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The Effect of Styrofoam Addition into HRS-Base on Marshall Characteristics

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Abstract—In this research, Styrofoam is added to the HRS-Base type of pavement to investigate the Marshall Parameter of its pavement mixture. Styrofoam is one type of waste that has characteristics that are nearly equal to asphalt, which are softened when heated and harden when temperatures return to normal. This study was conducted to determine the effect of Styrofoam on Hot Rolled Sheet-Base (HRS-Base) by varying the addition of Styrofoam in the mix. Based on the research, it can be concluded that the use of asphalt with the addition of Styrofoam as much as 0.5%, 1%, and 1.5% by weight of asphalt in an HRS-Base mixture improves the Stability of the mixture. The value of Flow is also increases when compared with asphalt mixture without Styrofoam. Asphalt mixture with the addition of Styrofoam as much as 1.5% has a maximum Stability above 1500 kg with optimum binder content is at 7.4%, and the value of Flow is above 3 mm. The 1.5% Styrofoam Asphalt ratio having the value of Voids in the Mixture is 4%, the Void in Mineral Aggregate is 19.2%, the Void Filled with Asphalt is 80%, and the Marshall Quotient is 260 kg/mm.

Keywords: Flexible Pavement; Hot Rolled Sheet-Base (HRS-Base); Styrofoam; Marshall Parameters

I. INTRODUCTION

HRS-Base is pavement type which having a gap grading gaps. It is mixed, spread, and compacted in hot conditions at a given temperature. The function of asphalt on the flexible pavement is to bind the aggregate which will form asphalt pavement construction, so the ability to bind the aggregate is an important parameter to be considered.

Styrofoam or foamed polystyrene (FPS) is lightweight, compact and categorized as plastic. Styrofoam as well as plastics has many benefits and commonly used for daily activities. Such as food and fruits packaging, electronic buffer, and it is known as cork is indeed practical, lightweight, relatively leak proof and can keep the temperature of the food properly. This is what makes this material well-liked and widely used, including in the instant food industry.

Styrofoam is the brand name for polystyrene foam. Styrofoam is a plastic made from petroleum, styrene monomer by suspension polymerization at a certain pressure and temperature, further heating to soften the resin and evaporating the residual blowing agent. The basic material used is 90-95% and 5-10% polystyrene gases such as n-butane or n-pentane [1]. Furthermore, Styrofoam is actually no less dangerous than plastic.

Styrofoam is harmful to the body as well as plastics when using it as food container and harmful to the environment when disposed to landfill.

Styrofoam produces styrene oxide which may possibly increase the carcinogenic production, especially when they used as warm food or drink container as well as, oils, acidic foods and alcohol causing human contamination and pose a health risk to people [2].



Fig. 1 Styrofoam remains on its shape
Credit: Rebecca Grabill E+ Getty Images

Styrofoam waste increases from time to time, because of Styrofoam waste cannot be easily recycled. If the plastic waste takes up to 500 years to decompose in the soil. So, the Styrofoam waste will remain on its shape, does not change or disappear until the end of life as shown on Figure 1.



Fig.2 Styrofoam and Plastic waste in Indonesia River
Source: <http://majalah1000guru.net/2011/11/plastik-minyak/>

Several efforts of reducing waste production have been investigated. For instances, producing biodegradable plastics, or using alternative materials such as natural lime in order to reduce the cement replacement [3] [4].

The research of using Styrofoam as an alternative material for pavement strengthening is expected to reduce the waste instead of dispose to the landfill. The Styrofoam used in this study is shown on Fig. 3, while the Styrofoam that has been shredded is shown on Fig. 4.



Fig. 3 Styrofoam from Electronic Safety Packaging

HRS-Base flexible pavement is one type of pavement structural with asphalt as an aggregate binder. Flexible pavement structure consists of several layers that are subgrade, subbase, base and surface at the top of the pavement. The surface is asphalt pavement mixed with coarse aggregate, fine aggregate and bitumen. One of the effort of increasing flexible pavement performance is to increase the aggregate binding.



Fig. 4 Shredded Styrofoam

Styrofoam or bubble plastics were investigated as bitumen additives to form a new binder for pavement structure due to its behaviour more likely bitumen. It is hard in low temperature and softens when temperature is increases. Styrofoam is being added to the bitumen aggregate mixture. In doing so, the strength of the flexible pavement may increase. The investigation of optimum Styrofoam usage into the bitumen was by Marshall test methods as per 2010 specification 6th division from Public Work Department standard in Indonesia, i.e high Stability, Flow, Void in mixture, Void in Mineral Aggregate and Marshall Quotient that meet based on this standards requirement [5].

The aim of this research is to investigate the effect of Styrofoam addition to the bitumen to form a Hot Rolled Sheet-Base Course (HRS-Base) mixture by means of several testings in lab.

II. LITERATURE REVIEW

Many efforts have been done to improve the quality of pavement structure, such as base course strengthening using geogrid [6], embankment or subgrade strengthening using coal ash mixture [7] or using the special material added to the asphalt.

Plastics are high demand materials, employed in a wide range of applications, from household packaging, agricultural, automotive, to building construction, due to their lightweight characteristics, high chemical Stability and low degradability.

The main application of the Styrofoam as seen on Figure 3 is as an electronic safety packaging. The use of Styrofoam in this investigation is due to its behaviour more likely bitumen, that is melted if burning it and hardened when the temperature is decreased.

Moreover, the HRS-Base is one of the flexible pavement type. The use of HRS-Base as a flexible pavement depends on the material available locally. It consists of coarse aggregate, fine aggregate and filler.

Coarse aggregate are grains of crushed stone, gravel, sand and other minerals, whether from natural or man-made in the form of solid minerals whether a large size, or small, or fragments [8]. Based on Indonesian Standard, coarse aggregate is retained at the sieve size No.4 (4,75 mm), fine aggregate is passing No.4 while filler is in the form of stone ashes or limestone ash which agree with AASHTO M303-89 [9].

The colour of bitumen is black, when it was warm, is sticky. Bitumen was visco-elastic material or semi-solid form of petroleum and solid or semi solid in room temperature [10]. If the temperature raise the bitumen is melted and if the temperature is decrease the bitumen will become a solid again due to the thermoplastic behaviour of the bitumen.

Styrofoam is a type of plastic made from 90% -95% polystyrene and 5% -10% of gases such as n-butane or n-pentane, which are widely used as protective and retaining vibration items such as for electronic goods. The use of Styrofoam as additives is due to having thermoplastics behaviour that is a solid room temperature and melted if heated above about 100 °C. Styrofoam becomes rigid again when cooled.

On the other hand, Styrofoam resist on acid, alkaline and other corrosive behaviour. One of the functions of Styrofoam is as an adhesive when mixed with gasoline. Consequently, as bitumen is an aromatic hydrocarbon, then the addition of Styrofoam into the bitumen is expected to improve the adhesion between the aggregate and bitumen, thus it will improve the quality of pavement mixture that meet the requirements by the Ministry of Public Works General Directorate of Highways [5]. In doing so, the waste Styrofoam that to dispose on the landfill is reduce.

The investigation of the use of Styrofoam addition to the Asphalt Concrete pavement mixture achieved its optimum Marshall parameter at 6% bitumen content, where the variations are 0%, 0.01%, 0.015%, 0.02%, 0.025% with the bitumen content 5%, 5.5%, 6%, 6.5%, 7% [11]. Moreover, Styrofoam has higher tensile strength so it can improve the strength, especially the elasticity of bitumen [12].

Furthermore, the investigation of the use of Styrofoam on Porous Asphalt pavement achieved its Marshall requirement specification at 6.26% and 9% Styrofoam addition except the Stability which is only 495.92 kg. It is slightly below the specifications required by the Australian Asphalt Pavement Association (1997) that a minimum of 500 kg [13].

Thus, the investigation of the use of Styrofoam is continued to HRS-Base pavement type to see its suitability to generate a more stable pavement. In doing so, it can also be protecting the environment by reducing the amount of waste Styrofoam.

HRS-Base is applied for surface pavement under HRS-Wearing Coarse layers for flexible pavement. HRS-Base is pavement type which having a gap grading gaps. In order to investigate its Marshall properties that uses Styrofoam in its binder, thus several samples were produced then tested by Marshall Test in Lab. Some of the Marshall parameters that have been investigated are Stability, Flow, Marshall Quotient, Void in Mineral Aggregate, Void in Mix and so on to obtain the optimum bitumen content that meet the requirements as can be seen in Table 1.

From the requirements of the HRS-Base as shown on Table 1, the stability of the pavement should be more than 800 kg, with the number of blows on each face is 75 blows. Marshall Quotient minimum is 250kg. Moreover, the minimum void in mixture, in mineral aggregate, and filled with bitumen were 4%, 18% and 68% respectively to ensure

the durability, stiffness and stability to resists the deformation due to traffic loads.

TABLE I
MARSHALL PARAMETER REQUIREMENTS

Marshall Parameter Properties		Lataston (Gap Graded)	
		Wearing Coarse	Base Coarse
No. of blows on each face		75	
Void in Mix (%)	Min.	4	
	Maks.	6	
Void in Mineral Aggregate (%)	Min.	18	
Void Filled with Bitumen (%)	Min.	68	
Marshall Stability (kg)	Min.	800	
Flow (mm)	Min.	3	
Marshall Quotient (kg/mm)	Min.	250	

To determine the optimum content of bitumen the maximum stability and maximum unit weight were chosen as well as the median limits for VIM and VFA [9].

III. MATERIAL AND METHODOLOGY

For the most part, Hot Rolled Sheet-Base mix design procedures (the 6th division specification from Public Work Department standard in Indonesia) and applicable AASHTO and ASTM testing standards for the Marshall Sample and Testing Procedure were followed [5].

The materials used for the research consists of coarse aggregates, fine aggregates, Cement filler, Styrofoam and bitumen. The mineral fillers used are the Portland Cement. The 85-100 penetration grade bitumen was chosen for the study. The samples were prepared at four different percentages of Styrofoam in bitumen i.e. 0%, 0.5%, 1% and 1.5% to form a new binder. The properties of the binder and its physical properties are listed in Table 2. There are three quantified samples at each percentage then the results are presented in average value.

TABLE II
BITUMEN PROPERTIES

Performance Indexes	Styrofoam			
	0%	0.5%	1%	1.5%
Penetration (25°C, 100 gr, 5 s) (0.1mm)	87 mm	95 mm	98 mm	92 mm
Unit Weight (25°C)	1.041	1.025	1.006	1.014
Flash Point (Cleveland Open Cup)	236°C			
Burning Point (°C)	327°C			
Softening Point (Ring and Ball Test)	54.5°C	53.5°C	52.5°C	56.5°C
Lost on Heating (163°C, 5 hours)	0.05	0.03	0.015	0.02
Penetration due to Loss on heating (25°C, 100 gr, 5 s) (0.1mm)	71 mm	75 mm	81 mm	85 mm

A. Sample Preparations

The mixes studied were compacted to 75 blows on each surface of the Marshall sample [5]. The bitumen is heated to a temperature of 90°C then the shredded Styrofoam as seen on Fig 2, was mixed with bitumen conventionally. It is stirred for 5 minutes until completely mixed. The mixed temperature of 90°C is hot enough to make a solid mixture, and does not exceed the weight loss tests temperature of 163°C (ASTM D 2872), so the content of the bitumen does not change due to heating [5][14].

The type of pavement used to investigate the Styrofoam usage is a flexible pavement, Hot Rolled Sheet-Base. Moreover, Styrofoam variations are 0%, 0.5%, 1%, and 1.5 % by total weight of bitumen.

B. Test Performed

The tests were performed at civil engineering laboratory for highway engineering at Andalas University. Aggregate and bitumen were available at the lab. Both aggregate and asphalt were examined of their properties as pavement materials, before mixing it together in order to produce a high-quality pavement mixture as per Public Work Department standard in Indonesia specification [5].

1) Aggregate Testing

- *Specific Gravity (SNI 1969:2008/ SNI 1970: 2008)*
The specific gravity of coarse aggregate is 2.60 with an absorption of 0.014% and for fine aggregate 2.47 with an absorption of 0.046%. Based on the 2010 General Specification of Division 6 Revision 3, the specific gravity of the coarse and fine aggregates shall not differ by more than 0.2 and water absorption should be less than 3%.
- *Volume Weight (SNI 03-1970-1990)*
The volume weight was examined in order to determine the amount of aggregate to be used along the road. In doing so, the amount of aggregate can easily be measured by volume. Knowing the length and the width of the road and the thickness of the pavement, the amount of aggregate can be quantified.
- *Coating and Stripping of Bitumen Aggregate Mixture (SNI 03-2439-1991).*
The allowable percentage of uncoated aggregate is 5% retained. In this investigation, for all the percentage of Styrofoam addition, there were 98% of aggregate surface were coated by bitumen.
- *Los Angeles Abrasion Value (SNI 2417 : 2008)*
The maximum loss value of Los Angeles Abrasion test is max 40%. Thus, the aggregate used in this investigation was having 19.18% loss on abrasion.
- *Aggregate Impact Value (SNI 03-4426-1997)*
The value of aggregate impact of 8,04 % shows that the aggregate is strong enough that the value is lower than the maximum value of 30%.

2) Bitumen Testing

- *Loss on Heating (SNI 06-2440-1991) (max. 0.8%).*
Loss on heating for 0% Styrofoam is 0.05%, while for 0.5%, 1%, and 1.5% Styrofoam their loss on heating were 0.03%, 0.015%, and 0.02% respectively.
- *Softening Point and Flash Point (SNI 06-2433-1991)*
Softening Point for all the variation of Styrofoam addition were in the range 53°C – 57°C. According to SNI 06-2434-1991, the Softening Point should be in the range of 48°C -58°C. Moreover, Flash Point for 0% Styrofoam in bitumen is 236°C, and for bitumen with Styrofoam addition is 318°C for all the percentage Styrofoam in bitumen.
- *Penetration (SNI 06-2456-1991)*
The bitumen penetration results of all the percentage of Styrofoam addition were in the range of 7.0 mm - 8.0 mm.

Marshall parameters were used to determine the material suitability for pavement surface layer, and the value of all parameters were used to determine optimum bitumen content that achieve the maximum stability [5][16].

Two important properties are determined from the Marshall test, first is the maximum load the specimen can be carried before failure, which is known as the Marshall Stability and the amount of deformation of the specimen before failure occurred, which is known as the Marshall Flow.

Other Marshall parameters were also observed such Marshall Quotient, Void in Mixture, Void in General Aggregate (VMA) and void filled with bitumen. The ratio of Stability to Flow is known as the Marshall Quotient. Marshall Quotient is a sort of pseudo stiffness which is a measure of the material's resistance to permanent deformation [17].

Stability of the pavement structure were used to determine the asphalt mixture characteristics. Asphalt pavement quality can be characterized by its their stiffness, stability, durability, permeability, workability, fatigue resistance, skid resistance, and resistance to moisture damage [18].

The characteristics of the Styrofoam added to bitumen to form a HRS-Base pavement mixture was performed in the Civil Engineering laboratory in Andalas University. The results were then analysed in accordance with the existing theory which accomplish the specifications set by the Ministry of Public Works General Directorate of Highways, AASHTO and ASTM standard [5].

IV. RESULTS AND DISCUSSIONS

A. Marshall Stability

Marshall Stability test is the performance prediction measure conducted on bituminous mix. Optimum bitumen content is a adequate amount of bitumen to ensure a durable pavement. The procedure consists of determination of the

properties of the mixture, Marshall Stability and Flow analysis and finally determination of optimum bitumen content.

Properties of the HRS-Base mixture determine the proportion of aggregate and bitumen to produce the bituminous mix, which is then used for the Marshall properties determination.

The Stability test results are shown in Fig. 5. The results show that for each percentage of Styrofoam the Stability increases with increasing bitumen content up to the optimum bitumen content and thereafter the Stability of the mixtures decreases.

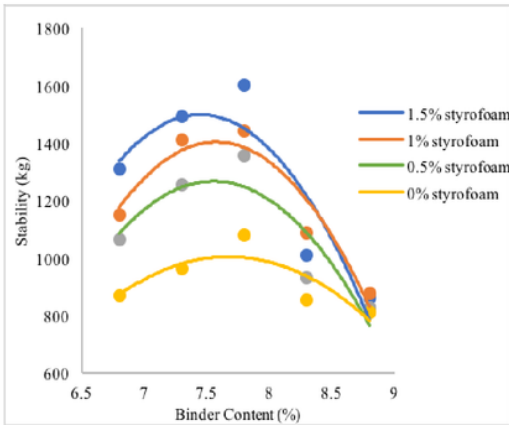


Fig. 5 Stability (kg) vs Binder Content (%)

The optimum bitumen content was found to be 7.7%, 7.6%, 7.6%, 7.4% for 0%, 0.5%, 1%, and 1.5% Styrofoam in bitumen respectively. By examining the plot at the point of optimum bitumen content, the stability values were estimated as 1000 kg, 1270 kg, 1400 kg and 1500 kg for 0%, 0.5%, 1%, and 1.5% Styrofoam respectively, all these values exceed the minimum requirement for high traffic [5].

It can be seen that the Stability values for all various Styrofoam addition mixtures met the SNI specification of not less than 800 kg. The results indicate that the bitumen with Styrofoam addition can bind the HRS-base pavement mixture due to having better Stability value. The increase in Stability of the mixture can be attributed to improved adhesion between the aggregate and bitumen, having longer service life and can carry the higher load of the vehicle.

B. Flow

Flow is the amount of deformation occurs in a layer of pavement due to withstand the load received. The amount of deformation occurring in the pavement layer also affected by the value of VFB, VIM and Stability. The Flow values of the Styrofoam variation against bitumen content are shown in Figure 6.

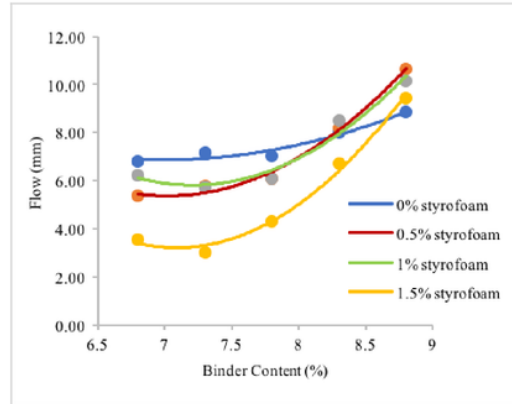


Fig. 6: Flow (mm) vs. Binder Content (%)

It can be seen that the Flow increased with increasing bitumen content. Moreover, increasing the Styrofoam content in the mixture resulted in increasing the Flow value too. At the optimum binder content of 7.7%, 7.6%, 7.6%, 7.4% for 0%, 0.5%, 1%, and 1.5% Styrofoam in bitumen respectively, the value of Flow of the mixture with Styrofoam was 4 mm, 6 mm, 6.2 mm and 7 mm, with 1.5% Styrofoam showing the lowest values for Flow and having the highest the Stability. Increases in Flow value indicated a higher the amount of deformation before failures occurs.

For 1.5% Styrofoam that having the highest Flow, it may be due to the quantity of the Styrofoam used in the mixture, that soften the mixture but the mixture is stable. More tests like the repeated load axial test (RLAT), wheel tracking test, etc. that can evaluate the permanent deformation resistant of asphalt mixtures better would be carried out in future studies.

C. Marshall Quotient

Marshall Quotient represent the ratio of load to deformation. Marshall Quotient can be used to give an indication of the mixture stiffness. The higher the ratio the stiffer the mixture is.

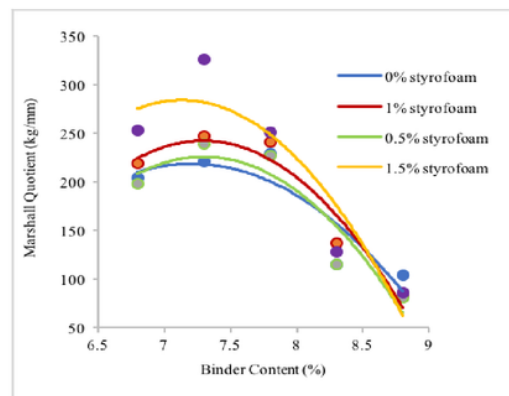


Fig. 7 Marshall Quotient (kg/mm) vs. Binder Content (%)

As can be seen from Fig. 7, as the Styrofoam Bitumen ratio increases the Marshall Quotient of the mixture are also increases. The higher the Styrofoam in the mixture the higher the Marshall Quotient is. The highest the Marshall Quotient achieved at the 1.5% Styrofoam.

It is found that Marshall Quotient of the Styrofoam addition at 1.5% Styrofoam content in the bitumen is 1.5 times with respect to the 0% Styrofoam. It can be inferred that these Styrofoam additions provide better resistance against permanent deformations due to their high stability and high Marshall Quotient and also indicate that these mixtures can be used in pavements where stiff bituminous mixture is required. Thus, the higher the Styrofoam in the mixture the higher the stiffness of the mixture is.

D. Void Filled with Bitumen (VFB)

Void Filled with Bitumen is part of a space between aggregate minerals (VMAs) filled with asphalt effectively, expressed in percent. The minimum value of Voids Filled with Bitumen (VFB) is 70% [5]. Most Department of Transportation specifications require 70-80 during the design phase [4]. In this investigation, the value of VFB are more than 70%. It exceeds the minimum required, thus result in a low air voids as seen on Fig. 8.

Air void contents may be very critical in terms of resisting permanent deformation. Thus, in this research the VFB for all various Styrofoam in the mixture are sufficient to avoid rutting in heavy traffic situations.

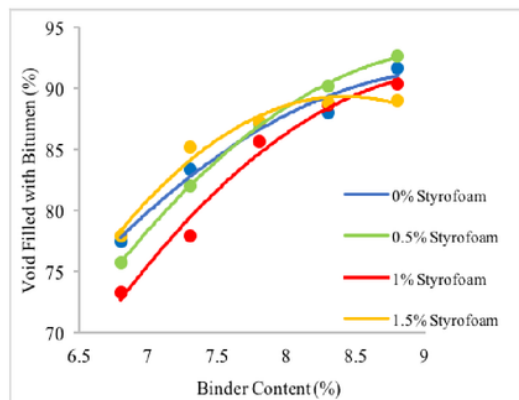


Fig 8. Void Filled with Bitumen (%) vs. Binder Content (%)

E. Void in Mixture (VIM)

Void in Mixture also known as air voids is the ratio of the volume of voids in a compacted mixture to the total compacted mixture volume [5].

The value of VIM may be influenced by compaction temperature, gradation, grade and type of pavement additive and the type or concentration of asphalt used. In this research the temperature, aggregate gradation and the type of asphalt used are not varied, thus the factors affecting the value of VIM only by the variation of Styrofoam and binder content.

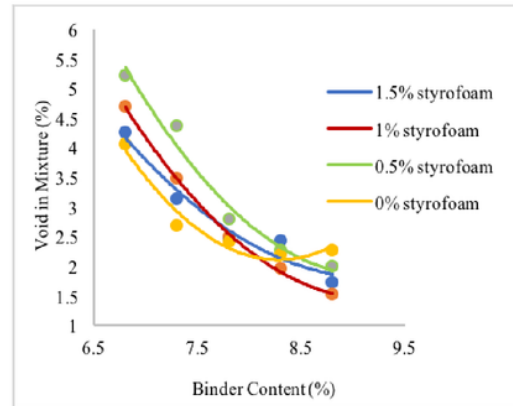


Fig. 9 Void in Mixture (%) vs. Binder Content (%)

Fig. 9 shows the voids in the total mix against the bitumen content for all various Styrofoam in bitumen. The voids are reduced as the percentage of Styrofoam increased.

Voids in Mix (VIM) should be in the range between 3.5% - 5.0%. VIM is the total volume of air between the aggregate particles are covered with asphalt in a mixture which has been compacted, and expressed as a percent of bulk volume. Optimum bitumen content should be in the interval of this figure [6]. It can be seen that the Void in Mixture for the Styrofoam added in bitumen are in the range of the voids content of the mixture. Unless the mixture without Styrofoam. The bitumen with Styrofoam has more voids than the mixture without Styrofoam.

F. Void In Mineral Aggregate (VMA)

The void spaces between the aggregate particles of the compacted mix or VMA for the various Styrofoam addition is presented in Fig. 10. VMA is the sum of the air voids and the effective asphalt content as per ASTM D6995 [15].

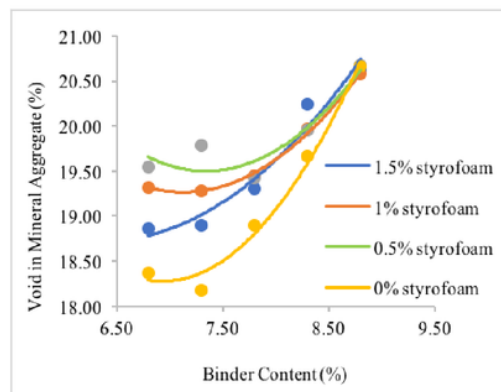


Fig. 10. Void in Mineral Aggregate (%) vs binder content (%)

Fig. 10 shows the Void in Mineral Aggregate (VMA) against the binder content. Generally, the voids in mineral aggregate decrease with increasing Styrofoam in binder except the 0% Styrofoam. At lower binder content, the VMA at four different mixture of Styrofoam were widely varied.

The highest void is for the lesser content of Styrofoam in binder, while the highest percentage of Styrofoam in binder having the lower void, except for the 0% Styrofoam. As the binder increasing the variations of VMA were continuously merging. It can be concluded that higher Styrofoam in binder reduces the VMA then it can reduce the oxidation thus it expected to increase the service life of the pavement. However, If the VMA is too low, it can be increased by modifying the gradation, asphalt content, or particle angularity.

V. CONCLUSIONS

The following conclusions are drawn based on laboratory investigation.

1. The properties of Styrofoam are found to be suitable as additive for HRS-Base pavement.
2. The higher the Styrofoam in mixture, the higher the stability of the HRS-Base pavement is.
3. The optimum bitumen content was 6.85% with 1.5% Styrofoam addition was resulted in the highest Stability.
4. The Stability, bulk density increased with increase in percentage of Styrofoam in the mix irrespective of the Styrofoam proportion and size. This indicates high stiffness

Thus, the use of Styrofoam in bitumen has produced a better result of Marshall Parameter, which having higher Stability, meet the required of Flow value, higher Marshall Quotient, lower Void in Mix. Consequently, it can solve the problem of Styrofoam waste disposal and environmental issue.

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