The Performance of Various Hot Mixed Asphaltic Concrete Component Types Affected by Flood and Temperature

Eva Azhra Latifa[a]
[a] Lecturer of State Polytechnic of Jakarta, Depok 16425, Indonesia
E-mail :evaalmy@gmail.com

Abstract: This research is part of the topic on finding the best composition of hot mix asphaltic concrete resistant to flooding and variations of temperature. This research was done by increasing the performance of asphaltic concrete using stone dust, fly ash and Portland Cement as aggregate filler, polyethylene terephthalate (PET) wastes as an added material of asphalt, and refined Buton asphalt. Each asphaltic concrete mixture is submerged for 24, 72 and 120 hours, assuming the longest time of flooding submersion. The Marshall characteristics were tested and calculated by regression analysis. The results showed that, under the worst conditions, retona blend is recommended as binder and Portland Cement is recommended as filler. Fly ash showed good performance, although further research is needed to determine its resistance to abrasi on and being slippery. PET also needs more investigation to minimize flow under the worst condition.
Keywords : aggregate filler**,** asphalt additive, flooding submersion, hot mixed asphalt, temperature

1. INTRODUCTION

Floods caused by the recent heavy downpour frequently occurring in Jakarta pose significant aggravation to the economy and daily lives of the citizens. Various approaches have been carried out in order to minimize the heavy damage suffered by infrastructures that deterioriated quicker than they should.

The general problem with asphaltic concrete mixture is its lack of resilience to traffic load and high air temperature stated by Ginting (2011). Problems escalate in lowlands with higher likeliness of getting hit by floods and the road drainage system not functioning as it should. Damage caused by a flood starts with exfoliation on the asphaltic concrete layer, continued by the forming of a hole due to the loose bonds between asphalt and aggregate which creates deformation and, in the end, lowers the durability of asphaltic concrete. Damage escalates as road temperature increases due to the sunlight and the friction of wheels as the roads are not designed for long-term submersion.

In accordance, a research is carried out on the durability of hot mix asphaltic concrete under submersion and increasing temperature as simulated with the test example at the laboratory. This research aims to obtain the economical asphaltic concrete mix with high durability to flood submersion at high temperature. The expected outcome of this research is a high-quality design of an economical mixture as a solution to the road damage problems caused by the effects of floods.

Improvement on performance is done in various ways. First, the asphaltic concrete mixture is made more impermeable by using filler aggregate with finer grains such as Portland cement and fly ash. Next, the performance of asphalt is improved by adding mineral water bottle wastes, referred to as PET (*polyethylene terephthalate*) from now on, and adding processed natural asphalt from Buton Island in Indonesia into cement asphalt (which is composed of residual petroleum oil). The methods employed to increase the performance of asphaltic concrete include stabilizing the amount of pores, keeping the stability value above requirements, preventing the flow value from decreasing drastically so that the mixture would retain sufficient stiffness even under the worst conditions caused by an increase in temperature and submersion time.

2. LITERATURE REVIEW

The construction of asphaltic concrete layer is intended to attain a kind of surface layer or a layer between road pavements that is able to exert measurable resilience and function as an impermeable layer that can protect the construction below. As a surface layer, asphaltic concrete needs to be able to exert high comfort, durability and strength. Asphaltic concrete is also needed to repair roads with high volume of traffic load which is not possible to halt for the sake of reparation.

However, as is known, asphaltic concrete is a material that is prone to deformation due to external influences such as temperature change and flood water submersion which is a common occurence in Jakarta, Indonesia. Therefore, it is necessary to come up with a way for asphaltic concrete to attain the resilience to withstand such influences; for example, by manipulating the forming materials so that they can withstand the influence of climate and load. The submerged of asphalt road pavement can result in reduced quality, which is marked by the release of granules aggregate bonding of asphalt and peeling of asphalt from road construction (Amal 2009).

Asphaltic concrete layer is expected to have the following characteristics: being resistant to wearing out caused by traffic; being impermeable so that it can protect the construction layer below from the effects of water and the weather; possessing structural value able to support heavy traffic; possessing enough sensitivity to deviation in planning and execution so that sufficient accuracy is needed in both planning and execution.

The preservation potential of asphaltic concrete mixture can be defined as the mixture’s resistance to the effects of damage combination due to water and the temperature. Continuous flood submersion of roads is predicted to cause damage on a large part of the road infrastructure, affecting the stability of asphaltic concrete pavement layer stated by Bowoputro (2009). Rainwater submersion with low pH and relatively high oxygen causes asphalt to experience degradation. This affects the bonds between asphalt and aggregate and causes deformation which, in the end, diminishes the durability of asphaltic concrete. This deformation gets worse under high temperature which works on the road surface through the friction of wheels caused by braking and the reduction of velocity due to traffic congestion. The duration of submersion is also important as a measurement of casualties caused by this flood disaster stated by Widodo (2010). If there is an extending crack followed by water infiltration to the foundation layer, it can also affect the performance of the road pavement structure.

Durability is affected by the small air pores, the thickness of the asphalt blanket, and well grading, is needed in the mixture, especially for the surface layer in order to be able to resist layer disintegration of aggregate and asphalt films from aggregate loss due to polymerization and oxidation of asphalt. This happens due to the influence of temperature, air, water, and traffic load stated by Latifa (2011).

Continuously graded aggregate can provide small voids in mineral aggregate (VMA), because the pores formed by the arrangement of large aggregates will be filled by smaller aggregates. This situation produces a high stability, but requires lower bitument to bind the aggregate. Asphalt with smaller VMA can result in limited aggregate envelop and produce thin films of asphalt,making asphalt easily taken apart, resulting in layers no longer watertight, easy oxidation and pavement layers become damaged. Whereas, the use of much blanket asphalt can lead to excess aggregate due to the small VMA being prone to bleeding.

Fillers consist of fine-grained materials that pass sieve No.. 200 or 0.075 mm with a minimum of 75%. The filler is used to fill the voids between aggregates in order to reduce the size of the pores and increases the density and stability of the pavement layer. Nowadays, hotmix asphaltic concrete generally uses a filler consisting of a mixture of stone dust, limestone dust, cement, non-plastic materials and others in its use as a filler in asphaltic concrete. Portland Cement and fly ash are used because they are easy to find and provide better results for asphaltic concrete mix stated by Latifa (2011).

Asbuton is a kind of Indonesia's natural asphalt that is more flexible and durable than petroleum asphalt.The content of bitumen in Asbuton varies greatly, starts from 10% to 30%. Too much use of the Asbuton grain will result in a very stiff and brittle mixture. Therefore, conventionally, Asbuton is processed before use in order to improve the performance of asphaltic concrete mixture. Retona Blend 55 is consists of oileum asphalt and refined Buton Asphalt. It is a mix of oil asphalt and Buton Asphalt, after having been extracted and has very good flexibility. Buton Asphalt makes up to about 45% to 55% of the asphalt. Unfortunately, at 60°C, it starts to get soften. This combination of oil asphalt and Buton Asphalt is expected to be able to increase the asphaltic performance.

PET is the third largest polymer product after the Polyethylene and Polypropylene. Its characteristics are clear: tough; resistant to solvents; density: 1.4 g/cm^3: 1.370 g/cm^3 (amorphous): 1.455 g/cm3 (crystal); Modulus of Elasticity (E): 2800-3100 MPa; tensile strength 55-75 MPa. Glass temperature (Tg): 75^0 C. The melting point of 260^0 C can be achieved. Thermal Conductivity: 0.24 W / m.K. (Kautsar, 2012).

Environmental experts say that plastics are made from non renewable natural resources that can not be substituted, namely oil, causing toxic gas to emerge when it is burned in landfills–which also contributes to global warming because of the energy used to produce it, and the heat that at the time accumulates from the burning trash. Undegraded plastics,after disposal,break into tiny particles and contaminate soil, rivers and the sea. Discarded plastic trash poisons marine life. (Huda, 2008). PET wastes are added to the asphaltic concrete mix with the expectation not to only improve their performance, but also to make an environmentally friendly product.

3. METHODOLOGY

The first thing done in order to obtain supporting data for the research is laboratory testing. Before making hot mix asphaltic concrete samples, the forming material data is also needed. Characterstics of the affecting aggregate and asphalt are tested. The obtained data is then used for mix design in order to obtain the Marshall characteristic values.

Before designing the asphalt needed for the mixture, first the aggregate is blended in order to get the right proportion of coarse aggregate, fine aggregate and filler aggregate for the Laston ACWC mixture in accordance with the requirements of Highways Department of Public Works, 2010. From each aggregate proportion percentage, the next step is estimating the optimum asphalt values in accordance with the available aggregate gradation to fulfill the mixing mechanical characteristics as required.

Any kind of additional filler, either Portland Cement or fly ash, the addition of PET, and the use of refined Buton Asphalt (retona) 55, has experienced trial and error and the best result is processed further.

This mix design then undergoes testing in laboratory to get the Marshall characteristic values. Marshall Test is the most famous and widely used method in Indonesia for estimating and assessing the properties of asphaltic concrete mixtures. Although Marshall characteristics apparently do not significantly describe the performance of asphaltic concrete as a whole, for the initial step, the test results are acceptable as a depiction of the performance of hotmix asphaltic concrete.

Hot mixed asphaltic concrete is made in four types as follows:

1. Stone dust filler aggregate with retona blend 55 as the bitumen
2. Stone dust filler aggregate with petroleum asphalt pen 60/70 with PET added
3. Fly ash filler aggregate with petroleum asphalt pen 60/70
4. Portland cement filler aggregate petroleum asphalt pen 60/70

The reference is the mix with stone dust filler and petroleum asphalt pen 60/70. The planning of the mix has produced an optimal asphalt percentage taken from laboratory sampling data. It is assumed that the conditions on the field differ from those of the planning. During emergency conditions where the materials present do not match what was planned, aggregate and asphalt fillers are substituted with the aforementioned materials, albeit based on the already-obtained optimal asphalt percentage.

Sample is submerged in water at different times and under different temperatures as simulating the conditions of asphaltic concrete submerged at maximum temperature. At 30^0C, the submersion lasts for 24 hours; at 38^0 C, 72 hours; and,at 50^0 C, 120 hours. The maximum temperature is 50°C, in accordance with the highest estimation received by roads during congested traffic hours in the afternoon. With 25°C as the test's standard, an amount is picked up in the midst to determine the slope graphic. The average flood submersion time in Jakarta is 72 hours. To achieve the worst conditions that asphaltic concrete can still endure, the submersion time is increased, while still being within the maximum temperature that works on the roads.

4. ANALYSIS.

Asphalt specific gravity, penetration, softening point, ductility and flash point value all depict the composition of asphaltene and maltene, which determines its adhesiveness. The flash point testing is meant to determine the temperatures at which asphalt ignites and then burns Softening point is tested at 5°C of temperature, whereas the rest are all tested at 25°C.

Table 1 shows the results of testing the physical properties of asphalt in accordance with the requirements of Highways Department of Public Works, 2010 Edition. According to the results of testing, it is obtained that asphalt is included in the group with a 60/70 penetration and minimum 48^0 C softening point; suitable for roads with large traffic volumes and high temperature of road surface.

4.1 Asphalt testing

Table 1 Asphalt testing tabulation

Test	**Results**		**Specifications Bina Marga 2010**
	Pertamina Pen 60/70	**Retona Blend 55**	
Density	1,025	1,059	Min 1,0
Penetration	*71,66*	61,778	60-79
Softening Point	$48{,}25^0$C	$50{,}25\ ^0$C	48-58
Ductility	107,5 cm	112 cm	Min 100
Flash Point	$326\ ^0$C – $338\ ^0$C	$310\ ^0$C – $325\ ^0$C	Min 200
Solubility	99,8%	99,9 %	Min 99%

4.2 Aggregate testing

Table 2. Aggregate Testing tabulation

No	Test	Results		Requirements
		Coarse aggregate	Fine aggregate	
1	Apparent Relative density	2,511	2,6	Min 2,5
2	Bulking relative density	2,495	2,501	Min 2,5
3	Moisture content, %	0.886	1.99	Max 3
	Material finer than 200 μm, %	0,53	5,46	Max 1 and 8
4	Los Angeles abration,%	29.1	--	Max 40

Table 2 shows the results of testing the physical properties of coarse and fine aggregate. Aggregate characteristics are in accordance with the requirements. Test results with specific gravity greater than 2.5 indicate that the aggregate can be used on roads with large volumes of traffic and high temperature.

Table 3. Filler Testing tabulation

No	Type	Relative Density
1	Stone dust	2,60
2	Portland Cement	3,10
3	Fly ash	2,51

Table 3 shows the relative density of filler resulted from the test. Portland Cement has the highest relative density compared to stone dust and fly ash. Relative density values are related to the density of compound materials, while Portland cement is composed with more complete materials than the fly ash and stone dust, so Portland cemen thas a greater relative density

The equation to obtain the percentage of each aggregate is done as follows:

$$Y = Ya\frac{a}{100} + Yb\frac{b}{100} + Yc\frac{c}{100} \qquad (1)$$

$$a + b + c = 100\% \qquad (2)$$

Where,
Y : percentage of each aggregate from the definitive hole of the curve that uses aggregate
Ya : ordinate of the curve aggregate A on the same hole with sieve Y
Yb : ordinate of the curve aggregate B on the same hole with sieve Y
a,b,c : percentage of each aggregate on the same hole with Y

Table 4. Blending Aggregate

Sieve		Coarse Aggregate		Fine Aggregate		Filler		Total	Spec of Bina Marga 2010	
No.	(mm)	100	38%	100	52%	100	10%		Fine	coarse
1 1/2"	37,5									
1"	25									
3/4"	19	100	38	100	52	100	10	100	100	100

1/2"	12,5	99,07	37,65	100	52	100	10	99,65	90 -100	90 - 100
3/8"	9,5	78,89	29,98	99,88	51,94	100	10	91,92	72 - 90	72 - 90
No. 4	4,75	5,82	2,21	86,61	45,04	100	10	57,25	54 -69	43 -63
No. 8	2,36	1,24	0,47	62,77	32,64	100	10	43,11	39.1 - 53	28 - 39.1
No. 16	1,18	1,02	0,39	43,98	22,87	100	10	33,26	31.6 - 40	19 -25.6
No. 30	0,6	0,94	0,36	30,96	16,10	100	10	26,46	23.1 -40	13 - 19.1
No. 50	0,3	0,76	0,29	20,39	10,60	100	10	20,89	15.5 - 22	9 - 15.5
No. 100	0,15	0,64	0,24	10,18	5,29	100	10	15,54	9.0 - 15	6.0 - 13
No. 200	0,075	0,53	0,20	5,46	2,84	75	7,5	10,54	4.0 - 10	4.0 - 10

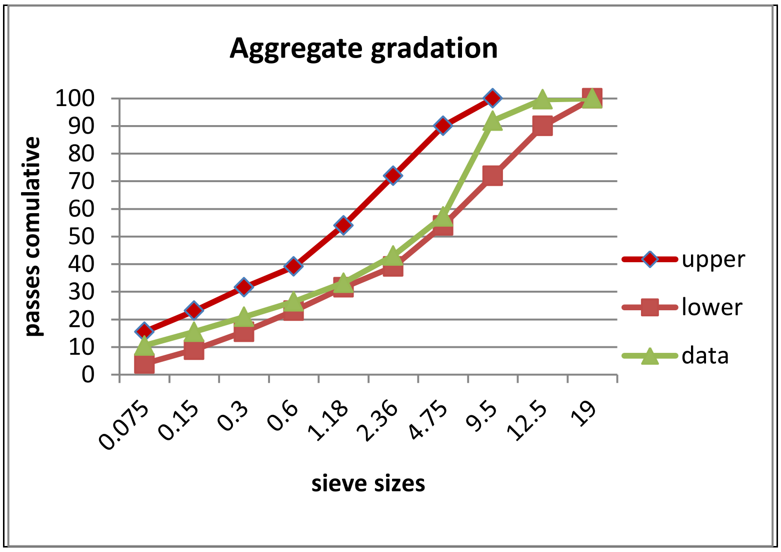

Fig 1 Blending aggregate based on Highways Department of Public Works, 2010

Table 4 and fig 1 show aggregate blending according to the requirements of Highways Department of Public Works, 2010. There is no restriction zone in this requirement, but it is automatically included. The initial blending aggregate filler used as reference is stone dust. Fly ash and Portland Cement are then used as a comparison. Each of them is used directly replace the stone dust without changing the composition of blending with reasons as above

4.3 Designing mixture

From the aggregate blending data estimation, asphalt percentage is calculated. In preliminary tests to determine the characteristics of the mixture with three variations of filler aggregate, the obtained optimum bitumen percentage is 6.4%, obtained through the following equation:

$$Pb = 0.035\,(\%CA) + 0.045\,(\%FA) + 0.18\,(\%filler) + K \qquad (3)$$

Where,
Pb : percentage of binder
CA : % coarse of aggregate retained no 8

FA : % fine of aggregate passed no 8
K : constants from type of hot mixed asphalt

The same mixtures with various aggregate filler are then used on this test. Trial mix formula is applied to get a precise optimum asphalt percentage of asphaltic concrete mixture which is then determined based on a number of different asphalt percentages to certain aggregate graded by trial and error.

4.4 Marshall Test

Marshall Testing is done by destroying the test samples to determine the characteristics of hot mix asphaltic concrete, as expressed in stability, flow and Voids in Mineral Aggregate (VMA), Voids Filled with Binder (VFB) and Voids In Mixture (VIM).

According to the research's aim, Marshall's specimenis submerged for varying durations. The maximum submersion time is five days, which is equal to one hundred and twenty hours as the real maximum approximate flooding time in Jakarta. Data analysis using linier regression and chart of each Marshall's properties with the same aggregate gradation using three types of filler and each type of asphalt's percentage. shown on Figure 2 to figure 8 below

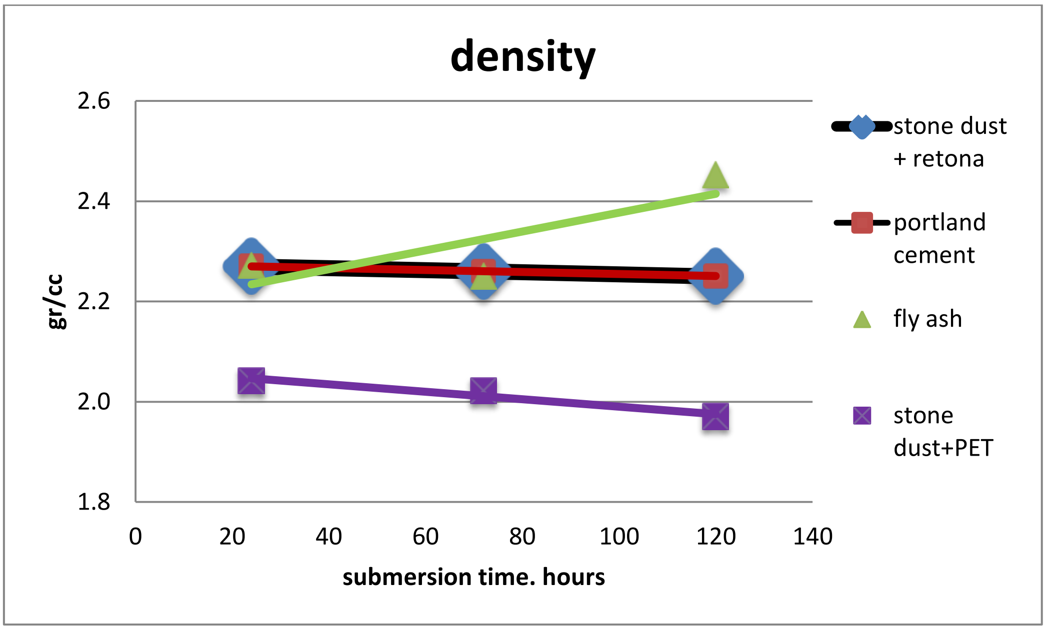

Fig 2 Marshall Density

The Marshall density of each mixture is shown on fig 2; where stone dust filler with Retona asphalt has the same value as Portland Cement filler, and shares the same pattern with Portland Cement as well as stone dust with PET. Density decreases along with the increase in temperature and submersion time while fly ash shows the opposite trend. It can be analyzed that, as submersion time increases, volume increases while weight stays the same. Therefore, all density value except the fly ash mix decreases. It is thus necessary to conduct a further research.

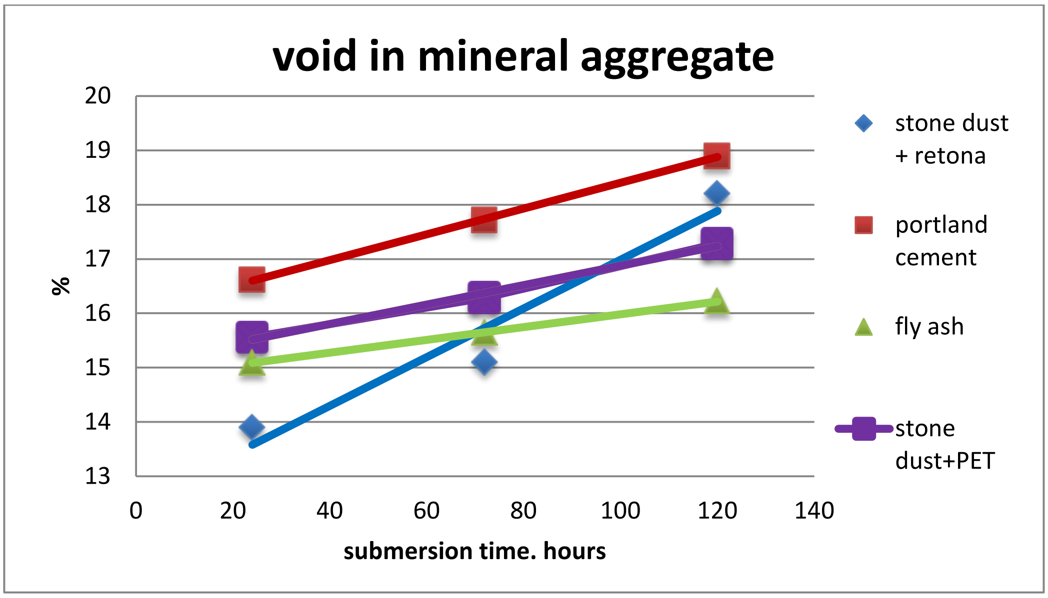

Fig 3. Void in Mineral Aggregate

Void In Mineral Aggregate for all mixture increases with increasing temperature and submersion time as shown on fig 3. Increasing void in mineral aggregate value means two things: an increase the number of voids in mixture or an increase the number of voids filled with binder.

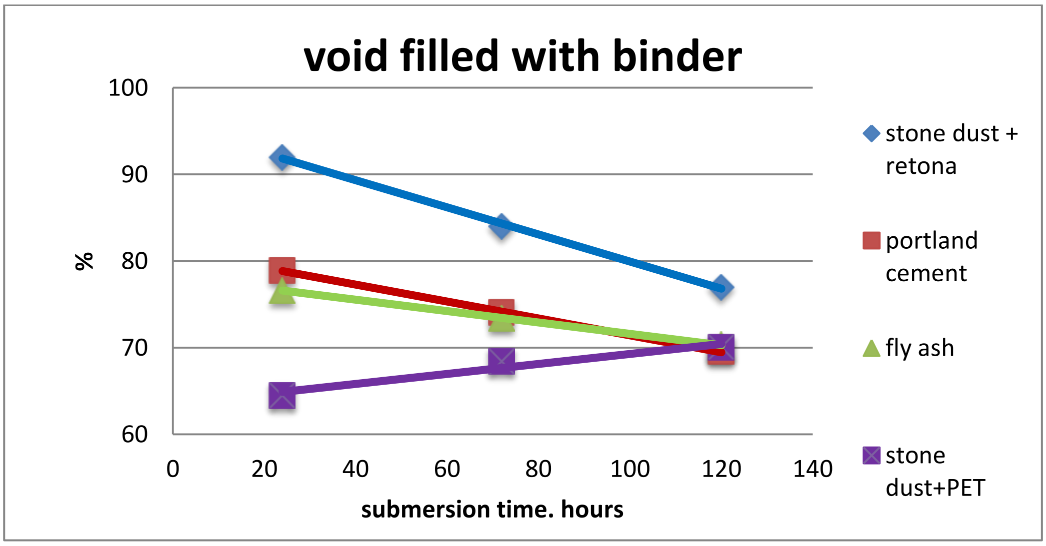

Fig 4. Void Filled with Binder

Void filled with binder of all mixtures decreases with increasing temperature and submersion time, while stone dust added PET shows the opposite trend, as shown in fig 4. It can be analyzed that, as submersion time increases, the bond between aggregate and asphalt loosens as there is water in between with sufficient temperature to cause asphalt to begin to melt. It is possible for bleeding to happen, where asphalt detaches itself from the bond and is replaced by water.

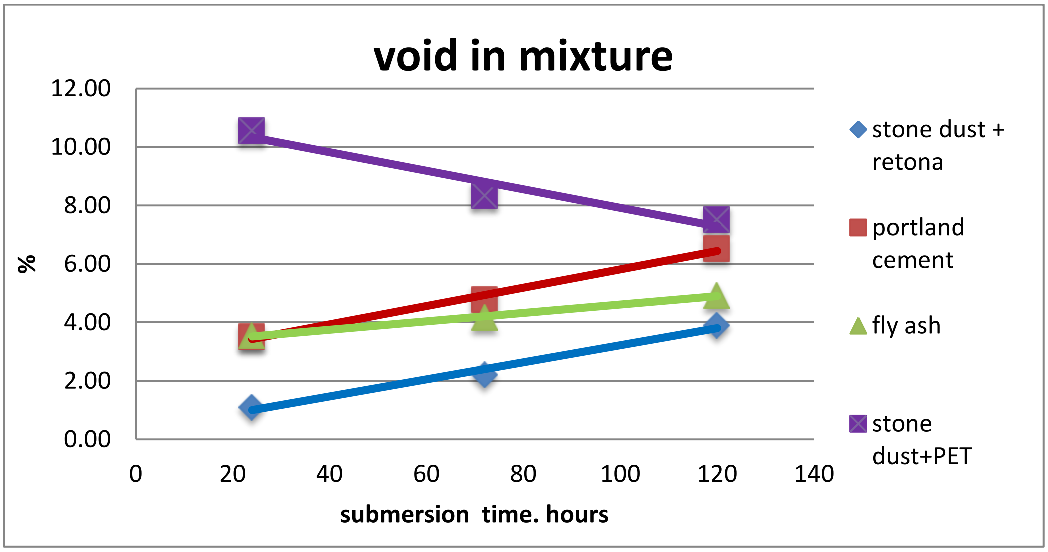

Fig 5. Void In Mixture

Fig 5 shows that Void In Mixture of all mixtures increases with increasing temperature and submersion time while stone dust added PET shows the opposite trend. It is analyzed that if temperature and submersion time increase, the bond between aggregate and asphalt loosens or even detaches so that void increases. In particular, for asphalt added with PET which shows the opposite trend, it is indeed possible that PET starts to melt, despite the literature review stating that the melting point of PET is 260 C. However, it is uncertain whether PET as a mineral water bottle has the exact same substance as stated in theory.

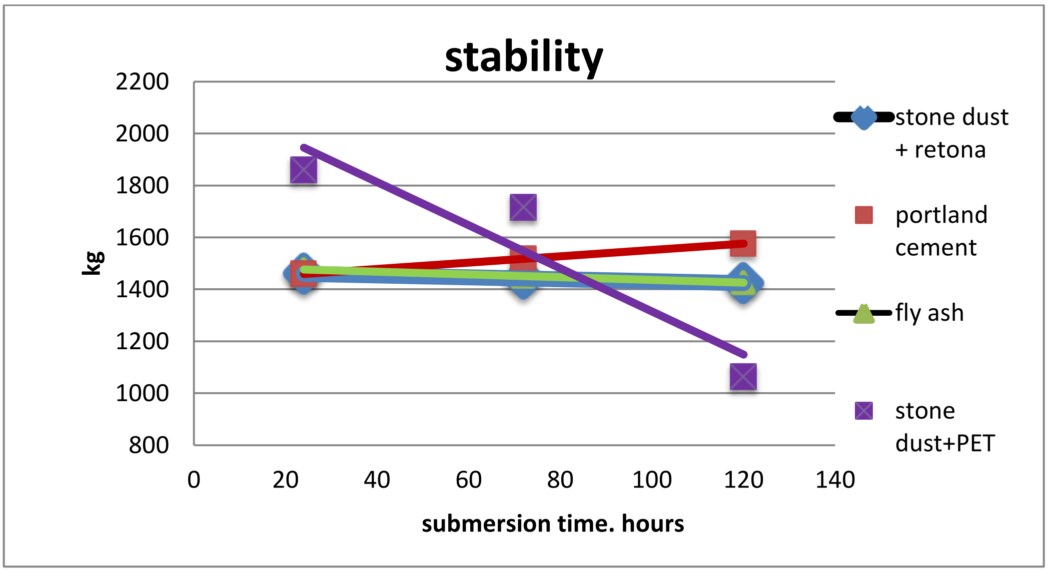

Fig 6.Marshall Stability

Marshall stability, as shown in fig 6, indicates different results. In line with increasing temperature and submersion time, the stability of fly ash and stone dust increases just a little, whereas Portland Cement has significant increments and the stone dust added PET mixture tends to decrease. But all of the stability meet the requirement of Highways Department of Public Works, 2010. This situation makes discussions interesting over whether the Portland Cement compound, when submerged at 50C of temperature, undergoes hydrative reactions and develops its strength as hydraulic PC.

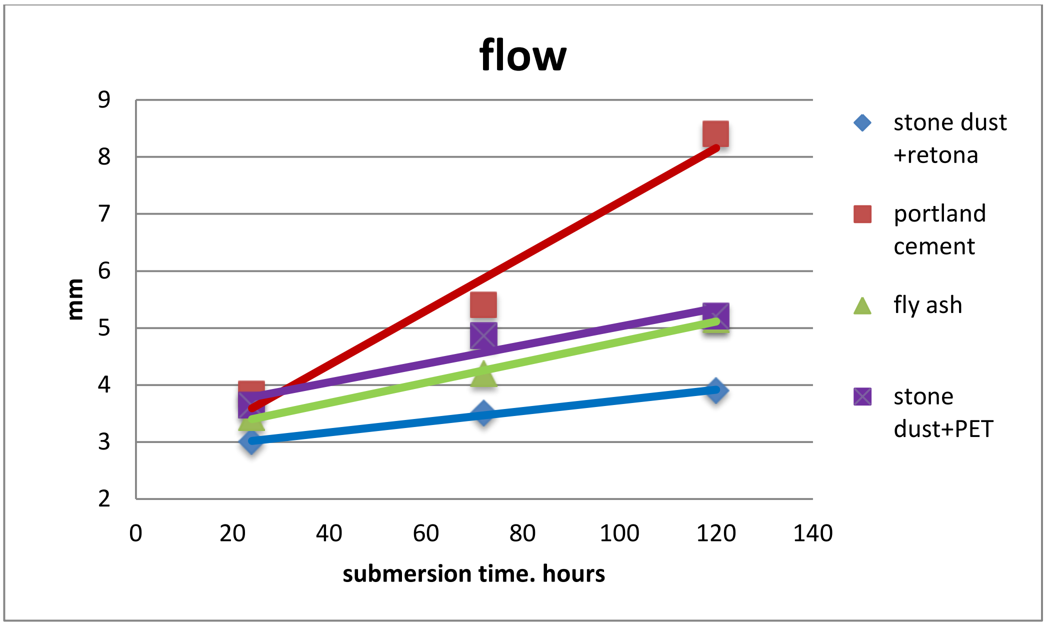

Fig 7. Marshall Flow

Fig 7 shows that all of Marshall flow mixture increases in line with increasing temperature and submersion time. It is a given that flow increases as asphalt submerged for a long time under high temperature tends to start to melt. However, the question is, instead, why the Portland Cement has the highest melting rate, when it is resistant to heat increase below 100C. This demands further research.

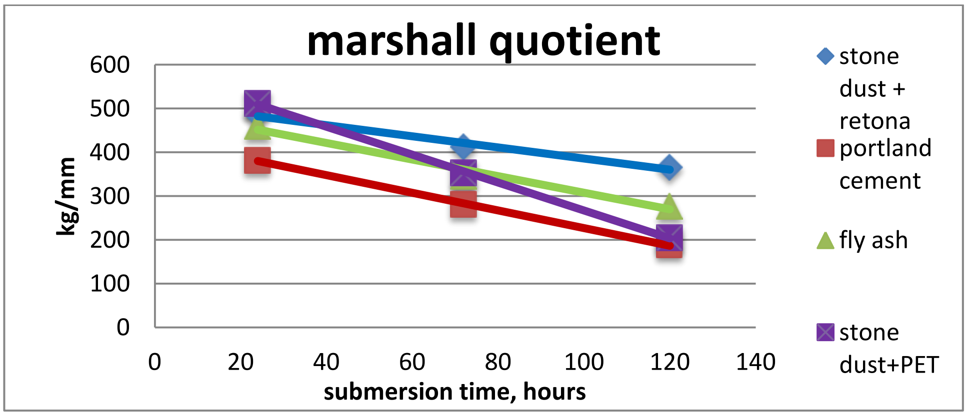

Fig 8. Marshall Quotient

All the mixtures show an identical trend, that they decrease as submersion time and temperature increase, despite the stability condition and flow of each mixture not having an identical trend.

5. RESULT AND DISCUSSION

PET

The addition of PET is meant to increase Marshall stiffness without losing its ductility, as well as reducing the pores of mixture. However, after being submerged for 120 hours at temperature of 50^0 C the density decreases, stability decreases,flow increases and the Marshall Quotient decreases significantly because asphalt that contain PET starts to melt. In accordance with the melting, the pores diminish but remain bigger than other mixes. On the implementation PET is, technically, rather hard to work on because molten PET will harden due to the air, although it remains on its melting point.

Retona Blend 55

The Asbuton addition into petroleum asphalt shows an increase in asphalt performance and, consequently, mixture performance. As shown in fig 6, while its stability may not be very high, it also has the lowest deformation, as shown in fig 7; therefore, its Marshall Quotient remains the highest among all the mixtures. Consequently,void in mixture is also the lowest, whereas void filled with asphalt is the highest among all the mixtures.

Fly Ash and Portland Cement as Filler

Both materials have similar fineness and usually uses as hydraulic cement. However, in asphaltic concrete mix, there is no water as a reactant medium and, as such, both of them function as pore fillers. Their behavior also shares the same tendencies on forming pores or to mixture resilience. The density of fly ash increases significantly as time passes and along with submersion temperature. Portland Cement, however, has higher hardness than fly ash, causing mixtures to have higher stability and, unfortunately, higher flow as well. What is interesting is that stability increases as mixture is submerged at high temperature, which raises a question on whether Portland Cement does its function as hydraulic cement as it is exposed to water at high temperature which helps its hydration reaction.

6. CONCLUSION

Based on the research that has been conducted in accordance with its objectives, which is to get an economical asphaltic concrete mixture with high durability to flood submersion at high temperature, it can be concluded that:

a. Under the worst conditions, i.e. 50^0C of temperature and 120-hour-long submersion time, retona blend is advised as the binder for hot mixed asphaltic concrete

b. Under the worst conditions, i.e. 50^0C of temperature and 120-hour-long submersion time, Portland Cement is advised as filler
c. As all the materials for asphaltic concrete will be used as flexibel surface layer pavement, it is important to find a material that will get eroded and become slippery after undergoing friction against wheels of vehicles. Despite showing fine performance, fly ash needs to be assessed further on its resistance to wearing out on mixture to ensure that it is not prone to friction and being slippery.
d. The PET research result shows high Marshall Quotient under room temperature and 24 hours of submersion time; however, further research is necessary to decrease its melting rate under submersion at 50^0C for 120 hours.

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