Styrofoam Waste as Bitumen Modifier in Hot Mix Asphaltic Concrete

By

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CERTIFICATION OF APPROVAL

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Aproved by,

(Associate Professor Dr. Madzlan Napiah)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

December 2011

CERTIFICATION ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements and that the original work contained herein have not been undertake nor done by unspecified sources or persons.

SITI SARA LYANA BINTI BADLY SHAM

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Thank You.

ABSTRACT

The study investigates the potential use of Styrofoam waste (polystyrene) as bitumen modifier in asphaltic concrete for road pavement construction. It aims to meet two distinct needs which are to reuse plastic waste as well as protecting the environment and to improve the resistance of bitumen which is prone to cracking or creep under extremes of temperature. The results will be presented by the ability to produce homogenous and stable modified bituminous mixture and the workability of the asphaltic concrete. Laboratory tests for bitumen which are Penetration Test, Ductility Test and Softening Point Test were undertaken in order to evaluate the properties of the modified bituminous blends of different Styrofoam waste content (0%, 4%, 6%, 8%, 10% by weight of bitumen). Results showed that modified bitumen yields lower penetration value, very minimum value of ductility and rise in softening point. Next, the performance of the asphaltic concretes produce using the modified binders were evaluated through Marshall Stability Test and result indicates that the performance increases up to 8% addition of Styrofoam content as modifier.

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

Hot mix asphalt pavement or asphaltic concrete pavement refers to the base course layer of flexible or semi-rigid pavement. It consists of aggregate and bituminous binder [1]. Bituminous binder has been widely used across the globe for road paving purposes due to its high impermeability, good adhesiveness to aggregates, high elasticity and cost effective [2]. However, the demand for higher pavement quality from users is ever increasing due to the structural failure faced by flexible pavement namely surface cracking and rutting [3]. The demand was also driven by the high maintenance cost for road repairing.

On the other hand, plastic faces its own issue. Plastic was recorded as the second highest landfill volume contributor in Malaysia. It was proven that 12.6% of the total landfill volume is plastic waste while the main contributor is food waste as shown in Table 1 [4]. However, plastic waste will consume the space for a longer period than other wastes that are biodegradable. Plastic waste retains its shape and mounted up in the landfill. Besides, the operation of the landfill is undoubtedly very costly. This statement is being supported by the fact that in the Seventh Malaysia Plan (1995-2000), cost of RM20.9 million was released for the purpose of building up 9 sanitary landfills and upgrading 27 existing landfills in 34 local authorities where at that mean time there are around 180 operating landfills. These two factors have triggered the demand for disposal alternatives of plastic waste.

Table 5 Landfill Composition in Kuala Lumpur

Composition	Percentage (%)
Food	59.2
Plastic	12.6
Paper	8.0
Yard	7.9
Wood	2.3
Textile	1.4
Rubber	0.7
Organic fine	4.0
Ferrous	2.0
Glass	1.6
Aluminium	0.4

In response towards these two issues, several research studies have proven polymer modified binder as one of the answer to improve fatigue life, reduce rutting, thermal cracking in the pavement as well as saving the environment [5, 6, 7].

This study was undertaken to evaluate the potential of Styrofoam waste (polymer) as the binder modifying agent. It is aim to serves dual purposes which are improving structural failure in road pavement and providing better means of disposal or recycle of Styrofoam waste.

1.2 PROBLEM STATEMENTS

1. Hot mix asphaltic concrete faces performance issue whereby the default road pavement easily deteriorates as a result of extreme climate.
2. High maintenance cost has to be allocated in road repairing purposes.
3. Plastic waste has been recorded as the second highest contributor of waste generation in Malaysia over years.
4. Plastic waste compared to other wastes, do not decompose, and thus occupies the volume of the landfill in longer period which has cause plastic waste to mount up in the landfill.
5. A high amount of money has been put in the effort in building up new sanitary landfills as well as to operate and maintain the existing ones.

1.3 OBJECTIVE

1. To evaluate the potential of Styrofoam waste as binder modifier in asphaltic concrete pavement.
2. To improve bitumen resistance which is prone to cracking and creep under climate factor.
3. To cater 'white pollution' cause by plastic waste which is known for being hazardous to human and animal.
4. To prepare a medium for reuse of Styrofoam waste in reducing volume contributed to the landfill.

1.4 SCOPE OF STUDY

In completing the study, several scopes of study will be covered. The major scopes are as follows;

1. To gather information regarding asphaltic concrete pavement.

   Background study will be made on the asphaltic concrete pavement materials, properties, existing performance and preparation procedures.

2. To gather information regarding Styrofoam as the source of plastic waste.

   Background study will be made on the Styrofoam properties, hazard and potential usage in bitumen mixture.

3. To prepare and test asphaltic concrete using the default bitumen mixture and modified mixture.

   The preparation of the asphaltic concrete will be adapting the Marshall Mix Design Method. Several tests will be made on the samples to evaluate the performance of the asphaltic concrete produced using different type of bitumen mixture.

4. To compare the test result and analysis the competency of Styrofoam as bitumen modifier.

   Analysis will be made based on the result on the performance of the asphaltic concrete. At the end of the study, the possibility of Styrofoam as bitumen modifier will be revealed.

CHAPTER 2

LITERATURE REVIEW

'White pollution' cause by plastic waste is a serious environmental issue which is alarming the world. It has not only causing visual pollution where plastic waste mounted up at the disposal site due to its difficulty to decompose. It has also been recognized to be dangerous to lives for its hazardous properties. Thus, many researches were undertaken in order to address this issue. Most researches focus on the opportunity in recycling and reusing plastic waste in replacement of existing materials in a particular product or production of new invention. References were made through many sources of information such as books, journals, article and others in acquisition of the credibility of the topic selected.

A reference book by H.L. Robinson entitled Polymer in Asphalt discover various types of polymers that can be used in asphaltic concrete in order to enhance its performance and resistant towards deterioration mechanism. This book provides information on application of polymers in asphaltic concrete as well as its advantage and disadvantages.

Bituminous Binders and Mixes by L. Francken, RILEM Technical Committee 152-PBM, Performance of Bituminous Materials expose readers to concepts and relevant testing procedures for the design of bituminous materials for road surfaces construction. Tests are divided into thee sections which covers binder testing, mix design and performance of the asphalt concrete test. It also describes the techniques for polymer modified binder's production and correlated test to be undertaken to asses the properties of the modified binders.

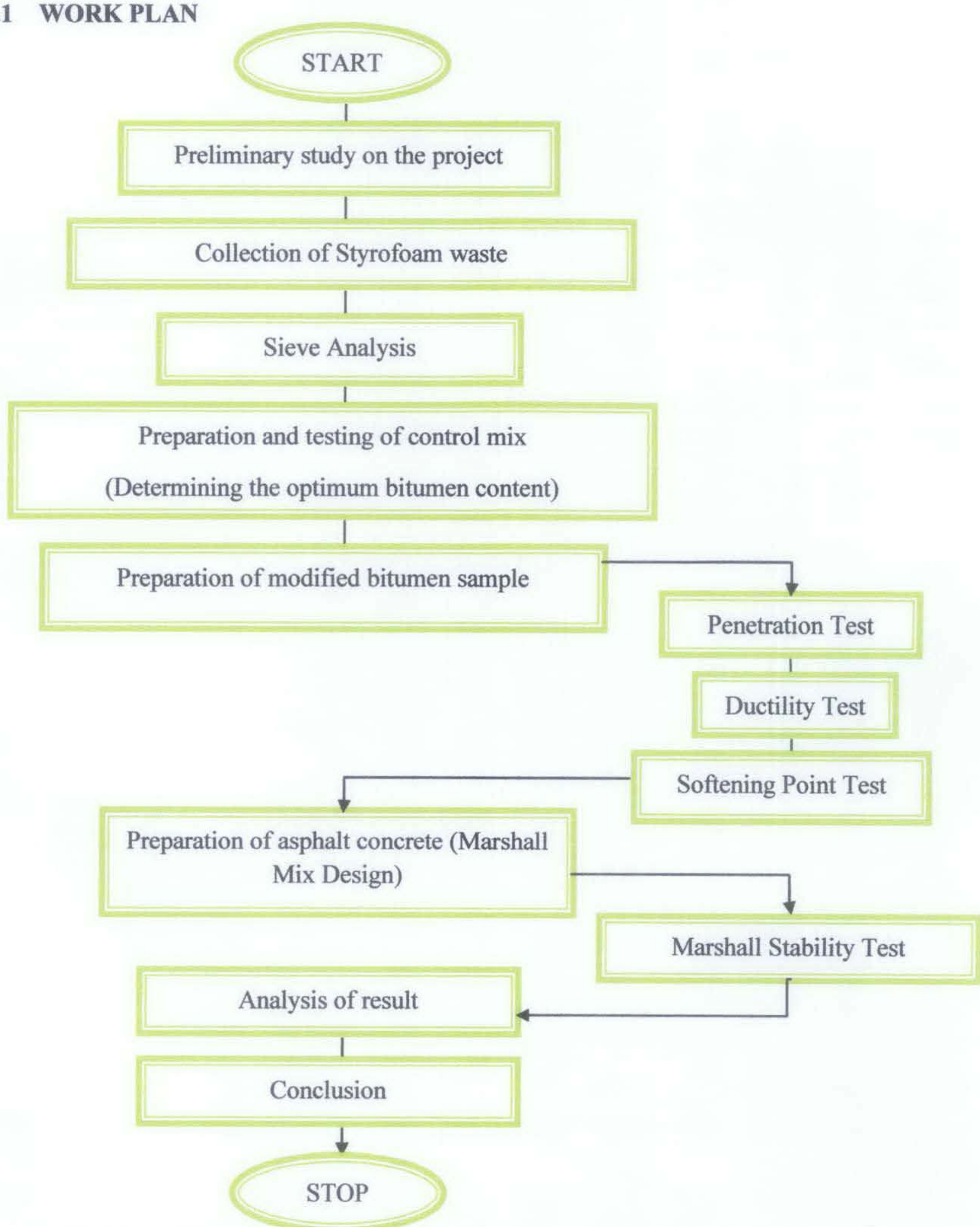
Journal on Use of Waste High Density Polyethylene as Bitumen Modifier in Asphalt Concrete Mix written by Hinislioglu, Sinan and Agar, Emine presented the potential of using various plastic wastes containing high density polyethylene in asphaltic concrete. By manipulating several control factors such as mixing time, mixing temperature and high density polyethylene content, the asphalt concrete produced were evaluated through basic asphaltic concrete performance test. It is proven that HDPE modified bituminous binder offers better resistance against deterioration.

Another journal written by Naskar, M. , Chake, T.K. , Reddy, K.S. entitled Effect of Waste Plastic as Modifier on Thermal Stability and Degradation Kinetics of Bitumen/Waste Plastic Blend presented the thermograymetric studies conducted on the modified bitumen. The plastic contents were differ from 0% to 7% by weight of the bitumen and the optimum plastic content was determine based on the thermal stability and the overall performance.

CHAPTER 3

METHODOLOGY

3.1 WORK PLAN



3.2 MATERIAL

3.2.1 Aggregate

Aggregate is from the highway laboratory with gradation limits by Jabatan Kerja Raya for Hot Mix Asphaltic mixtures and the selected gradation in this research is at the middle of the limits as shown in Table 2.

Table 6 Jabatan Kerja Raya Standard - Gradation of Aggregate

Sieve Size (mm)	% by Weight Passing
28.0	100
20.0	76 - 100
14.0	64 - 89
10	56 - 81
5.0	46 - 71
3.35	32 - 58
2.35	20 - 42
0.15	12 - 28
0.075	6 - 16
Filler	4 - 8

3.2.2 Bitumen

The bitumen used in this investigation is obtained from the highway laboratory. The bitumen is 60/70 penetration grade. The properties of the bitumen are shown in Table 3.

Table 7 Rheological Properties of Bitumen 60/70

Property	Test Conditions	ASTM Designation No.	Specification
Penetration (dmm)	25°C, 100, 5s	D-70	60/70
Softening point (°C)		D-36	49/56
Ductility (cm)	25°C, 5cm/min,	D-113	100 (min)
Specific Gravity	25°C / 25°C	D-70	1.01-1.06
Flash Point (°C)		D-92	250

3.2.3 Styrofoam

Styrofoam is a petroleum-based plastic made of the styrene monomer. It is also called polystyrene. The physical properties of polystyrene are shown in Table 4.

Table 8 Physical Properties of Polystyrene

Property	Specification
Density (kg/m3)	29
Vicat Softening point (°C)	64.0 – 263.0

3.3 PREPARATION OF STYROFOAM WASTE/BITUMEN BLENDS

Styrofoam/styrene modified asphalt was prepared by melt blending. Using the laboratory mechanical stirrer, the asphalt was mixed with the Styrofoam waste at 500 rpm and 180°C temperature. In the preparation, the asphalt was first heated to fluid condition and the Styrofoam waste was weight and softened at 180°C temperature for 30 minutes before mixing. The 600 g melted bitumen was poured in a flask and mix with the mechanical stirrer. As the temperature reached 180°C, the softened Styrofoam was slowly added to the bitumen. The mixing time continue for about an hour until a homogeneous mixture is produced.

Sample varies with the manipulation of Styrofoam concentrations. Sample with Styrofoam concentrations of 0%, 4%, 6%, 8%, 10% by weight of bitumen were prepared. For each variation of Styrofoam concentrations, 3 samples were prepared. Samples will be tested in determining the optimum Styrofoam concentration.

Figure 7 Preparing modified blend

3.4 PREPARATION OF ASPHALTIC CONCRETE SAMPLE

Asphaltic Concrete samples were prepared using the Marshall Mix Design based on the sieve analysis as shown in Table 5. All materials were batched and kept in an oven at 160°C. After 24 hours, the batched granular material was placed in the mixer which was also heated to 160°C. The materials were mixed dry for about 1 minute then the appropriate amount of bitumen should be added to the aggregate. Mixing continued until all particles are coated with bitumen. The batched materials were compacted in a 100 mm diameter steel moulds (which was also kept at 160°C). After filling the mould with the appropriate amount of material, the mould was compacted using the Marshall Compactor Machine with 75 blows for both sides. When the sample has cooled down to room temperature, it was extruded from the mould. The weight of each sample in air and water was taken. The procedure was repeated by varying the percentage of bitumen content from 4.0%, 4.5%, 5.0%, 5.5%, 6.0%, 6.5%, and 7.0% by the weight of the sample. Three samples were prepared for each concentration of bitumen content. Marshall Stability Test was conducted and the optimum bitumen content was determined to be 6% by the total weight through the sampling of the control sample.

Three asphaltic concrete samples were prepared for each variation of Styrofoam modified bitumen using the same mix design procedures by applying the predetermined optimum bitumen content.

Figure 8 Mixing granular materials with bitumen

3.5 RHEOLOGICAL PROPERTIES OF STYROFOAM MODIFIED BINDER TESTS

Rheological parameters of the modified bituminous blends were determined to observe the performance of the bitumen.

3.5.1 Penetration Test

Penetration test measures the consistency (hardness or softness) of the bitumen samples by determining the depth in tenths of millimeter to which a 100g loaded needle will penetrate vertically in 5seconds at 25°C according to ASTM D5.

Figure 9 Penetrometer

3.5.2 Ductility Test

Ductility test measures the cohesive strength of the bitumen by defining the distance in centimetre to which a sample of material will be elongated at 5cm/min until it breaks at test temperature of 25°C according to ASTM D113.

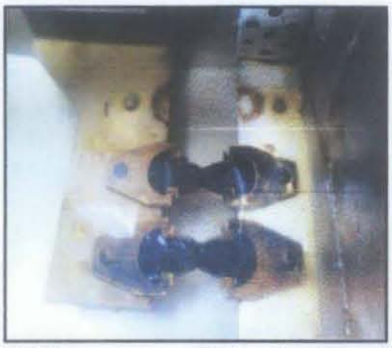


Figure 10 Bitumen condition for Ductility Test

3.5.3 Softening Point Test

Softening point test measures the temperature at which the bitumen sample reaches a degree of softening under the specified test condition according to ASTM D36.

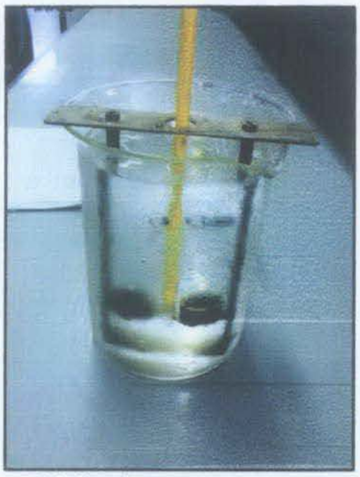


Figure 11 Setting temperature to 5°C

3.6 TESTING FOR ASPHALT CONCRETE PERFORMANCE

The testing for asphalt concrete was conducted to determine the effect of the modified bitumen on the performance of the asphalt concrete.

3.6.1 Marshall Stability Test

The Marshall Stability test measures the ability of the asphaltic concrete in resisting heavy load before experiencing deformation. Before testing, samples were placed in water bath at 60°C for 30 minutes.

Figure 12 Marshall Stability Test

CHAPTER 4

RESULT AND DISCUSSION

4.1 SIEVE ANALYSIS

Sieve analysis was conducted at the early stage of the project in order to determine the aggregate gradation to be used in the Marshall Mix Design process. The aggregate of course and fine were washed and dried separately for 24 hours at the temperature of 160°C. After 24 hours, aggregate was sieved using the Sieve Analysis Device. The weights of aggregate that retain on each sieve pan were weighed and percentage for each aggregate was calculated. The result is presented in Table 5 and Figure 7.

After 3 repetitions of the procedure, the 3rd experiment managed to satisfy the JKR standard. The result is tabulate in the table below;

Table 5 Sieve Analysis Result

Sieve Size (mm)	Course Aggregate	Fine Aggregate	Filler	% by Weight Passing Spec		Mid Point	
				Min	Max		
28.00	100.00	100.00	100.00	100	100	100	100.00
20.00	96.92	100.00	100.00	76	100	88	98.69
14.00	33.16	100.00	100.00	64	89	76	71.56
10.00	5.04	100.00	100.00	56	81	69	59.59
5.00	0.50	99.32	100.00	46	71	58	57.32
3.35	-	99.11	100.00	32	58	45	57.00
2.35	-	74.21	100.00	20	42	31	44.52
0.15	-	5.31	100.00	12	28	20	9.97
0.08	-	0.31	80.00	6	16	11	6.00
Filler	-	-	-	4	8	6	

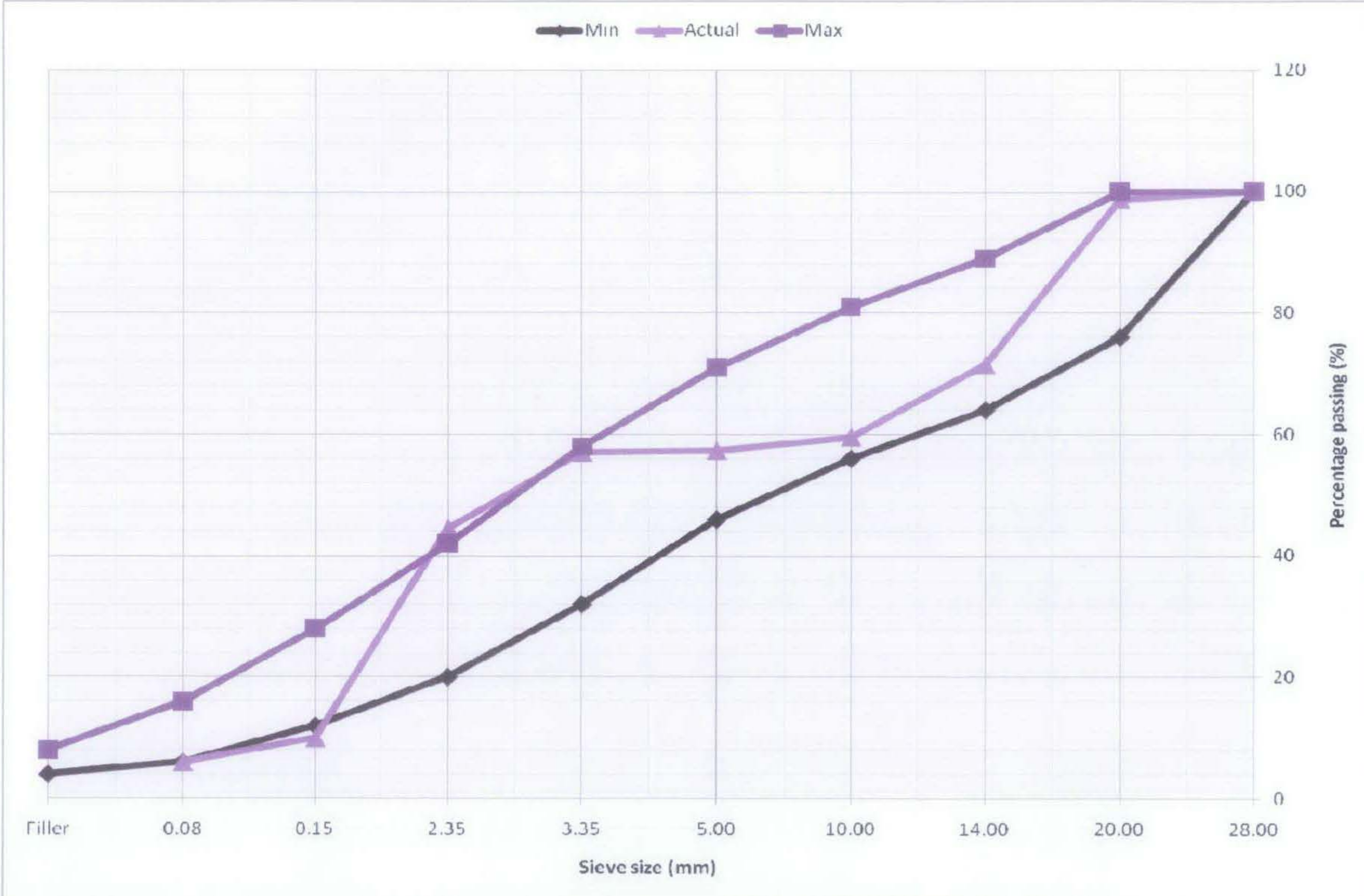


Figure 7 Sieve Size Vs Percentage Passing

From the graph above, it can be observed that the result obtained comply the specifications. The percentage of coarse aggregate, fine aggregate and filler required by weight is calculated as follows;

Course Aggregate	: 42.60%
Fine Aggregate	: 50.10%
Filler	: 7.30%

Thus, for each mould of total weight 1200 g, the weights required are as follow,

Course Aggregate	: 511.2 g
Fine Aggregate	: 601.2 g
Filler	: 87.60 g

The result obtained is applicable to the Marshall Mix Design process as it satisfied the JKR standard. The project was continued with the mixing and moulding process of the control samples and modified samples by using the percentage by weight obtained from this sieve analysis.

4.2 MARSHAL MIX DESIGN AND TESTING FOR CONTROL SAMPLE

In order to find the optimum bitumen content, asphalt concrete samples were prepared using Marshall Mix Design procedure. The samples were first weigh both in air and in water. Then, each sample was placed in the water bath at 60°C for 30 minutes before it is subjected to Marshall Stability Test. The result is presented in Table 6.

Table 6 Marshall Stability Test Result

Bitumen content (%)	Weight of bitumen (g)	Sample no.	Weight in air (kg)	Average weight in air (kg)	Weight in water (kg)	Average weight in water (kg)	Stability (kN)	Average stability (kN)	Flow (mm)	Average flow (mm)
5.0	63.0	1	1.134	1.133	0.606	0.610	3.59	3.51	2.19	2.43
		2	1.135		0.610		3.50		2.45	
		3	1.129		0.615		3.43		2.65	
5.5	70.0	1	1.173	1.180	0.635	0.632	6.40	6.33	2.47	2.25
		2	1.179		0.633		6.30		1.98	
		3	1.187		0.629		6.23		2.30	
6.0	77.0	1	1.203	1.206	0.648	0.651	9.18	9.28	2.12	2.19
		2	1.208		0.655		9.27		2.17	
		3	1.206		0.651		9.38		2.28	
6.5	83.0	1	1.240	1.241	0.671	0.671	7.18	7.05	1.84	2.00
		2	1.233		0.668		7.27		2.11	
		3	1.246		0.673		6.69		2.05	
7.0	90.0	1	1.290	1.298	0.680	0.685	5.01	5.05	2.19	2.22
		2	1.306		0.691		5.20		2.14	
		3	1.297		0.684		4.94		2.32	
7.5	97.0	1	1.298	1.307	0.711	0.702	4.93	4.77	2.81	2.75
		2	1.321		0.695		4.66		2.65	
		3	1.301		0.700		4.73		2.78	
8.0	104.0	1	1.316	1.316	0.701	0.707	4.22	4.30	3.00	3.07
		2	1.322		0.703		4.17		2.89	
		3	1.309		0.716		4.50		3.32	

The Marshall Stability Test provides the performance measure for the asphalt concrete in term of two parameters which are stability and flow. Two graphs were plotted and were analysis to determine the optimum bitumen content.

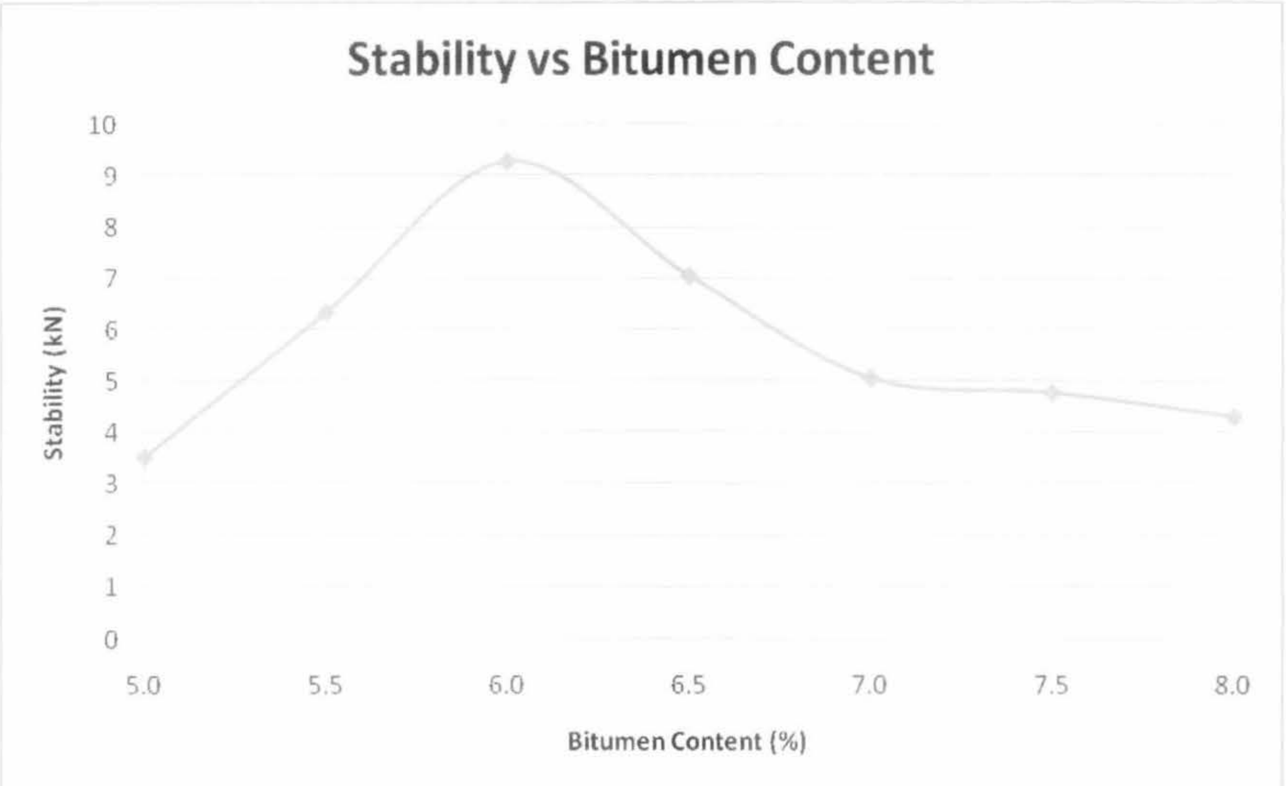


Figure 8 Graph of Stability Vs Bitumen Content

The graph above shows the effect of the bitumen content on Marshall stability. Based on observation, as the bitumen content increases, the Marshall stability value increases up to 6.0% bitumen content. This shows that the increase of bitumen content up to 6.0% enhances the interlocking between the aggregates which increases the stability of the asphaltic concrete. However, the stability drops when the bitumen content were increase more than 6.0%. Thus, it can be concluded that the stablity reaches its peak at 6.0% bitumen content.

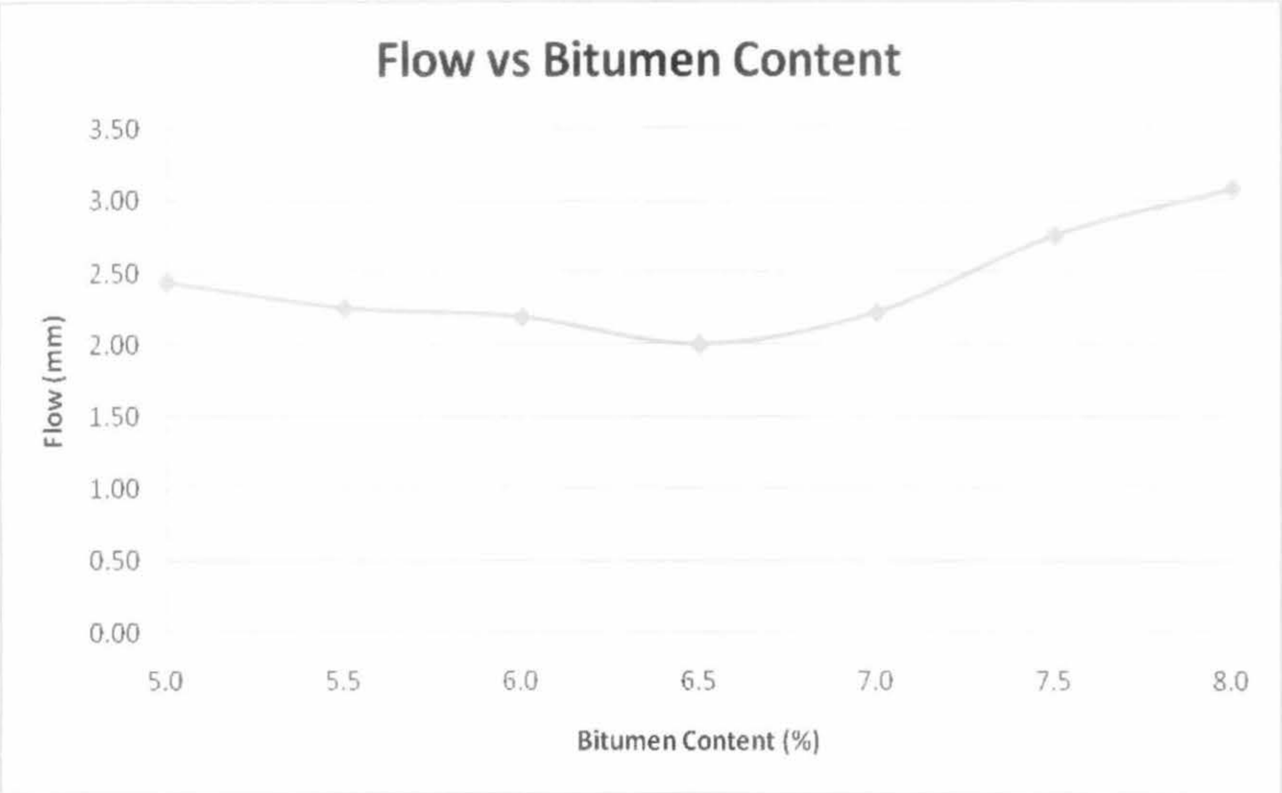


Figure 9 Graph of Flow Vs Bitumen Content

The graph above shows the effect of the bitumen content on Marshall flow. Based on observation, the Marshall flow value decreases as the bitumen content increases up to 6.5% but decline with further increament of butimen content. This relationship is the opposite of the Marshall stability versus bitumen content. According to the Jabatan Kerja Raya standard, the flow should range between 2 mm to 4 mm.

The Marshall stability reaches its peak at 6.0% bitumen content and flow strike its minimum value at bitumen content of 6.5%. Thus, the optimum bitumen content is 6.0%. The optimum bitumen content is used through out the whole project for Marshall Mix Design process.

4.3 RHEOLOGICAL PROPERTIES OF BITUMEN TESTING RESULT

Series of testing to determine the rheological properties of the virgin and modified bitumen was conducted. The testing related are penetration test, ductility test and softening point test. The readings were compiled and tabulated in Table 7. The data were analysed and further discussed in the following sections.

Table 7 Bitumen Test Series Result

Styrofoam Content (% by weight of bitumen)	Penetration (dmm)	Ductility (cm)	Softening Point ()
0	61.0	81.5	49.5
4	35.0	12.3	71.0
6	30.0	10.9	75.5
8	23.0	7.0	79.5
10	21.0	5.5	77.5

4.3.1 PENETRATION TEST

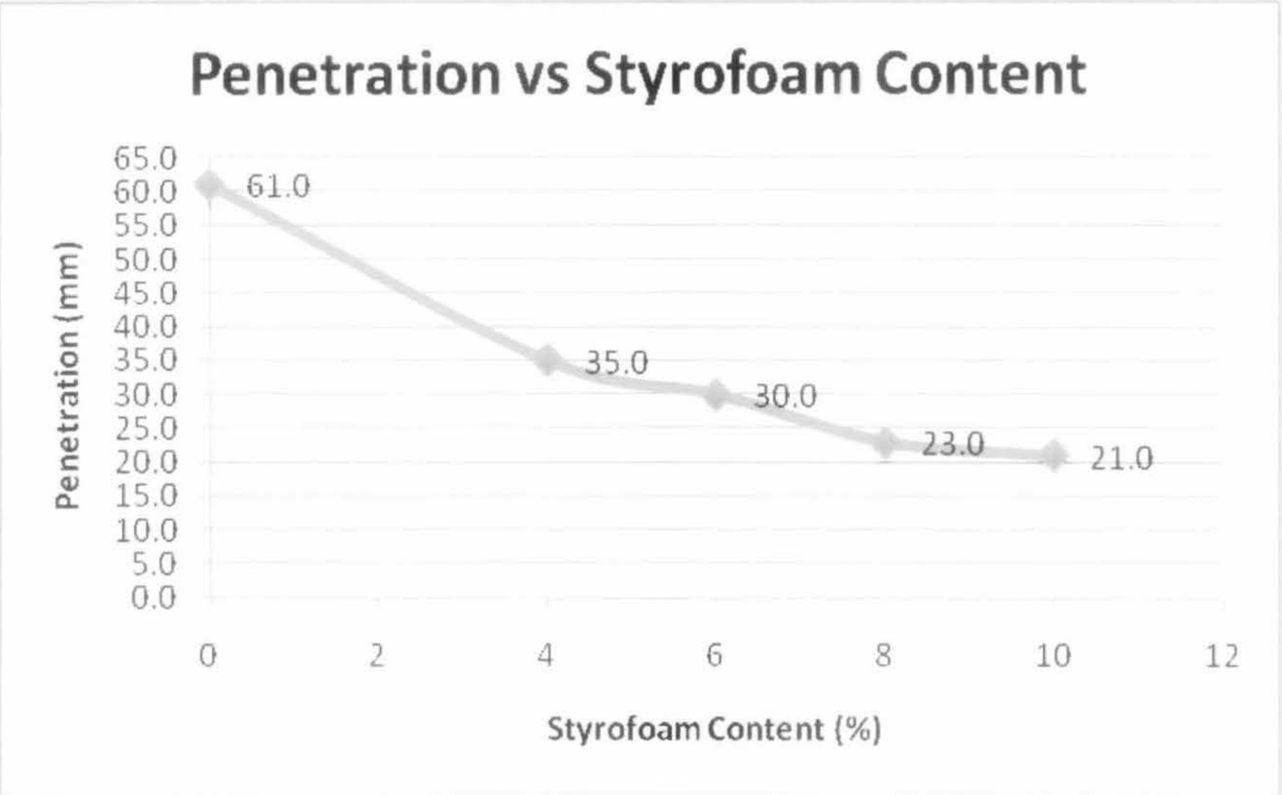


Figure 10 Graph of Penetration Value Vs Styrofoam Content

Based on Figure 4, the decrease of the penetration value of the virgin bitumen blend can clearly be observed from 61.0dmm to 35.0dmm with the first addition of 4% Styrofoam content. The values continue to drop until the final addition of 10% Styrofoam content which yield 21.0dmm penetration value. It can be observed that the penetration value decreases with the increase of the Styrofoam content. This signifies that the modified bitumen was increase in the hardness. This is due to the thermoplastic characteristic of the polystyrene that gives rigidity in binder and reduces the deformation under load [8]. The relationship between penetration value and the Styrofoam content also indicates an improved shear resistance in medium to high temperature [3].

4.3.2 DUCTILITY TEST

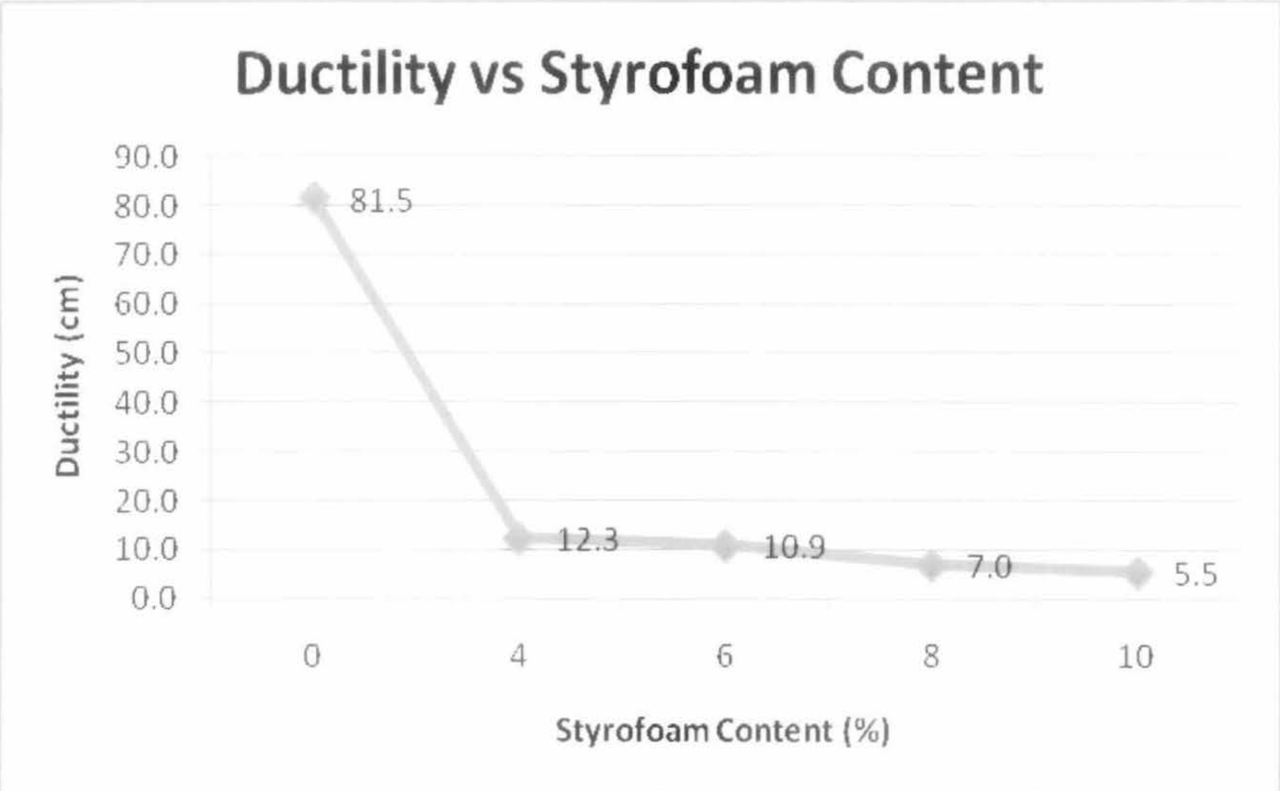


Figure 11 Graph of Ductility Value Vs Styrofoam Content

The result obtained from the ductility test presented in Figure 2 shows great difference in the ductility value for the unmodified bitumen and Styrofoam modified bitumen. By addition of 4% of Styrofoam content, the ductility value recorded was 12.3cm compared to 81.5cm for virgin bitumen. The ductility values decrease with addition of higher concentration of the Styrofoam content. The ductility values were kept in a very low range which indicates that the binders become more brittle with increasing Styrofoam content. This may due to the incompatibility of the blend which leads to phase separation [9].

4.3.3 SOFTENING POINT TEST

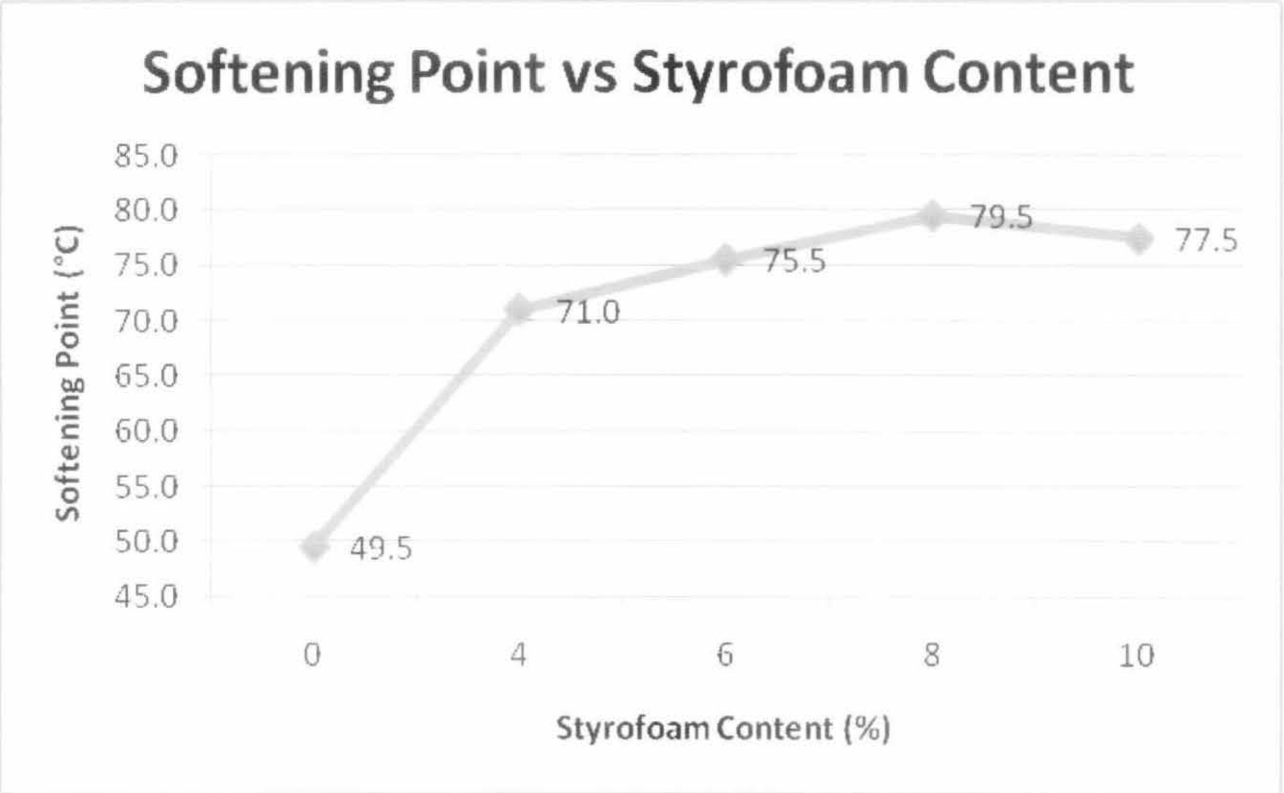


Figure 12 Graph of Softening Point Vs Styrofoam Content

Figure 3 presented the result of the softening point test which shows sharp increment of the softening point value from 49.5°C for virgin bitumen to 71.0°C for modified bitumen of 4% Styrofoam content. The softening point value increases up to 8% addition of Styrofoam content. Addition of Styrofoam beyond 8% recorded slight decrease in the softening point value from 79.5°C for 8% Styrofoam content to 77.5°C for 10% Styrofoam content. Higher softening point is preferable since bitumen with higher softening point may be less prone to permanent deformation or rutting [9].

4.4 MARSHALL STABILITY TEST

Marshall Stability Test was conducted to evaluate the performance of the asphalt concrete. The readings were compiled and in Table 8. The data were analysed and further discussed in the following sections.

Table 8 Marshall Stability Test Result

Styrofoam Content (% by weight of bitumen)	Stability (kN)	Flow (mm)
0	9.28	2.19
4	11.65	5.39
6	15.97	4.30
8	21.39	2.41
10	20.97	2.82

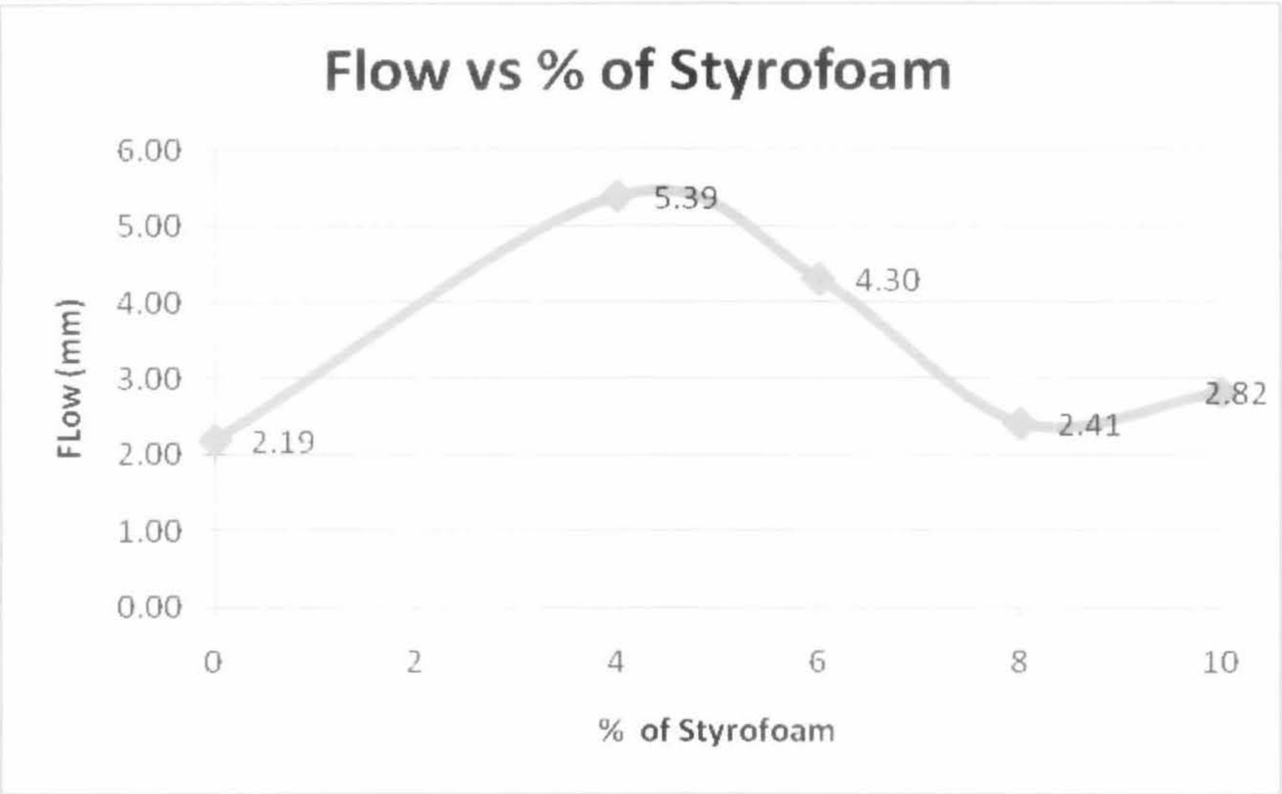


Figure 13 Graph of Flow Vs Styrofoam Content

Observation made on Figure 4 shows that the flow of the control asphalt concrete sample was elevated from 2.19mm to 5.39mm with the 4% Styrofoam content modified sample. This is not prefered as the flow should be low as it indicates the deformation which the Marshall sample undergoes when place under maximum load [10, 2]. However, it can be observed that the flow value decrease with further addition of Styrofoam. The flow reaches the lowest value at the usage of the 8% Styrofoam modified bitumen. The flow increases from 2.41mm for 8% Styrofoam modified bitumen to 2.82mm for 10% Styrofoam modified bitumen. This shows that the the flow of the asphalt concete is the lowest for the usage of 8% Styrofoam content modified bitumen.

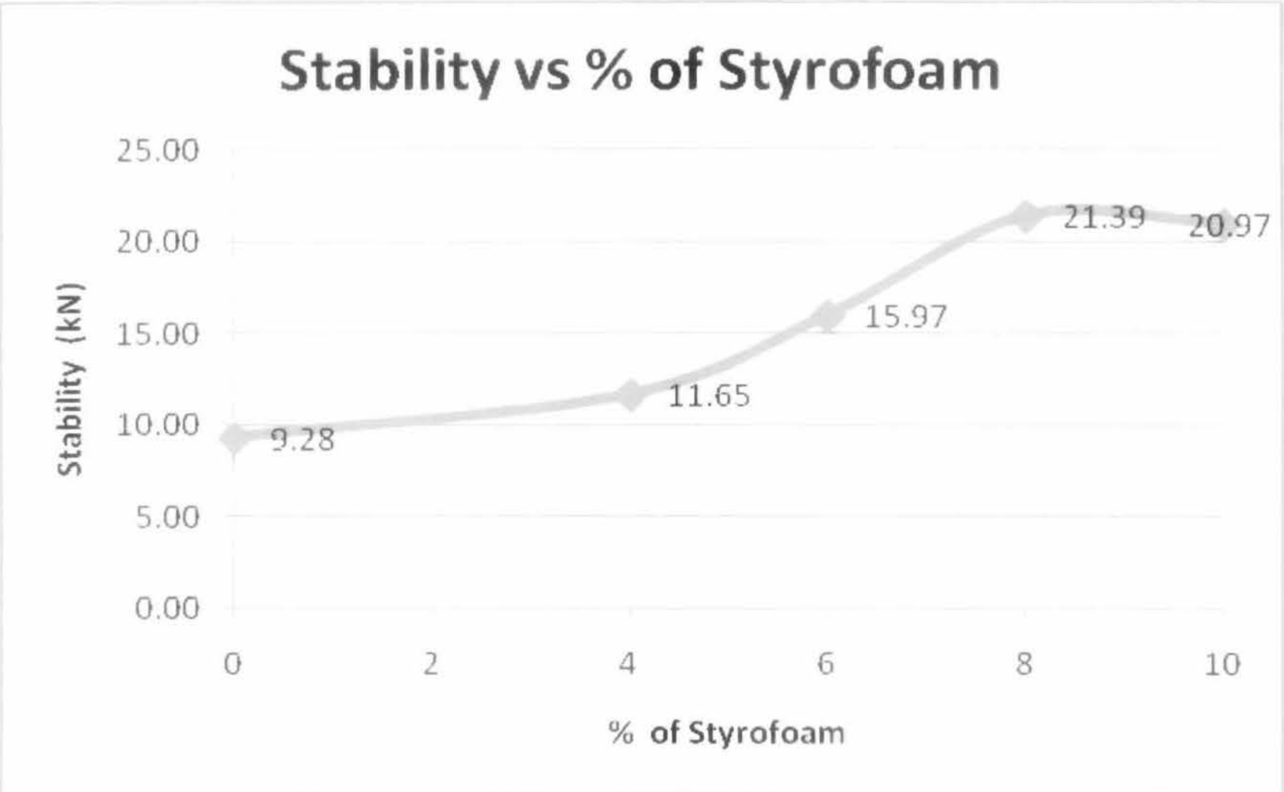


Figure 14 Graph of Stability Vs Styrofoam Content

Figure 5 shows the result of the stability values obtained from the Marshall Stability Test. It can be observed that the stability values increase gradually with the increase of Styrofoam content in the modified bitumen. Compared to the virgin bitumen the stability values were recorded higher for every variation of the modified bitumen. The stability values continue to increase up to the usage of 8% Styrofoam modified bitumen. The increase of the stability may be influenced by better adhesive bond strength as a result of the bitumen hardening [1]. The increase in the stability value signifies improved ability of the bituminous mixtures to resist shoving and rutting under heavy traffic load [10].

The Marshall Stability Test presented shows that the flow decreases and the stability increases with the usage of 4%, 6% and 8% Styrofoam modified bitumen. The asphalt concrete was proven to be able to resist higher load before permanent deformation compared to the control sample. However, minor increase of the flow and decrease of the stability were observed with the usage of 10% Styrofoam modified bitumen. This may indicate that 8% addition of Styrofoam content is the optimum addition for improving asphalt concrete performance.

CHAPTER 5

CONCLUSION

The study has revealed the potential of Styrofoam waste as bitumen modifier based on the improved properties of bitumen and asphalt concrete. Laboratory tests have proven enhanced rheological properties of bitumen to the extent of 8% Styrofoam content modification. The penetration value and softening point value was improved with modification up to 8% addition of Styrofoam content. This may be due to the hardening of the modified bitumen which indicates improvement in term of deformation resistance in medium to high temperature. However, the ductility value was very low compared to the virgin bitumen which denotes that the bitumen has become very brittle after alteration.

Marshall Stability Test for asphalt concrete has established significant enhancement towards the asphalt concrete by the application of Styrofoam modified bitumen. The stability increases while the flow decreases as the Styrofoam content of the modified bitumen increases up to 8%. This indicates that the modified binder rheological properties highly influence the performance of the asphalt concrete. The stability and flow value meet the Jabatan Kerja Raya Standard for Malaysian Highway as shown in Table 9.

Table 9 Specification of JKR Malaysia for AC Mixtures

Properties of Marshall Specimen	Specification Limits
Stability (kN)	>8
Flow (mm)	>2.0 – 4.0

As a conclusion, the objectives of the study were accomplished as the resistance towards deformation was improved by using 8% Styrofoam modified bitumen which was found as the optimum Styrofoam content. It is also proven that bitumen alteration is an effective disposal alternative for Styrofoam waste.

CHAPTER 6

RECOMMENDATION

Despite the results of this study, improvement on some areas of the study is recommended for the reliability of the study. The addition of Styrofoam waste can be increase beyond 10% addition. This is because the changes shown in the stability and flow value from 8% to 10% Styrofoam modification are quite minor. Thus, further addition of Styrofoam content may provide stronger defense on the optimum Styrofoam modification concluded by this study.

Besides that, the use of solvent in producing homogenous mixture of the modified bitumen is highly recommended. This can reduce the energy and times spend in producing the bituminous blend. It is also expect to improve the ductility value of the modified bitumen by increasing the incompatibility of the two materials.

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