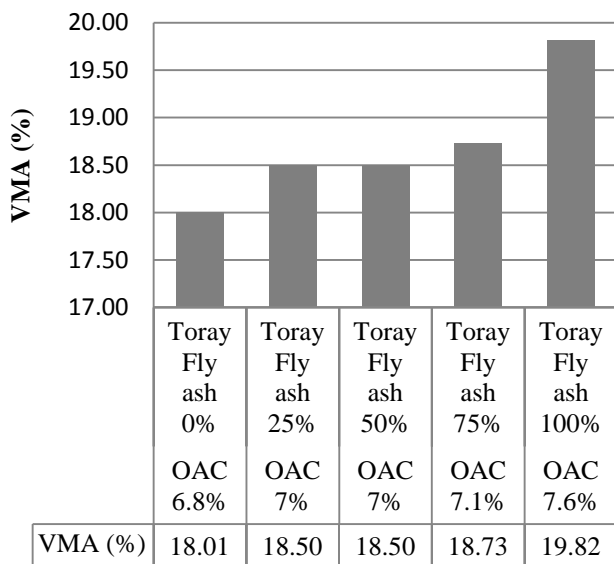|	Toray Fly ash 0% OAC 6.8%	Toray Fly ash 25% OAC 7%	Toray Fly ash 50% OAC 7%	Toray Fly ash 75% OAC 7.1%	Toray Fly ash 100% OAC 7.6%
VMA (%)	18.01	18.50	18.50	18.73	19.82

Figure 2. VMA in the variations of Toray fly ash percentage

Additionally, certain characteristics of a mixture that can change the VMA value and film thickness is *dust proportion*. Lower dust contents decrease surface area, increase film thickness, and tend to raise VMA. Research results shown in Figure 2 depicted that in variation of 0%, 25%, 50%, 75% and 100% Toray fly ash, VMA values in the mixture tend to decrease as the dust proportion decrease in variations. Dust proportions in variations are 1.48%, 1.43%, 1.43%, 1.41% and 1.31% respectively.

c) VITM in the variations of Toray Fly ash to the Stone Dust filler

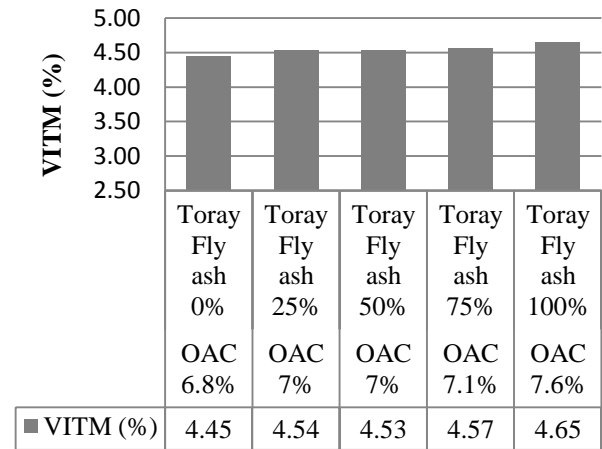|	Toray Fly ash 0% OAC 6.8%	Toray Fly ash 25% OAC 7%	Toray Fly ash 50% OAC 7%	Toray Fly ash 75% OAC 7.1%	Toray Fly ash 100% OAC 7.6%
VITM (%)	4.45	4.54	4.53	4.57	4.65

Figure 3. VITM in the variations of Toray fly ash percentage

The VITM is that part of the compacted mixture not occupied by aggregate or asphalt expressed as a percentage of the total volume. Voids in the Total Mixture generally decreased with increasing asphalt content, until it reaches a minimum air void content. In the research result shown in Figure 3 depicted that VITM in the variation of 0% Toray fly ash is 4.45% on optimum asphalt content, whilst VITM values in variations of 25%, 50%, 75% and 100% Toray fly ash tend to increase with the increasing of Toray fly ash in the mixture. VITM values are 4.54%, 4.53%, 4.57%, 4.65% respectively. Based on Ministry of Public Works, Agency for Research and Development, Institute of Road Engineering (2007) HRS-WC specification, VITM values in overall variations fulfill the requirement.

d) VFWA in the variations of Toray Fly ash to the Stone Dust filler

The percent voids filled with asphalt, VFWA, increases with increasing asphalt content. This should be expected since the VMA is being filled with the asphalt (The Asphalt Institute 1993). VFWA are the percentage of voids filled with asphalt in a compacted mixture, influenced by asphalt content, aggregate gradation, compaction process, and temperature.

Figure 4 depicted that in variations of 0%, 25%, 50%, 75%, and 100% Toray fly ash, VFWA values tend to increase due to the higher volume of mixture with the increasing of Toray fly ash percentage and optimum asphalt content. Hence, asphalt content filled the inter-granular void space between the aggregate particles in a compacted mixture.
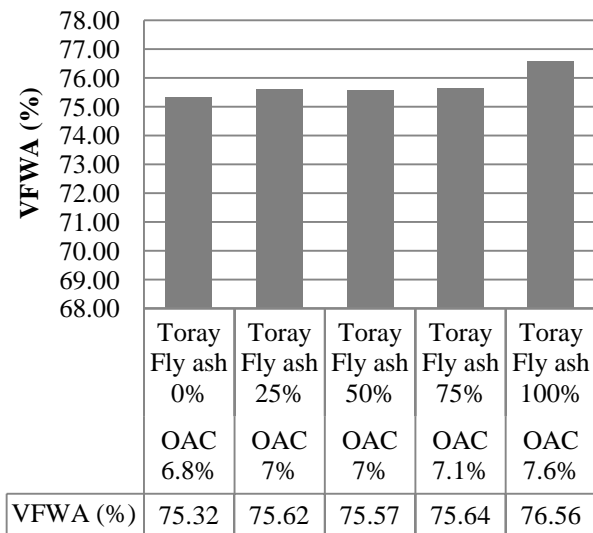

	Toray Fly ash 0% OAC 6.8%	Toray Fly ash 25% OAC 7%	Toray Fly ash 50% OAC 7%	Toray Fly ash 75% OAC 7.1%	Toray Fly ash 100% OAC 7.6%
VFWA (%)	75.32	75.62	75.57	75.64	76.56

Figure 4. VFWA in the variations of Toray fly ash percentage

e) Stability in the variations of Toray Fly ash to the Stone Dust filler

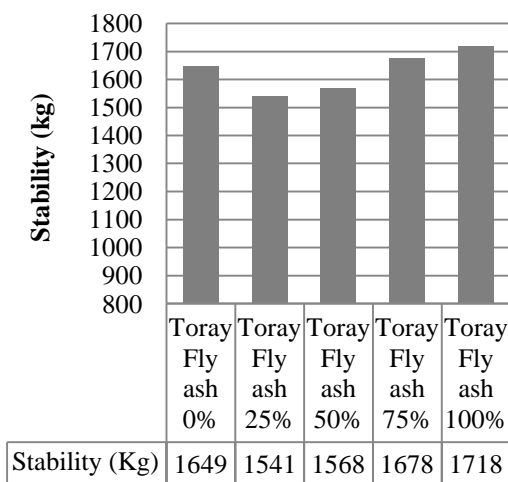|	Toray Fly ash 0%	Toray Fly ash 25%	Toray Fly ash 50%	Toray Fly ash 75%	Toray Fly ash 100%
Stability (Kg)	1649	1541	1568	1678	1718

Figure 5. Stability in the variations of Toray fly ash percentage

As shown in the Figure 5 Marshall Stability of 100% Toray fly ash mixture has a peak value as asphalt content in the mixture well absorbed by Toray fly ash variations.

f) Flow in the variations of Toray Fly ash to the Stone Dust filler

Flow increases with the increasing of Toray fly ash percentage and optimum asphalt content in the mixture is as shown in Figure 6.

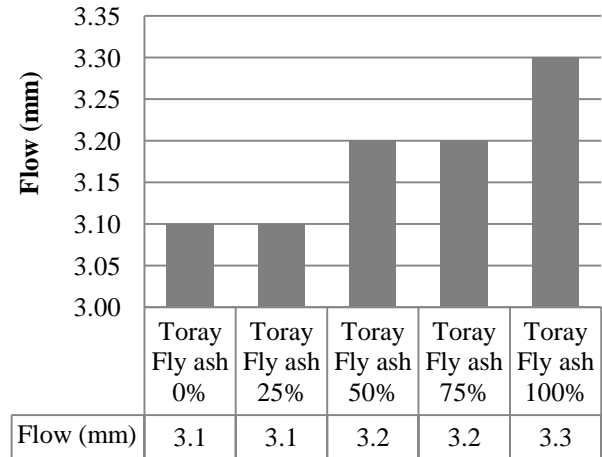|	Toray Fly ash 0%	Toray Fly ash 25%	Toray Fly ash 50%	Toray Fly ash 75%	Toray Fly ash 100%
Flow (mm)	3.1	3.1	3.2	3.2	3.3

Figure 6. Flow in the variations of Toray fly ash percentage

g) MQ in the variations of Toray Fly ash to the Stone Dust filler

Marshall Quotient is defined as the ratio of Marshall Stability to the Marshall Flow. The Marshall Quotient can be used to give an indication of the mixture stiffness. The higher the ratio, the stiffer the mixture is (Whiteoak, 1991).

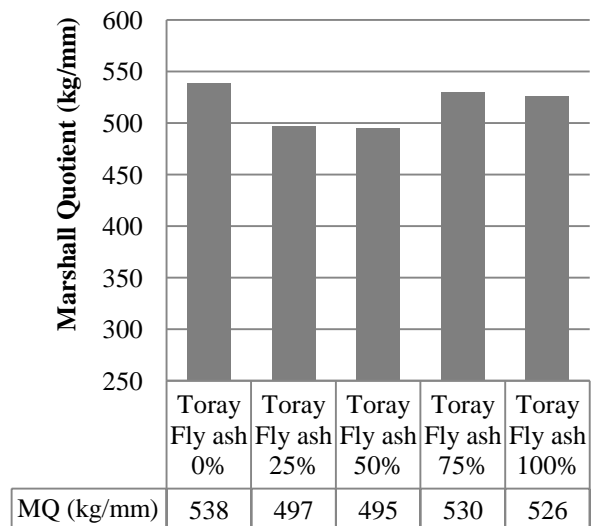|	Toray Fly ash 0%	Toray Fly ash 25%	Toray Fly ash 50%	Toray Fly ash 75%	Toray Fly ash 100%
MQ (kg/mm)	538	497	495	530	526

Figure 7. MQ in the variations of Toray fly ash percentage

As shown in Figure 7, variation of 0% Toray fly ash stiffer than others are, followed by 75% of Toray fly ash and 100% of Toray fly ash in the mixture.

C. ITS and TSR Calculation

Tensile Strength Ratio (TSR) is the ratio of indirect tensile strength value of conditioned specimens (ITS_{II}) to the indirect tensile strength value of unconditioned specimens (ITS_I) based on time series (48 hours). TSR is calculated from the following equation (Robert et.al., 1991):

$$TSR = \frac{ITS_{II}}{ITS_{I}} \times 100\,\% \qquad (7)$$

Indirect Tensile Strength and Tensile Strength Ratio calculations for Toray fly ash variations in HRS-WC Mixture shown are on Table 7. Optimum asphalt content.

D. Analysis on TSR values for Toray fly ash Utilization in HRS-WC Mixture.

According to Asphalt Institute SP-2 (1996), minimum TSR value required is 80%. In the research TSR values shown are in Figure 8. TSR values of Toray fly ash utilization in the HRS-WC Mixture.

As shown in Figure 8. TSR values of Toray fly ash utilization in the HRS-WC Mixture, TSR values tend to decrease with the increasing of Toray fly ash and OAC in the HRS-WC Mixture. TSR values in variations of Toray fly ash are 98.32%, 90.28%, 89.38%, 87.62%, 64.71% respectively, with minimum TSR value required is 80%. Based on overall parameters, the optimum Toray fly ash utilization in the HRS-WC Mixture recommend is *75% Toray fly ash.*

Table 8. ITS and TSR Calculation

% Toray Fly ash	Time Series day	P_{max} (kg)	Thick-ness (cm)	Diameter (cm)	ITS (kPa)	TSR (%)
0	0	981	6.76	10.2	889	100.00
	2	936	6.57	10.2	874	98.32
25	0	847	6.80	10.2	763	100.00
	2	764	6.79	10.2	689	90.28
50	0	847	6.86	10.2	757	100.00
	2	749	6.78	10.2	676	89.38
75	0	734	6.95	10.2	647	100.00
	2	644	6.96	10.2	567	87.62
100	0	764	6.96	10.2	673	100.00

| | 2 | 494 | 6.96 | 10.2 | 435 | 64.71 |

Tensile Strength Ratio (%)

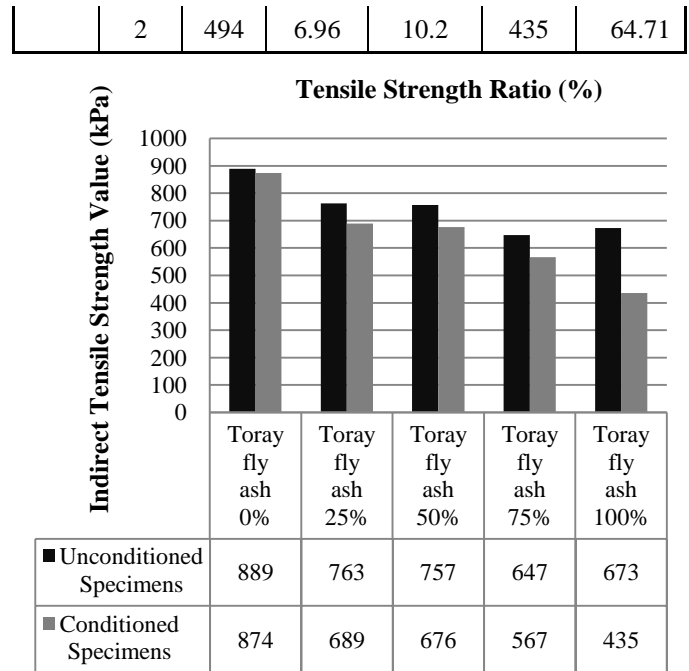|	Toray fly ash 0%	Toray fly ash 25%	Toray fly ash 50%	Toray fly ash 75%	Toray fly ash 100%
■ Unconditioned Specimens	889	763	757	647	673
■ Conditioned Specimens	874	689	676	567	435

Figure 8. TSR values of Toray fly ash utilization in the HRS-WC Mixture

CONCLUSION AND RECOMMENDATIONS

A. Conclusion

Based on the test research, parameters for determining optimum utilization of Toray fly ash as filler substitution in the Hot Rolled Sheet - Wearing Course (HRS-WC) Mixture taken into consideration are:

1. Fly ash utilization has significant environmental benefits, reduction in amount of coal combustion products that must be disposed in landfills and conservation of other natural resources and materials.

2. Toray fly ash is a *Class F fly ash* that fulfills the requirement from Ministry of Public Works, Institute of Road Engineering (2007) specification to utilize as filler in the Hot Rolled Sheet – Wearing Course (HRS-WC) Mixture.

3. Optimum Asphalt Content (OAC) tends to slightly increase with the increasing of Toray fly ash utilization (0%, 25%, 50%, 75%, and 100%) in the HRS-WC Mixture. OAC in the mixture are 6.8%, 7%, 7%, 7.1%, 7.6% respectively.

4. Densities in the HRS-WC compacted mixture tend to decrease with the increasing of Toray fly ash due to the differences in specific gravity value influence the average

specific gravity of mixture variations. Specific gravity of Toray fly ash higher than stone dust and it generates higher volume in the mixture. Toray fly ash tends to create mortar with asphalt due to the higher effective asphalt content in a compacted mixture and the increasing of asphalt content will increase the inter-granular voids space between the aggregate particles which not occupied by aggregate, hence decreasing the density value.

5. VMA increases with the increasing of Toray fly ash utilization (0%, 25%, 50%, 75%, and 100%) in the HRS-WC Mixture. One of the characteristics of HRS − WC mixture that can change the VMA value and film thickness in this research is *dust proportion.* Lower dust contents decrease surface area, increase film thickness, and tend to raise VMA. VMA values in the mixture are 18.01%, 18.50%, 18.50%, 18.73% and 19.582% and dust proportion in variations are 1.48%, 1.44%, 1.44%, 1.41% and 1.31% respectively.

6. Voids in the Total Mix (VITM) slightly increases with the increasing of Toray fly ash utilization (0%, 25%, 50%, and 100%) in the HRS-WC Mixture. VITM values in the mixture are, 4.45%, 4.54%, 4.53%, 4.57% and 4.65% respectively.

7. VFWA increases with the increasing of asphalt content and Toray fly ash utilization (0%, 25%, 50%, 75%, and 100%) in the HRS-WC Mixture. VFWA values in the mixture are 75.32%, 75.62%, 75.57%, 75.64%, and 76.56% respectively.

8. Marshall Stability in 0% Toray fly ash (100% Stone dust filler) is 1649 kg whilst the Marshall Stability utilizing Toray fly ash (25%, 50%, 75%, and 100%) in the HRS-WC Mixture tends to increase with increasing of Toray fly ash percent due to the asphalt content in the mixture well absorbed by Toray fly ash. The highest value of stability is 1718 kg in 100% Toray fly ash utilization and the lowest stability is 1541 kg in 25% Toray fly ash. Marshall Stability of overall Toray fly ash variations meets the requirement.

9. Flow in the HRS-WC compacted mixture 0%, 25%, 50%, 75%, and 100% utilization of Toray fly ash are 3.1 mm, 3.1 mm, 3.2 mm, 3.2 mm, and 3.3 mm respectively. Flow value increases with the increasing asphalt content, the higher the asphalt content, the greater the specimen deforms under load (Patrick G. Lavin in Asphalt Pavements, 2003).

10. Marshall Quotient (MQ) in the HRS-WC compacted mixture 0%, 25%, 50%, 75%, and 100% utilization of Toray fly ash are 538 kg/mm, 497 kg/mm, 495 kg/mm, 530 kg/mm, and 526 kg/mm respectively.

11. Indirect Tensile Strength (ITS) value in 0% Toray fly ash (100% Stone dust filler) is 889 kPa, whilst the ITS values utilizing Toray fly ash 25% is 763 kPa, 50% Toray fly ash is 757 kPa, 75% Toray fly ash 647 kPa, 100% Toray fly ash is 673 kPa.

12. Tensile Strength Ratio (TSR) value in 0% Toray fly ash (100% Stone dust filler) is 98.32%, whilst the TSR value utilizing Toray fly ash 25% is 90.28%, 50% Toray fly ash is 89.38%, 75% Toray fly ash is 87.62% and 100% Toray fly ash is 64.71%. TSR value minimal *80%* is the standard requirement.

B. Recommendations
1. Further research is considered necessary to study the maximum percentage of Toray fly ash in the HRS-WC Mixture.
2. There is a need for further research to study the influence of anti stripping or adhesion agent to improve the performance of Toray fly ash filler in the mixture and is tested for its susceptibility in moisture damage.
3. Ideal research methodology is required to produce asphalt mixture design which is consistently applied to the closest simulations of the field condition.

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