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Evaluation of fly ash Geopolymer on Asphalt Mixture Against Resilient Modulus Test

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Abstract: The continuous increase of traffic volume and traffic load in this modern era contributes to the asphalt pavement defect. High traffic volume and traffic load lead to the impact of the workability and quality properties of the asphalt pavement. As the traffic volume increases, the load on the pavement increases as well which causes pavement failure especially in the cracking and fatigue. This study aimed to evaluate the resilient modulus performance of the asphalt pavement incorporating the fly ash geopolymer additives. The granite aggregate and bitumen grade 60/70 with the fly ash geopolymer at a concentration of 3%, 5%, 7%, 9%, and 11% of the total binder were used in this study to evaluate the Resilient modulus performance. The aggregate properties were determined using the flakiness index, elongation index, specific gravity, water absorption, and aggregate impact value respectively. The Resilient modulus test was performed using a Universal Testing Machine (UTM) at 25°C and 40°C test temperature following ASTM D4123-82 standard specifications. The study shows the resilient modulus of FAG modified samples was enhance approximately 30% compared to the controlled sample. Overall, it indicates the additions of FAG additives improve the stiffness of the asphalt mixture and increase the asphalt pavement endurance.

Keywords: Granite Aggregate, Fly Ash Geopolymer, Asphalt Binder, Stiffness Properties, Resilient Modulus, Universal Testing Machine

1. Introduction

Asphalt pavement is commonly used in road construction as a road surface to connect between one place to another. For vehicle travelling from one place to another. As the traffic volume increase with the passage of time, the asphalt pavement and the wheel traffic load such as horizontal force, vertical force, and impacted force, had a directly in contact with each other. Therefore, the service level of the pavement structure would be dominated by the quality of asphalt pavement, and they are needed to be maintained to preserve the quality of the asphalt pavement thus can improve the elasticity of the asphalt. The increasing asphalt elasticity could expand the actual contact area of the tire-pavement, giving the tires a stronger grip [1].

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In recent years, the study on modified asphalt mixture has been develop to enhance the pavement workability and performance. Since the fly ash waste is classified as a hazardous compound and the inappropriate disposal of fly ash will deteriorate the environment and ecology [2]. One of the solutions that can be taken is by recycling the fly ash waste into useful materials in asphalt mixture. The used of fly ash waste was one of the sustainable methods and solution to reduce the environmental pollution [2].

The performance of the pavement depends mainly on the selection of the suitable aggregates. The asphalt pavement design will have some failure due to the poor in designing the aggregates of asphalt mixture. The selection of the aggregates can influence the performances of the asphalt mixture [3]. The igneous rock type is suitable to be used in road pavement layer due to the strong properties and has a good traffic skid resistance [4]. Thus, it is important to use an aggregate according to the specification to assure the pavement had a long lifespan and provide comfort to road users [3].

The aim of this study is to evaluate the resilient modulus performance of the asphalt pavement incorporating the fly ash geopolymer additives. Additionally, this study determines the possibility of using FAG additives in improving the performance of asphalt pavement.

2. Materials and Methods

2.1 Materials and Sample Preparation

In this study, the granite aggregate was used as the aggregate mixture and bitumen grade 60/70 penetration test also was used as an asphalt binder in this study. Two different samples have been used in this study which is the controlled sample and the modified sample. The controlled sample represents 0% of FAG additive. Meanwhile, the modified sample represents 3%, 5%, 7%, 9%, and 11% of FAG additive. The selected percentage of FAG additives are based on the previous study conducted by Hamid et al [5], with the addition of 5%, 7%, and 11% of FAG additives. The batching process of the aggregates and additive material has been done first to ease the bitumen mixing process. Thus, as many as 36 samples have been batched for the further evaluation process. Also, the total of weight of each sample is 1200 gram approximately.

2.2 Superpave Mix Design

The Superior Performing Asphalt Pavements or Superpave mix design method was one of the principal results from the Strategic Highway Research Program (SHRP). The design of the Superpave mix method is to replace the Marshall mix design which is a conventional method in road construction. The differences between the design methods of the Superpave and the Marshall mix are mostly in the selection procedure of the material, compaction technique, sample dimensions, void analysis approach, and specifications. In addition, the Superpave mix design will improve the performance of asphalt pavement since the Superpave mix design performed better than the Marshall mix design [6].

2.3 Fly Ash Geopolymer

The geopolymer is a binding material made by activating source materials containing silica and alumina such as fly ash with alkali solutions and sodium silicate. The alkaline solutions used for the geopolymer process is a combination of sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3). When the source materials such as fly ash in solid form are mixed with NaOH and Na_2SiO_3 of adequate concentration, geopolymers are produced. The process of geopolimerization is shows in Figure 1. Furthermore, the asphalt mixture containing fly ash geopolymer show better resistance to permanent deformation, which points to their higher potential rutting resistance and longer fatigue life [7]. The fly ash geopolymer additives also will increase the creep stiffness of asphalt pavement [8].

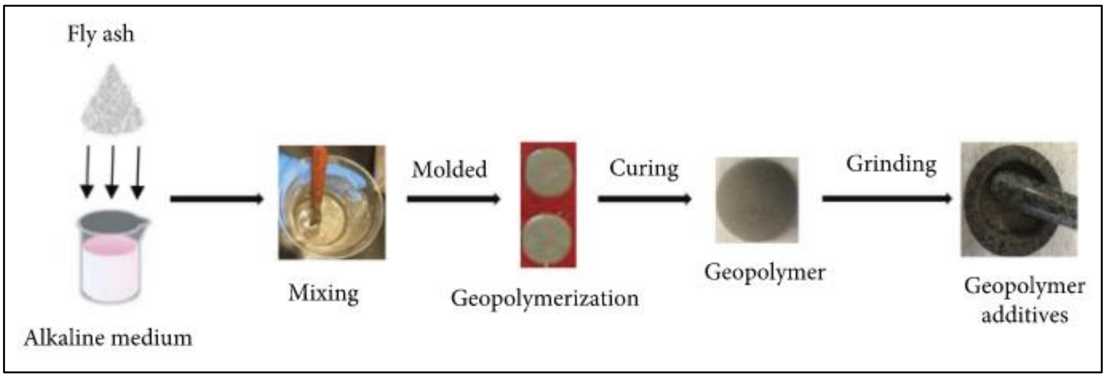

Figure 1: The process of geopolimerization [5]

2.4 Test Methods

i. Flakiness and Elongation Index test: The flakiness and elongation index test used to determine the aggregates shape. The flakiness and elongation index test also were conducted to identify the aggregate shape ratio with specific sieve size. The aggregates are considered flaky if it has a thickness less than 0.6 of their mean sieve size and the aggregates are considered elongation if it has a length of more than 1.8 their mean sieve size. The test was conducted following the standard specification ASTM D4791-10 procedure. The sample was sieved and a minimum of 200 pieces of the fraction was tested and weighed adequately. Then, each of the aggregates length and thickness was gauged to separate the elongated and flakiness aggregates. the flakiness and elongation index were calculated by using the equation 1. Also, the flakiness index result should less than 25% to comply with the JKR specification requirement.

$$Flakiness\ and\ Elongation\ Index\ (\%) = \frac{Total\ of\ the\ mass\ passing\ for\ each\ size}{Total\ of\ aggregates\ weight} \times 100\ Eq. 1$$

ii. Specific Gravity and Water Absorption test: The Specific Gravity (SG) test was conducted to evaluate the weight ratio of a volume aggregate weight to the equal volume weight of water. The SG test is important to tracking the deleterious particles in the aggregate. Meanwhile, the water absorption test was determined to estimate the increase of aggregate weight due to water contained in the material's pores. In this test, the aggregate weight was measure in three conditions: oven-dry weight, saturated surface dry weight, and underwater weight. The SG and water absorption conducted followed AASHTO T85 for coarse aggregate and AASHTO T84 for fine aggregate. The water absorption value must less than 2% to comply with the JKR standard specification.

iii. Aggregate Impact Value test: The Aggregate Impact Value (AIV) test was performed to determine the toughness of the aggregate due to sudden impact. The AIV test was conducted followed BS 812 standard specification. The AIV percentage required to be used in roadwork by JKR should not exceed 30%. Firstly, the AIV test was conducted with both aggregates grading passing through 12.5 mm sieve and retained on 10 mm sieve are 100%. Then, the sample has been dried for 4 hours at a temperature of 100˚C to 110˚C. After the cylindrical mould weight being measured, the cylindrical mould was filled with the cooled aggregates in the measured layer and each of the layers was tamper by using a tamping rod with 25 blows. Next, the hammer height has been adjusted to 380 mm above the upper surface and the aggregate was subjected to 15 blows with the delivered interval of impact not less than one second. The crushed aggregate then was being removed and was sieved with a sieve size of 2.36 mm. Lastly, the crushed aggregate passing through and retained sieve size 2.36 mm was measured for calculation purposes. The AIV results need to be compared with the AIV standard classification limit in Table 1 for the suitability aggregate used of roadwork.

Table 1: Aggregate impact value class limitation [9]

Aggregate Impact Value (%)	Coarse aggregate result
<10	Exceptionally strong
10-20	Strong
20-30	Satisfactory for road surfacing
>35	Weak for road surfacing

iv. Resilient Modulus test: The Resilient Modulus (Mr) test is an indicator to evaluate the stiffness and fatigue behavior of the asphalt pavement. The Mr is the evaluation of asphalt response on dynamic stresses and the corresponding strains [10]. The sample of Mr is basically approximate of Modulus Elasticity. The stiffness properties need to be in an optimum amount to resist the deformation toward pavement structure. The determination of the Mr is performed by using the Universal Testing Method (UTM) followed the standard requirement of ASTM D4123-82. A minimum of two samples from each of the FAG percent respectively was used to evaluate the stiffness and horizontal deformation of the samples under two different temperature which is 25˚C and 40°C.

3. Results and Discussion

3.1 Flakiness and Elongation Index

The aggregate shape is a crucial matter due to the flaky and elongated shape affected the asphalt mixture behaviour due to the fracture factor result from compaction work. It is important to determine the suitable aggregate shape before being used in asphalt mixture. Table 2 shows the result of the flakiness and elongation index of granite aggregate. The flakiness index value is less than 25% and has complied with the JKR specification requirement and suitable for roadworks. As mentioned by [11], the granite aggregate is one of the most suitable aggregates for road construction due to the lower flakiness and elongation indices.

Table 2: Flakiness and elongation index of granite aggregate

Properties	JKR Specification Requirement	Result (%)
Flakiness Index	Less than 25%	17.41
Elongation Index	Not Stated	12.24

3.2 Specific Gravity and Water Absorption

The specific gravity value for both coarse and fine granite aggregate is in range between 2.5 to 3.0 and suitable to be used in the road construction. The specific gravity result ranges from 2.5 to 3.0 is typically used in roadworks [12]. Meanwhile, the water absorption value for both coarse and fine granite aggregate was less than 2% and has complied with the JKR standard specification. In addition, the aggregate absorption is a valuable parameter where the higher value of water absorption indicates to non-durable aggregate and also indicate the total absorption of asphalt binder by the aggregates. Table 3 illustrates the specific gravity result for coarse and fine granite aggregate.

Table 3: Specific gravity and water absorption of coarse and fine granite aggregate

Properties	Coarse aggregate result	Fine aggregate result
Specific gravity	2.509	2.577
Absorption (%)	0.620	0.786

3.3 Aggregate Impact Value

The aggregate used in the road construction must be tough enough to withstand a crushing due to the heavy traffic volume loading. The AIV test is a crucial parameter to identify the suitable strength properties to be used in the asphalt pavement. The AIV result as shows in the Table 4 are within 10% to 20%, referred to the strong coarse aggregate properties and have complied with the JKR specification requirement for roadworks. Moreover, the aggregate types also contribute to the aggregate toughness properties. Based on Salam Al-Ammari et al., [13] reported that the granite aggregate has a lower AIV percent compare to the AIV percent of limestone aggregate, which is the granite aggregate has strong properties compare to the limestone and suitable to be used in the roadworks.

Table 4: Aggregate impact value of granite aggregate

Properties	JKR Specification Requirement	Result (%)
Aggregate impact value	Not less than 10% And Not more than 30%	12.25%

3.4 Resilient Modulus Performance

The Mr and total horizontal deformation value are varying between the controlled sample and modified sample. It can be seen that a trend where the increasing of the FAG additives resulting in the decreasing of the total horizontal deformation. The Mr value has decreased from 6751 MPa for 9% FAG additives to 4645 MPa for the 11% of FAG additives but still higher than the Mr value of the controlled sample. Additionally, the modified sample with 9% of FAG additives has the highest Mr value compared to the controlled samples, which are 6751 MPa and the modified sample with 9% of FAG additives has the lowest total horizontal deformation value compared to the controlled samples, which is 1.29 µm. Hence, the Mr value at 25°C for the controlled and modified sample has exceeded 2500 MPa and complied with the JKR standard specification. Therefore, Figure 2 illustrates the relationship between the Mr performance and the total horizontal deformation value of the sample incorporating the varying FAG percentage at 25°C.

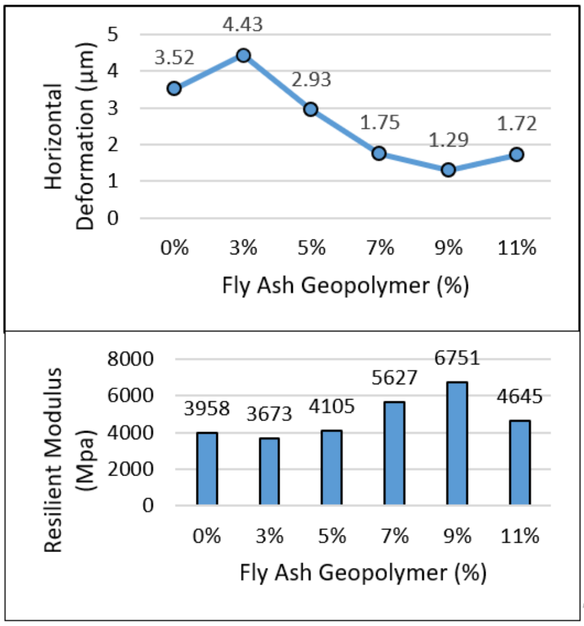

Figure 2: Relationship between resilient modulus performance and total horizontal deformation value at 25°C

The Mr test was also performed at 40°C to determine the stiffness between the controlled and modified samples at high temperatures. Figure 3 shows the relationship between the Mr performance and the total horizontal deformation value of the sample incorporating the varying FAG percentage at test temperature 40°C. The data result shows a similar trend observed at 25°C, which increases the FAG additives resulting in the decreasing of the total horizontal deformation value. The Mr and the total horizontal deformation value also varying at 40°C temperature test between the controlled and modified samples. The Mr value has decreased from 1954 MPa for 9% FAG additives to 1543 MPa for the 11% of FAG additives but still higher than the Mr value of the controlled sample. Thus, the modified sample with 9% of FAG additives has the highest Mr value compared to the controlled samples which are 1954 MPa, and the modified sample with 9% of FAG additives has the lowest total horizontal deformation value compared to the controlled samples which are 7.27 µm. However, the Mr value at 40°C for the controlled and modified sample has not exceeded 2500 MPa and has not complied with the JKR standard specification due to the higher temperature test.

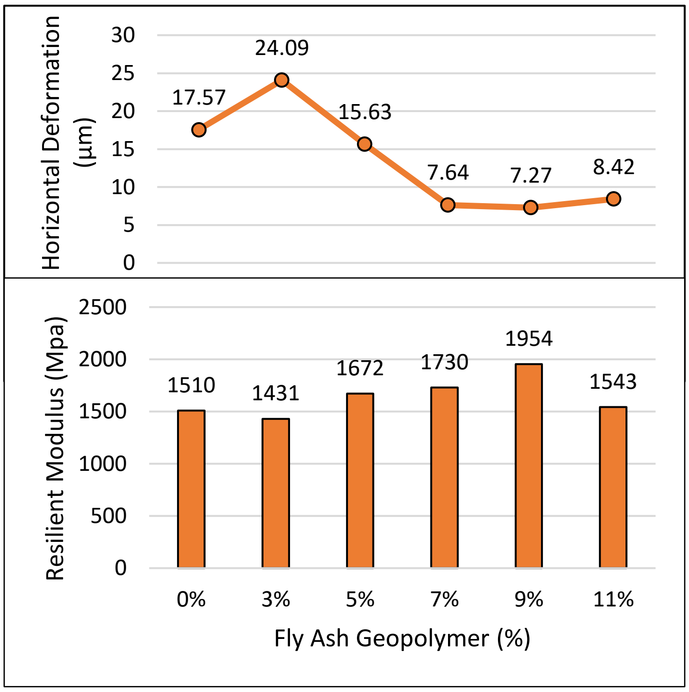

Figure 3: Relationship between resilient modulus performance and total horizontal deformation value at 40°c

4. Conclusion

This study focused to evaluate the Mr performance of controlled and modified sample using the UTM at 25°C and 40°C temperature tests. The modified samples conducted at 25°C and 40°C have a higher Mr value and lower of total horizontal deformation value. The 9% FAG additives performed at both 25°C and 40°C have the highest Mr value and the lowest total horizontal deformation value. However, the Mr value for both controlled and modified samples conducted at 40°C test temperature has not complied with the specification requirement by JKR. It can be verified that the FAG additives improve the stiffness properties and lesser the fatigue properties of the asphalt pavement.

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