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Resilient Modulus Assessment of Asphalt Mixture Incorporating fly ash Geopolymer

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Abstract: An increasing a traffic volume, higher axle loads and increased tire pressure influencing the pavement damage and accumulation of permanent deformation caused by repeated loads at high working temperatures. Due to these phenomena, road construction industry needs to focus how to improve the characteristics of asphalt mix by incorporating with fly ash geopolymer. This study aims to evaluate the effects of fly ash geopolymer with 0%, 3%, 5%,7%,9% and 11% by mass of total mixture. Conventional binder 80/100 penetration grade was used as the base binder. The asphalt mixture prepared with varies percentage of fly ash geopolymer was evaluated for resilient modulus using universal testing machine. The optimum binder content conducted using Superpave method indicates the percentage of bitumen content increase as the fly ash geopolymer increases. It can be concluded that the asphalt mixture incorporation of 9% fly ash geopolymer give the highest resilient modulus values and lowest horizontal deformation compared to the other specimens. Based on these results, mixes incorporating fly ash geopolymer has the potential to improve the deformation regardless of test temperature.

Keywords: Fly Ash Geopolymer, Resilient Modulus, Superpave Method

1. Introduction

Hot Mix Asphalt (HMA) technology produced around 160°C and compacted at temperatures of about 130°C, depending on the mix type and binder grade. HMA is mainly used in flexible pavement, and it can be produced by mixing different percentage of aggregate and asphalt binder [1]. In the asphalt mixture, aggregate constitutes approximately 95% of hot-mix asphalt by weight and volume. It will contribute a lot on the characteristic of asphalt mixtures which is affect the performance of pavement [2]. Geopolymer is used as an additive during the preparation of hot mix asphalt. The new additive with high properties such as fly ash geopolymer is needed to enhance the asphalt binder properties. The use of by-product materials such as fly ash which is a by-product of burning coal in power plants, will help to enhances the sustainability of pavement mixtures [3]. The fundamental properties of bituminous mixture influence the stability and durability of asphalt pavement to withstand the destructive effects of wheel loading. The failures of performance on pavement layer because of environmental conditions such as high temperature, the application of HMA technologies in asphalt pavement production need to

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be modified to enhance the performance of pavement by choosing the correct asphalt binder. The used of granite aggregate is able to gives good quality and performance in asphalt mix production. The evaluation of aggregates in terms of physical and mechanical properties is important to comply to the standard road specification and predict their performance needs to be investigated. The used of waste by-products have been proved to be a more practicable alternative to excavated materials in engineering structures. However, due to cement's harmful influence on the environment, it is critical to identify alternative green materials [4]. As for that, the used of Fly ash (FA) based geopolymer is an environmentally friendly that the materials that can be used to replace cement to enhance asphalt mixture performance [5]. For this reason, fly ash geopolymer has potential to use as alternative materials in mixture and can increase the performance of asphalt mixture properties.

The aim of this study is to assess the deformation of asphalt mixture containing different fly ash geopolymer percentage against to various test temperature. The laboratory performance test which is Resilient Modulus Test following ASTM D4123 was be conducted to investigate the asphalt mix properties to emerging HMA technologies incorporating additive material. Asphalt mixture incorporating with the fly ash geopolymer as additive material was investigated to improve the performance of mixture stability and properties. The use of high temperature testing on asphalt mixture can influence the mix deformation and performance of aggregate bitumen coating and their mix elastic properties.

2. Literature Review

Fly Ash (FA) is an abundant by-product material that can be a potential stabilizer for enhancing the physical and geotechnical properties of pavement aggregates. Due to low carbon dioxide, geopolymer can be one of the best alternatives as modifier binder because it is a sustainable product [6]. Fly ash geopolymer was using as an additive to evaluate the rheological behaviour and performance grading of geopolymer modified binder using several laboratory experiments. The results show that there is an impact on rheological behaviour of asphalt binder. It also increasing the temperature susceptibility and shear modulus of the modified asphalt binder through the fly ash geopolymer as an additive in the mixture [5]. Another study also reported that the geopolymer as additive was used as 6% from total weight of asphalt binder and enhance the mix properties [7].

The Resilient Modulus (Mr) is a fundamental property of materials, defined as the ratio between applied axial deviator stress and strain. The Resilient Modulus is used to measure the stiffness of material. Stiffness is an important parameter for design the flexible pavements and used in the mechanistic analysis of pavement response under dynamic traffic loads [8]. The stiffness is also used to study the rutting behaviour of pavement. Major maintenance is needed when the materials of pavement undergo a lot amount of pressure from traffic loads. The stiffness of material can be analysing under various of condition such as moisture content, density, and different stress. Modulus of asphalt mixture is influenced by many factors, including temperature, asphalt type, variations in asphalt levels, gradations, and variations in compaction. The value of resilient modulus is affected by content of modifier and the temperature. The resilient modulus values are higher in modified asphalt mixture compared to the base asphalt mixture. This due to the increase in modifier content will produces an enhancement in the elastic properties of the asphalt mixtures [1].

3. Materials and Methods

The laboratory work was conducted in Advance Highway Laboratory, Universiti Tun Hussein Onn Malaysia (UTHM). This study was started from the material selection of aggregates, binder and fly ash geopolymer. The aggregates were tested using three types of tests which are specific gravity and water absorption [10], flakiness index and elongation index [11] and aggregate impact value (AIV) [12]. Then, the mix samples were prepared using superpave mix design and optimum bitumen content (OBC) was determined. The resilient modulus test was conducted as final performance evaluation for this study [13].

3.1 Material Selection

For this study, granite aggregate, binder 80/100 penetration grade and fly ash geopolymer were used. The aggregate was obtained from Harson Batu Pahat quarry. The type of binder used is Chevron that has 80/100 penetration grade. Fly ash class F was used which is from Kapar Power Station, Selangor. Fly ash geopolymer is the combination of fly ash with sodium silicate and sodium hydroxide. In this study, the fly ash geopolymer in powder form was used as asphalt mixture additive are 0%, 3%, 5%,7%,9% and 11% from the total mass of mixture.

3.2 Methodology

The aggregate evaluation was conducted to evaluate the physical properties of aggregate that effects on asphalt mixture stiffness. Table 1 shows the standard method for aggregate evaluation. Optimum binder content was determined to investigate the binder content percentage used on asphalt binder containing with different percentages of fly ash geopolymer using Superpave method. The specified method for resilient modulus test was following ASTM D4123 [14]. This test was conducted to compare the behavior of the pavement material under different dynamic loading. This test was performed using the Universal Testing Machine (UTM). Firstly, the specimen test was conditioned for 4 hours and was testing at constant temperature 25°C and 40°C. Then, the compressive load 1200 N was vertically applied on cylindrical specimen and parallel to its vertical diametric plane. The test sequent consists of fifty counts of condition pulses followed by five loading pulses. 1000 ms was used as pulse repetition to represent high traffic volume. The rise time of peak force and force pulse at the point 10% and 90% were recorded [14]. Figure 1 shows the research flowchart of this study.

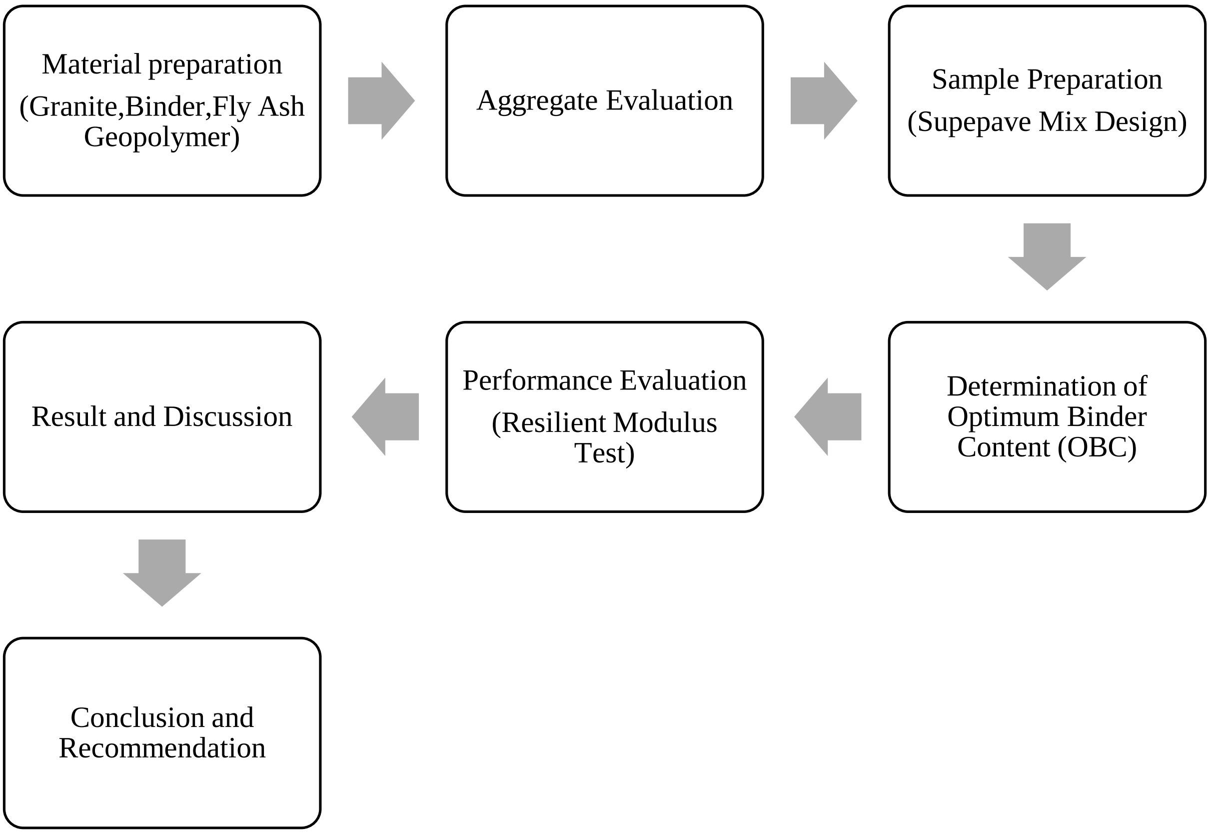

Figure 1: The research flowchart

Table 1: Standard method for aggregate evaluation

Aggregate Evaluation	Standard Method
Flakiness index and elongation index	ASTM D4791-10
Aggregate Impact Value (AIV)	BS 812 Part 112: 1990
Specific Gravity and Water Absorption	AASHTO T85

4. Results and Discussion

4.1 Aggregate Testing

4.1.1 Flakiness Index and Elongation Index test

The results of flakiness index and elongation index are recorded in Table 2. The percentage value of flakiness must fulfill the JKR Standard Specification for Road Work (2008). For this study, the percentage value of flakiness index is 19%, meanwhile for elongation index is 10%. The flakiness index testing is complying because the aggregate is not flaky.

Table 2: Summary value of flakiness index and elongation index

Properties	JKR Specification Requirement	Results
Flakiness Index	Less than 25 %	19 %
Elongation Index	Not stated	10 %

4.1.2 Specific Gravity and Water Absorption

The result for specific gravity and water absorption of the coarse aggregate is shown in Table 3 which is 2.51 and 0.62% respectively. Meanwhile, the result for specific gravity and water absorption for fine aggregates is 2.58 and 0.79% respectively as shown in Table 4. This result shows fine aggregate has higher value water absorption than coarse aggregate.

Table 3: Result of specific gravity and water absorption for coarse aggregate

Properties	Results
Weight of sample in air (g)	2030
Weight of sample in saturated (g)	2017.5
Weight of sample in water (g)	1226
Specific Gravity (SG)	2.51
Water Absorption (%)	0.62

Table 4: Result of specific gravity and water absorption for fine aggregate

Properties	Results
Weight of sample in air (g)	500
Weight of sample in saturated (g)	496.1
Weight of sample in water (g)	307.5
Specific Gravity (SG)	2.58
Water Absorption (%)	0.79

4.1.3 Aggregate Impact Value (AIV)

The percentage value of aggregate impact value must fulfill the JKR Standard Specification for Road Work (2008) [14]. For this study, the percentage value of aggregate impact value is 25% which is fulfill the standard requirement and suitable to be used in this study, Table 5 is recorded the results of aggregate impact value test for this study.

Table 5: Summary value for AIV test

Properties	JKR Specification Requirement	Results
AIV	Not less than 10 % and Not more than 30 %	25%

4.3 Optimum Binder Content (OBC)

The design binder content was used in mixture of specimens involving varying percentages of fly ash geopolymer which is 0%, 3%, 5%, 7%, 9% and 11%. Table 6 shows the result of optimum binder content for mixture involving various percentages of fly ash geopolymer.

Table 6: Optimum Binder Content used for mixture test

FAG	0 %	3 %	5 %	7 %	9%	11 %	STATUS
AIR VOIDS (%)	4.0	4.0	4.0	4.0	4.0	4.0	**COMPLY**
VMA (%)	18.5	18.7	18.9	19.9	19.4	19.5	**COMPLY**
VFA (%)	78.5	79	78	80	80	79	**COMPLY**
DUST PROPORTION	0.65	0.62	0.64	0.61	0.65	0.65	**COMPLY**
$\%G_{mm}$ at $N_{design} = 100$ gyration	96	97	96	96	96	96	**COMPLY**
OBC (%)	**5.25**	**5.02**	**5.30**	**5.60**	**5.65**	**5.83**	

4.4 Resilient Modulus Test

4.4.1 Effect of 25°C test temperature on FAG

The result indicates a general trend that increase content of fly ash geopolymer resulting in a rise of resilient modulus value and decrease the total recoverable horizontal deformation. The control sample (0% FAG) shows the lowest resilient modulus with 2771 MPa among the mixtures, while 9% FAG have the highest resilient modulus 5870 MPa compared with other modified binder content samples as shown in Fig 2. The increase in percentages of modifier content produces an improvement in the elastic properties of the mixtures [1]. Other than that, the difference in pavement temperature is very influential on the mixture stiffness modulus, this occurs because of the high binder content [9].

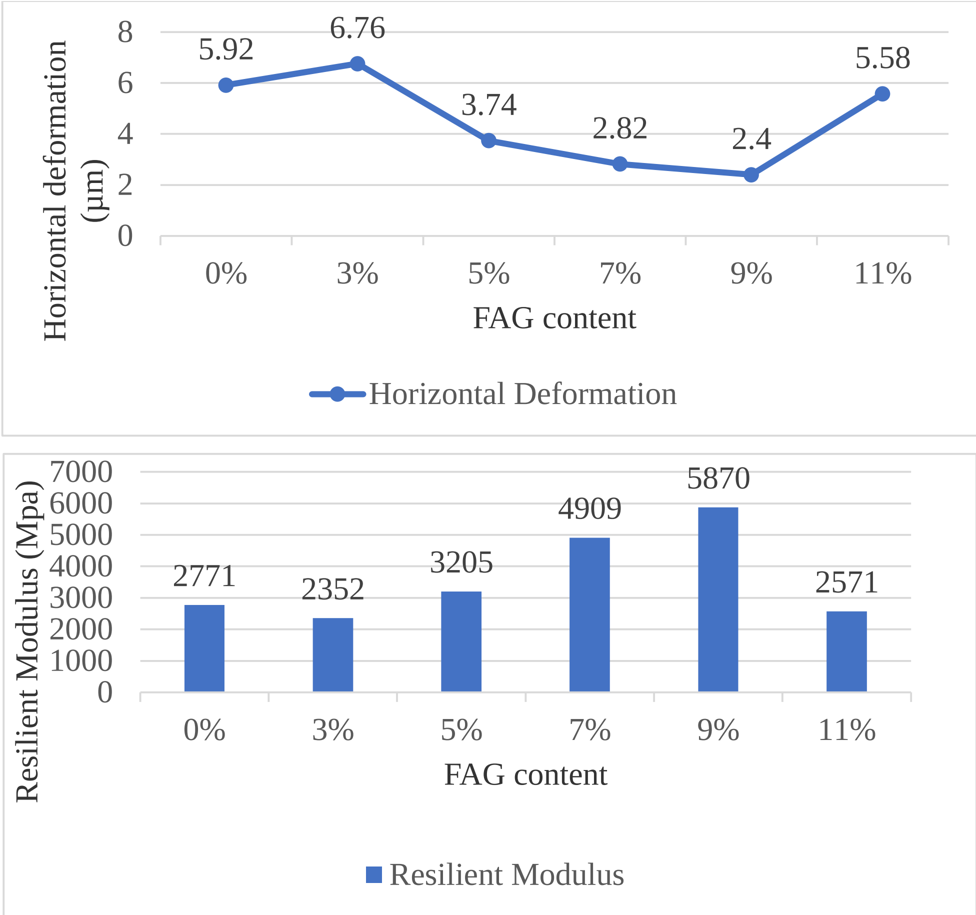

Figure 2: Effect of 25°C test temperature on FAG

4.1.2 Effect of 40°C test temperature on FAG

The addition temperature from 25°C to 40°C shows the resilient modulus values are reduces by 48%. This result shows that the addition of temperature is affect the values of resilient modulus. It can be concluded that the stiffness modulus of a mixture is depend to the mixture type which consist various of factors such as asphalt content in the mixture, mixture gradation, temperature, mixed humidity, aggregate form, and preparation of asphalt mixture [9]. Effect of using fly ash geopolymer with different percentages as a modifier of binder shows that as the temperature increases, resilient modulus decreases regardless of the modifier type and content. Meanwhile, values of horizontal deformation are increasing by 73% with the addition of temperature. This shows that the values of horizontal deformation are inversely proportional to resilient modulus values, Figure 3 shows the relationship between resilient modulus values and total recoverable horizontal deformation respectively with different fly ash geopolymer content at 40°C test temperature.

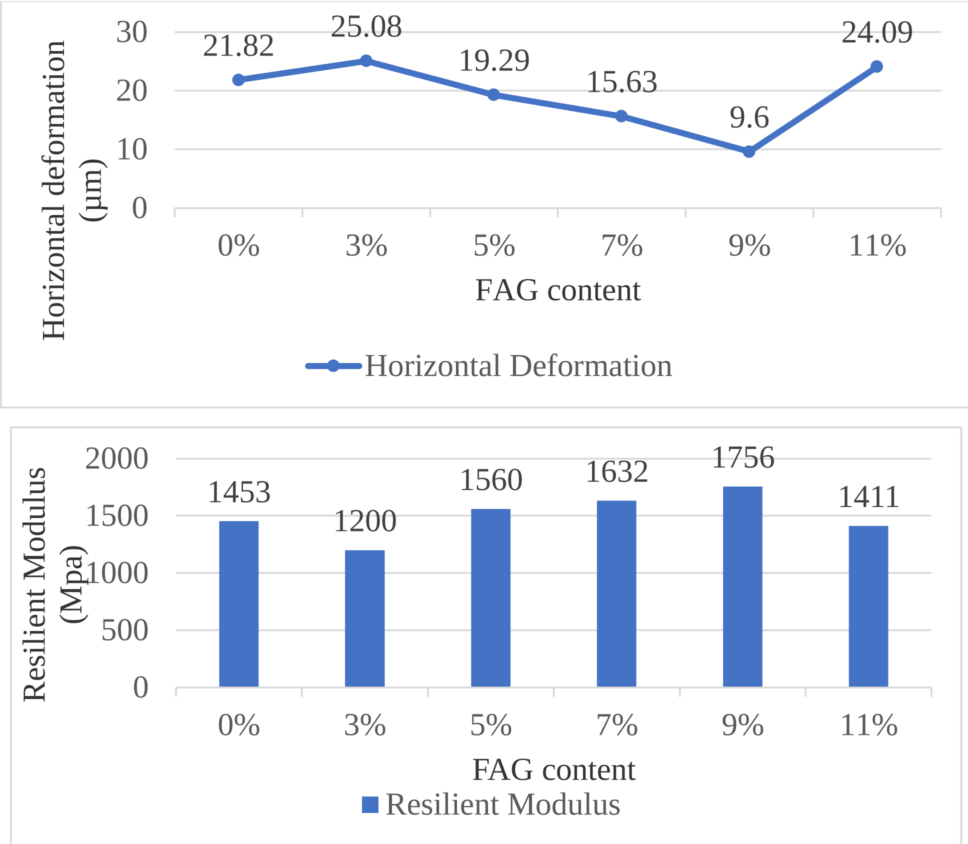

Figure 3: Effect of 40°C test temperature on FAG

5. Conclusion

In conclusion, 9% of fly ash geopolymer (FAG) is the ideal percentage to use in asphalt mixture for reduce deformation of asphalt mixture. The lowest deformation is shown which is 2.4% and 9.6% respectively for 25°C and 40°C test temperature. The effect of 25°C test temperature on FAG shows the resilient modulus values are fulfill the JKR method which is minimum 2500 MPa. The result shows all the FAG contents is pass the minimum value that required. It shows this performance test was successful conducted using the correct method. However, the effect of 40°C test temperature on FAG were not fulfill the standard requirement. The resilient modulus values were not passing 2500 MPa, the highest value only 1756 MPa.

Other than, the binder content of binder 80/100 penetration grade incorporating with different percentages of fly ash geopolymer also was successfully obtained for each binder content. The binder content for 0%,3%,5%,7%,9% and 11% are 5.25, 5.02, 5.30, 5.60, 5.65 and 5.83 respectively. The results of air voids, VMA, VFA and dust proportion are also fulfilling all of the requirement needed.

This study presents the resilient modulus assessment in asphalt mixture incorporating fly ash geopolymer modified binder for road construction industry. The binder content used in asphalt binder containing different percentages of fly ash geopolymer were successfully investigated. Other than that, the physical properties of aggregates that can affects stiffness of asphalt mixture also were evaluated. The deformation of asphalt mixture containing different percentages of fly ash geopolymer are increasing by increased of temperature.

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