The Use of Waste Materials to Modify Binder in Asphalt Concrete

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ABSTRACT: The behaviour of the asphalt concrete mix containing waste materials in binder was studied. Waste materials used in this research are fly ash and plastic milk cartoon. The waste materials were prepared with different content by weight of binder and modified binder properties have been evaluated in terms of penetration test at various temperatures (25^{o}C, 30^{o}C, 35^{o}C and 40^{o}C) and softening point test. The laboratory test revealed that the penetration values of modified bitumen were found lower than unmodified bitumen but the softening values showed higher than unmodified bitumen. Marshall tests were carried at optimum bitumen content to evaluate the effect fly ash and plastic milk cartoon on the properties of asphalt concrete in terms of rutting resistance (stability), unit weight, air void in mix, void in mineral aggregate and stripping resistance. Test results showed that the performance of bitumen mixes prepared using waste materials as modifier were better than origin bitumen mixes.

KEY WORDS: Waste materials, fly-ash, plastic milk carton, rut resistance, voids, asphaltic concrete

1. INTRODUCTION

Many cities in developing countries face serious problems in managing solid wastes. Rapid development and changing lifestyles in growing cities have also changed waste composition from mainly organic to mainly plastics, paper, and packaging materials. This issues related to disposal have become challenging as more land is needed for the ultimate disposal of these solid wastes. Several major cities in developing countries such as Asian countries have reported problems with existing landfill sites [3,9].

Using industrial waste materials in the asphalt concrete pavement cannot only eliminate environmental problems and but also many studies shown they can improve some properties of the pavement [7]. Fly ash and plastic bottle are solid waste materials which fly ash is a by-product of coal-fired power generation. In Indonesia approximately produced 100 million tons of fly ash and over 150.000 tons of waste plastics annually [9]. From the economic viewpoint, Fly ash and plastic milk cartoon may be quite possible used in asphalt concrete to improve engineering properties of asphalt concrete and increase its service life because using modified binder in asphalt pavement is expensive material.

The asphalt concrete as a wearing course mix has been widely used in Indonesia and the most common mode of failure in Indonesia roads is the permanent deformation (rutting) especially in the wheel track. This resulted in increased traffic volume, heavy loaded and the high ambient temperature because Indonesia as climatic conditions are much warmer than in the United Kingdom and the United State of America which the maximum, mean and minimum pavement temperature in Indonesia are 50^{o}C; 37.5^{o}C and 25^{o}C respectively [1].

There are several factors affecting the magnitude and the rate of permanent deformation (rutting) on the road pavement. The major factors affect the pavement performance resistance to rutting is binder in asphalt concrete mix [1]. Modifiers such as fly ash and polymer are included in asphalt concrete mixture to impart greater stability and strength. [7].

The objective this study was to investigate the effect of the amount between fly ash and plastic milk cartoon added to bitumen on both properties modified bitumen and asphalt concrete mixture. The asphalt concrete properties were studied using Marshal test in terms of optimum asphalt content, rutting resistance (stability), density, air void, void in mineral aggregate and stripping resistance.

2. MATERIALS USED

Waste materials as modifier used in this study are fly ash and plastic milk cartoon to modify penetration grade bitumen 60/70 which it is widely used in Indonesia for asphalt concrete. Fly ash used in this study was collected from Kilroot's power station. The properties and the chemical composition of fly ash can be seen in Table 1.

Table 1. The Properties of Fly Ash

ITEM	B.S. 3892 — Part 1 1997 Specification	Example of a typical Kilroot Result
Moisture Content	Max 0.5%	0.25%
Fineness (45 µm sieve residue)	Max 12%	9%
Particle Density	Min 2000 kg / m³	2350 kg / m³
Water Requirements	Max 95%	94%
Loss on Ignition	Max 7%	4%
Chloride	Max 0.1%	0.00%
Sulphuric Anhydride (SO3)	Max 2.0%	0.8%
Calcium Oxide (CaO)	Max 10.0%	4.5%

Source: www.conexpo.co.uk

Plastic milk cartoon used in this study was obtained from local household waste. Waste plastics milk cartoon, predominantly composed of High Density Polyethylene (HDPE). HDPE milk cartoon were cut into small pieces of approximately 2 x 2 mm^2 size. The thickness, density, melting point, tensile strength, and elongation at break of the material were 0.5 mm, 0.94 – 0.97 gm/cc, 120 – 130^{o}C, 31.35 MPa, and 100%, respectively.

Aggregate used in this study was crushed basalt obtained from Kennedy Quarries where located in thirty miles from Derry and the border to Donegal, and sixty miles from Belfast on the main Coleraine to Londonderry Road, NI, UK and the properties of aggregate can be seen in Table 2.

Table 2. Properties of Aggregate Used

No	Property	Standard Method	Basalt		Specification	
			Coarse	Fine	Indonesia	UK
A	**Physical Properties**					
1	Apparent Particle Density	BS 812 Part 2, BSI 1995	2.97	2.92	> 2.5	
2	Oven Dried Particle Density		2.87	2.79	> 2.5	
3	Saturated Surface Dry Particle Density		2.91	2.84	> 2.5	
4	Water Absorption, %		1.22	1.54	< 3%	
5	Flakiness Index, %	BS 812-105.1, 1989	23.5		< 25%	< 45%
6	Elongation Index, %	BS 812-105.2, 1990	18.70		-	-
B	**Mechanical Properties**					
1	Aggregate Impact Value (AIV), %	BS 812 Part 112 BSI, 1990a	9.60		< 30%	
2	Aggregate Crushing Value (ACV), %	BSI 812 Part 110 BSI 1990 b	13.60			
3	Ten Percent Fines Value (TFV), kN	BSI 812 Part 111 1990	289.70		-	140 kN
4	Fragmentation by LA test *)	BS EN 1097-2, 1998	19.00		< 40%	
5	Resistance to Wear by Micro Deval Test*)	BS EN 1367-2, 1998	24.00			
6	Magnesium Sulphat Soundness *)	BS EN 1367-2, 1998	9.00			
7	Aggregate Abrasion Value (AAV) *)	BS EN 1097-8, 2000	6.3			
8	Polished Stone Value (PSV)*)	BS EN 1097-8, 2000	58			

*) Data from Whitemountain Quarries Ltd, 2003

The filler defined in this study is the material passing through 0.075 mm sieve and the filler type used in asphalt concrete is limestone dust.

3. PREPARATION OF SPECIMENS

- **The Fly Ash-Bitumen Blend**

The fly ash-bitumen mix was prepared with 3%, 6% and 9% of binder content (by weight of bitumen used). The fly ash was pre-heated by oven storage at 170^{o}C for 24 h to remove any water present. 60/70 penetration grade bitumen was heated to temperature of 150^{o}C before the fly ash is added and then the fly ash was blended for 15 min at constant temperature of 150^{o}C.

- **The Plastic Milk Cartoon-Bitumen Blend**

The chopped plastic milk cartoon in 2 x 2 mm^2 in size was blended with bitumen at low speed for about 5 min until all of plastic quantity required was added. The mixture is heated constantly to 160 - 170^{o}C and mixed at high speed for about 1 hour using a mechanical stirrer. Three types of blends were prepared by varying content of HDPE (0.75%, 1.5% and 3% by weight of binder) in the mixture. Based on previous studies and observed that a uniformly dispersed binder formed only if the temperature and time of blending exceed 160^{o}C and 1 hour respectively.

The modified bitumen properties for both have been evaluated using the penetration test at various temperatures (25^{o}C, 30^{o}C, 35^{o}C and 40^{o}C) and softening point test.

- **The Asphalt Concrete Specimen**

The laboratory work was started by determining the optimum bitumen content for all the mixes using the Marshall mix design method which usually used in Indonesia. The coarse aggregate, fine aggregate, and the filler material should be proportioned so as to fulfill the requirements of Indonesian specification [4] as shown in Figure 1. The method used for compaction was the Marshall compaction hammer with according to BS 598 part 107 (1996). The mixing and compaction temperature of each sample were carried out on 170^{o}C (a viscosity of 170 ± 20 cSt) and 140^{o}C (a viscosity of 280 ± 30 cSt) respectively. The mix is placed in a mould and compacted with number of blows was 75 each side of the specimen. The bitumen content of AC specimens was found 6 %.

Test specimens were prepared for Marshall testing for two types of modifier on optimum bitumen content of 6%. Based on previous study that the amount of waste materials in binder did not significantly affect the value of the optimum binder content [5,7]. Six specimens were prepared for each asphalt concrete mix containing modifiers. Three of the six specimens were used to evaluate stability, flow, Marshall quotient, VMA, VFB, VIM and density, and the other two specimens were immersed in water bath at 60^{o}C for 24 hours to predict stripping potential in bitumen mix.

Figure 1. The Grading Curve of Asphalt Concrete

4. RESULTS AND DISCUSSION

- **Properties of Waste Materials – Bitumen Mixture**

The results of penetration test on both fly ash and waste plastic modifier - bitumen mixture under various temperatures (25^{o}C, 30^{o}C, 35^{o}C and 40^{o}C) and softening point test are expressed in Table 3 and Figure 2. Table 3 showed the penetration values of virgin and modified bitumen increased as the temperature increased. The penetration values of modified bitumen at 25^{o}C were found decreasing as waste materials content increased in bitumen, but penetration value of modified bitumen using fly ash did not decrease significantly. The softening point of the 60/70 pen bitumen increased as the percentage of waste materials in bitumen increased and the softening values of modified bitumen using waste plastic were found more increasing significantly than fly ash.

Table 3. Summary of The Penetration Value of Waste Materials-Bitumen Mixture

Test	**Modifier - Bitumen Mixture**			
	Fly Ash (FA)			
Penetration	0%	3%	6%	9%
25°C	78	75	74	72
30°C	149	134	126	120
35°C	239	221	219	217
40°C	350	342	340	338
	Waste Plastic			
Penetration	0%	0.75%	1.5%	3%
25°C	78	72	66	55
30°C	149	122	103	85
35°C	239	206	176	133
40°C	350	319	285	223

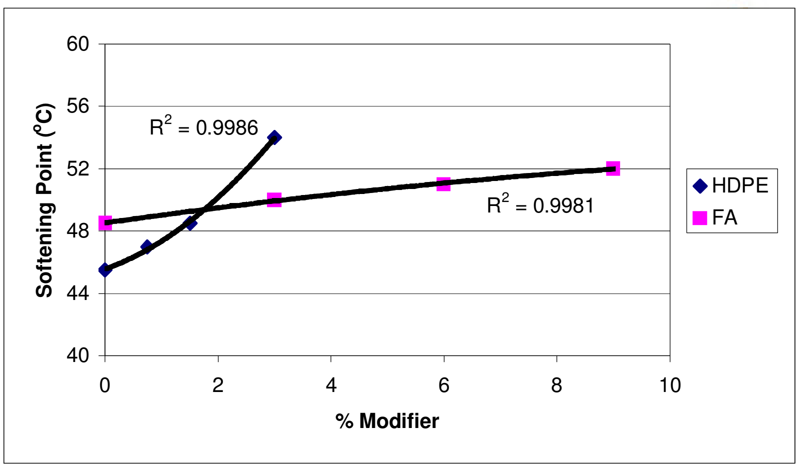

Figure 2. The Effect of Modifiers on Softening Point (°C)

Temperature susceptibility of binder can be assessed using penetration index as shown in Figure 3. It is clearly that modified bitumen using waste materials can reduce temperature susceptibility. The temperature susceptibility for modified bitumen using waste plastic decreased as waste plastic content in bitumen increased. For modified bitumen using fly ash, temperature susceptibility decreased as fly ash content in bitumen increased by 4 to 5 %, then increases.

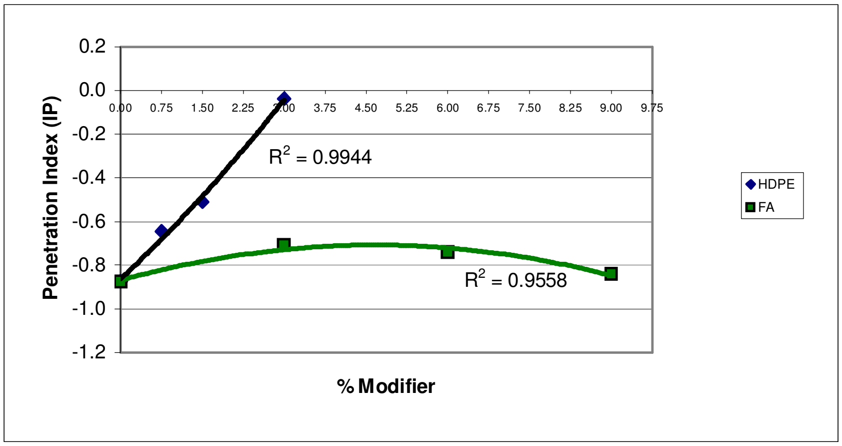

Figure 3. The Effect of Modifiers on Penetration Index of Modified Bitumen

- **Characteristics of Asphalt Concrete using Waste Materials as Modifier**

The results of these Marshall testing for waste materials as modifier on optimum bitumen content of 6% are illustrated in Figure 4 to 9. The figures show the relationship between modifier content and properties of mix such as stability, flow, Marshall quotient, density VMA and VIM. The effect of waste materials content as modifier on susceptibility of asphalt concrete using unmodified and modified bitumen to be attacked by water and loss of the cohesion between binder and aggregate were evaluated using the static immersion test. Result of this test is demonstrated in Figure 10.

Marshall stability

Figure 4 shows the result of Marshall stability as a function of waste materials content as modifier and type. It is observed that the Marshall stability becomes higher as the amount fly ash content increases from 3 up to 6% and then decreases as fly ash content increases, while the Marshall stability increased as waste plastic content in bitumen increased. The higher Marshall stability caused by increasing the amount of waste materials in binder may be related to properties of waste materials. Increasing the amount of waste plastic in binder will cause the mix become stiffer and shear resistance will increase too. Fly ash as filler tend to fill more voids between aggregate grains. The mix will continue to gain strength from contact between aggregate due to the existence of filler in the void between aggregate.

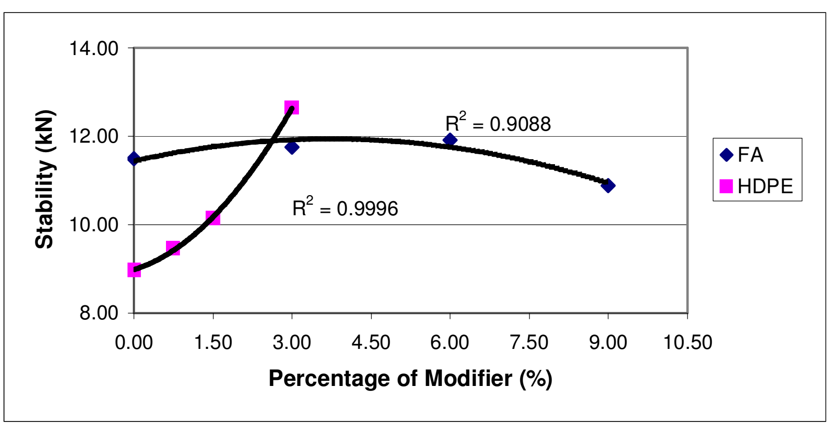

Figure 4. The Effect of Modifier Types and Content on Marshall Stability (kN)

Increasing the amount of filler in binder above the optimum value will reduce contact between aggregate, leading to reduction in stability and also more filler in binder will reduce adhesion between aggregate in mix and its lubrication capability.

Marshall flow

The flow is measured at the same time as the Marshall stability. The flow is equal to the vertical deformation of the sample in mm. Figure 5 demonstrates Marshall flow on the mixes made with using waste materials in binder, the Marshall flow tend to decrease as the amount of waste materials content increase but the Marshall flow of asphalt concrete prepared using fly ash decrease as fly ash content increase up to the minimum Marshall flow value and then increases as the fly ash content increase. The optimum value of fly ash content has yields the minimum Marshall flow value is 6%.

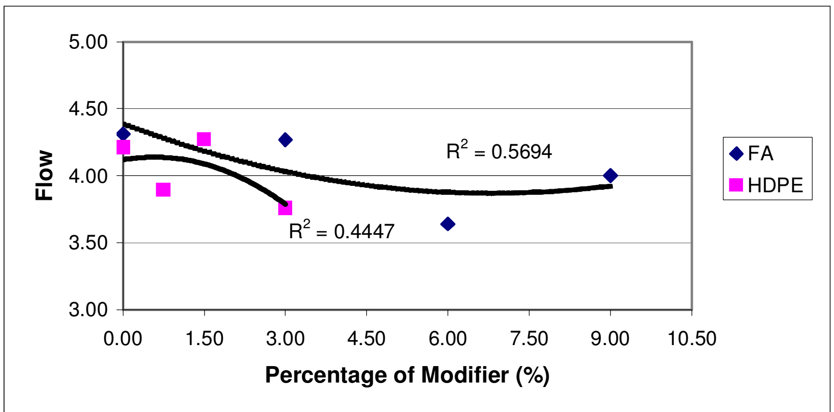

Figure 5. The Effect of Modifier Types and Content on Marshall Flow (mm)

This is result of fly ash content in binder to optimum value would fill the void of aggregate, causing denser aggregate gradation and the shear resistance will increase and so the Marshall flow will be reduced. On the other hand, fly ash content increases above the optimum value, it can reduce adhesion or lubrication capability, leading to increases the Marshall flow value.

Marshall quotient (MQ)

Marshall quotient is the ratio between stability and flow. It is emperical stiffness value which can be used to evaluate the quality of bitumnious mix. A higher value of the Marshall quotient indicates a stiffer mixture and the mixture is likely more resistance to permanent deformation [5,6].

Figure 6 demonstrate that the result of Marshall quotient as a function of varying waste materials content as modifier and type. It is observed that the Marshall quotient for asphalt concrete prepared using fly ash increases as fly ash content increases from 3% to 6% and then decreases as fly ash content increases. Meanwhile, the Marshall quotient for asphalt prepared using waste palstic increased as waste plastic in binder increased. The emperical stiffness value of asphalt concrete mix prepared using waste plastic higher than fly ash.

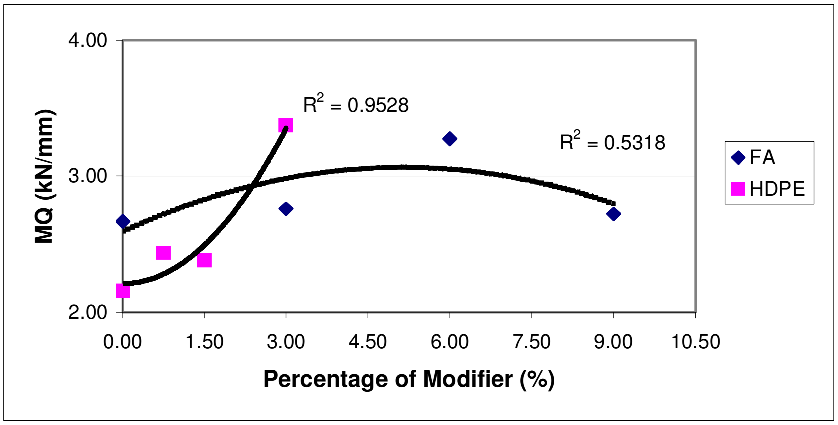

Figure 6. The Effect of Modifier Types and Content on MQ (kN)

Density

The effect of both waste materials in binder and their contents on the density of compacted mixes is demonstrated in Figure 7. The density of bitumen mixes prepared with using modified binder decrease as the waste materials content in bitumen increase. The density of bitumen mixes containing waste plastic showed lower than those containing fly ash. Increasing the amount of waste materials in bitumen will reduce the mix lubrication capability particularly for waste plastic tend to be stiffer, leading to less of a degree of compaction under the same compaction effort. As a result, the density of bitumen mixes will be reduced.

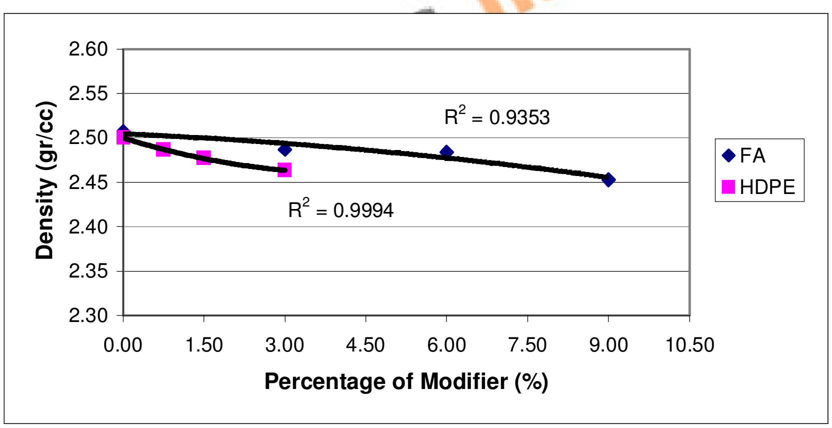

Figure 7. The Effect of Modifier Types and Content on Density (gr/cc)

Void in mix (VIM)

The results of void in mix of bitumen mix prepared with using both waste materials as the modifier is shown in Figure 8.

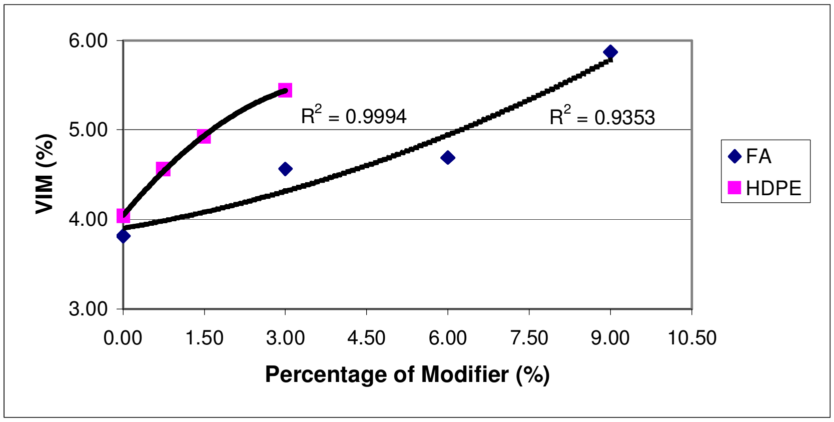

Figure 8. The Effect of Modifier Types and Content on VIM (%)

The effect of increasing both waste materials content as modifier in bitumen will increase void in mix value. Void in mix of bitumen mix prepared with waste plastic is higher than fly ash. This is result of increasing the amount of waste materials in binder will reduce the mix lubrication capability and tend to be stiffer, causing to require greater compaction effort.

Void in mineral aggregate (VMA)

Figure 9 illustrate the effect of waste materials as modifier and their content on void in mineral aggregate (VMA). The VMA increases as the amount of waste materials in binder increases. The VMA value of mixes made with waste plastic in bitumen is higher than fly ash. This occurs because the amount of waste materials in binder will reduce the mix lubrication capability and tend to be stiffer, causing to require greater compaction effort. It is clear that all the VMA values are higher than the limit set by Indonesian specification of 16%.

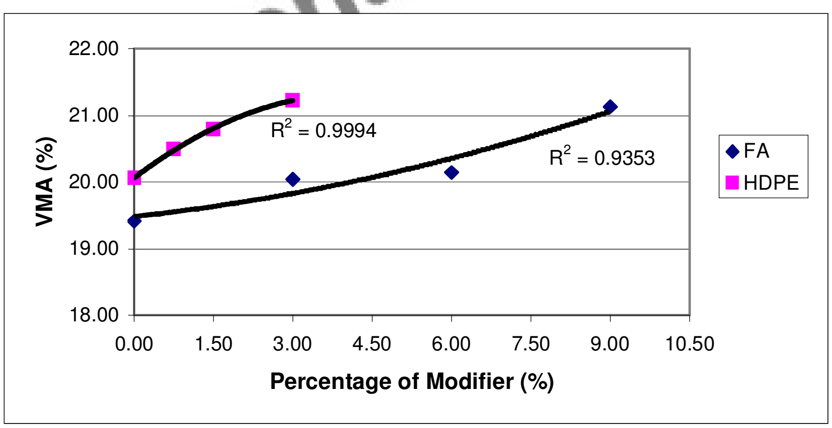

Figure 9. The Effect of Modifier Types and Content on VMA (%)

Moisture susceptibility

The effect of both waste materials in binder and their contents on the moisture susceptibility of compacted mixes is demonstrated in Figure 10.

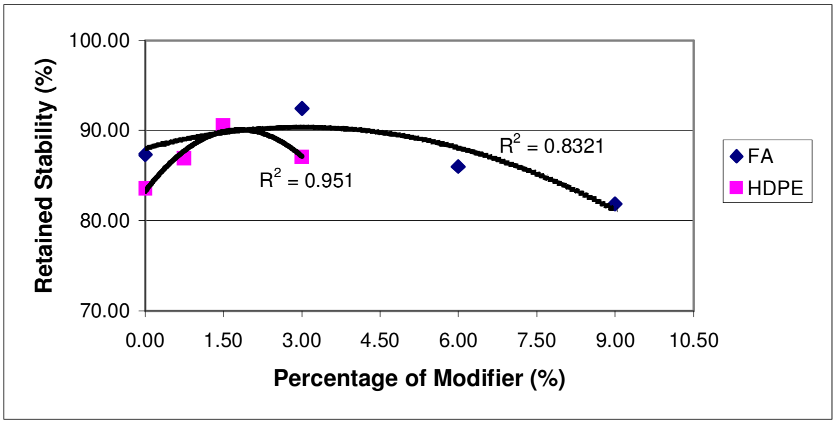

Figure 10. The Effect of Modifier Types and Content on Retained Stability (%)

From Figure 10 illustrates that the moisture susceptibility of asphalt concrete mixes using waste materials in binder decreased as waste materials content increased up to optimum at 4% for fly ash and 1.5% for waste plastic after that increases. This results agrees with the previous study results [1,5,7,8], and literature that the filler and polymer as antis tripping agent. In general, both waste materials mixed in binder can reduce moisture susceptibility (stripping potential) for asphalt concrete mix and it is clear that the retained stability values are higher than the minimum requirement by Indonesian specification.

5. CONCLUSIONS

Based on the results of the experimental investigations conducted on normal and modified bitumen using waste materials in asphalt concrete mixes, the following summaries have been drawn:

1. Waste plastic more significantly influence on rheology of binder than fly ash.
2. Basically, the addition of waste materials in binder cause the Marshall stability increases.
3. The Marshall flow increases as waste materials content in binder increase and the optimum values of fly ash content is recommended at 4%.
4. The density of bitumen mixes prepared with using modified binder decrease as the waste materials content in bitumen increase.
5. Increasing waste materials content will increase void in mix value and the void in mix of bitumen mix prepared with waste plastic is higher than fly ash.
6. The VMA increases as the amount of waste materials in binder increases and the VMA value of mixes made with waste plastic in bitumen is higher than fly ash.
7. Waste materials used in binder can reduce the moisture susceptibility and recommended using fly ash content in binder at 4% and 1.5% for waste plastic.
8. In general the performance of bitumen mixes prepared using waste plastic and fly ash as modifier were better than origin bitumen mixes.

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REFERENCES:

[1] Al-Suhaibani, A., et. al. Effect of filler type and content on properties of asphalt concrete mixes. *Symposium on Effects of Aggregates and Mineral Fillers on Asphalt Mixture Performance*, pp107-130. Dec 10 1991, 1992, Published by ASTM, Philadelphia, PA, USA.

[2] Aschuri, I et. al. Temperature and Time Loading Influence on Stiffness Modulus of Asphalt Concrete Mixture and Design Life by Using Analytical method on Indonesian Tropical Condition. Paper 248, *CD Proceedings,. The 5th International Conference of Eastern Asia Society for Transportation Studie*s, Fukuoka, Japan, October 29 – November 1, 2003.

[3] Idris A, Nasir Hassan M, Chong TL (2003) Overview of municipal solid waste landfill sites in Malaysia. Proceedings of the 2nd Workshop on Material Cycles and Waste Management in Asia, December 2–3, Tsukuba, Japan

[4] KIMPRASWIL, Specification of Hot Mix Asphalt, Departemen Kimpraswil, Indonesia. 2001

[5] Quadis, S.A. and ET. AL. Effect of Pozzolan Modifier on Bituminous Mixtures Properties. *Highway and Transportatio*n, 1999

[6] Roberts, F.L. and ET. AL. Hot Mix Asphalt Materials, *Mixture Design, and Construction. 2nd edition*. USA: National Asphalt Pavement Association Education Foundation. 1996

[7] Tuncan, M, A. Tuncan & A. Cetin, The use of waste materials in asphalt concrete mixtures, Waste Management & Research, ISSN 0734–242X, International Solid Waste Association, UK, 2003

[8] Shell. Shell Bitumen Hand Book . UK: Shell Bitumen. 1990

[9] World Bank, Reducing Pollution in Indonesia, Environment Monitor, Jakarta, 2003