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Evaluation of Fly Ash Geopolymer on Bitumen Mixtures Against Moisture Damage

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Abstract: Presence of water in asphalt pavement may lead to adhesive failure at binder-aggregate interface and cohesive failures within the binder-filler mastic. The continuing action of moisture induced weakening and traffic load induced mechanical damaged can cause a progressive dislodgement of the aggregate, weakening of the aggregate-mastic bond and known as stripping of the pavement surface. The aim of this study was to evaluate the effectiveness of fly ash geopolymer as an additive material on bitumen mixtures against moisture damage. The bitumen mixtures incorporating fly ash geopolymer with 0%, 3%, 5%, 7%, 9% and 11% by mass of total mixture were used to determine the moisture susceptibility of bitumen mixture using moisture sensitivity test. Conventional bitumen 80/100 penetration grade was used as the base binder. The compacted specimen was conditioned for wet and dry condition and assessed the moisture sensitive according to the AASHTO T283. The result shows that the addition of 9% fly ash geopolymer in asphalt mixture conditioned for wet and dry condition indicates the highest of tensile strength at 1346.9 kPa and 1628.7 kPa, respectively. In contrast the specimens containing 11% fly ash geopolymer show a better resistance to moisture damage as 85% and comply to the standard specification. This due to the highest of wet ITS value compared to the dry specimen. From the result, conclusion can be made that the asphalt mixture prepared with various fly ash geopolymer percentage are compliance with the standard specification which is more than 80%. The specimens prepared with various fly ash geopolymer shows a good potential to the resistance moisture damage. The increasing of ITSR value produce a better the performance of the bitumen mixture with a greater withstands to moisture damage.

Keywords: Fly Ash Geopolymer, Moisture Damage, AASHTO T283

1. Introduction

Nowadays, to evade the problems such as lack of existing materials therefore, the improvement material of pavement is important. Due of the good accomplishment and compared to rigid pavement, construction costs are lower, the Hot Mix Asphalt (HMA) is frequently used mix on road pavement.

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The HMA used is intended to maintain its durability, strength, consistency, and ability to resist to pavement distresses in a long-term if viewed from performance perspective. In addition, the surface layer should withstand the durability of the skid so that it can provide to safe driving (Gedik, 2020). High moisture content, heavy rains, freeze/thaw cycles, and other environmental factors are rising the moisture exposure of materials, increasing the risk of moisture damage (Bozorgzad *et al*., 2018). Moisture damage is the main distress in HMA, and it accelerates the formation of other problems in the bitumen mixture. Moisture can connect with the bitumen, resulting the reduce of the strength in cohesive and correspondingly lower a stiffness in the mixture. The primary part in the behavior of bitumen mixture against water permeability is the filler such as fly ash. Fly ash as an effective source to produce geopolymer, a new binder or cement in appearance, reactivity, and properties approximately comparable to hydrated cement. Fly ash based geopolymer generally indicates mechanical strength and durability almost similar to hydrated Portland cement that can be used as a green cement class with natural resource efficiency (Zhuang *et al*., 2016).

The primary objective of this study is to evaluate the effect of fly ash geopolymer percentage on binder bitumen based on Superpave mix design and to assess aggregate-bitumen bonding due to presence of water that enables prediction of water induced damage in asphalt mixes containing different fly ash geopolymer percentage. The laboratory performance test which is Moisture Sensitivity Test (AASHTO T283) was conducted to determine the effectiveness of additives on bituminous mixes tensile properties accordance different percentage of fly ash geopolymer. The presence of an additive was enhance the susceptibility to moisture damage in asphalt mixes (Nazrul *et al*., 2017).

2. Literature Review

The application of fly ash-based geopolymer paste to natural aggregates improves the physical and mechanical characteristics of marginal aggregates, rendering them consistent with pavement construction requirements. In addition, the use of such coated aggregates in bituminous mixtures would lead to the improvement of the stability and longer service life of these mixtures and can also be a remedial step for disposal of fly ash (Dayal & Soundarapandian, 2018). The production is more energy-efficient due to the fly ash geopolymer is industrial waste. The geopolymer production technology are not necessarily require high-temperature calcination and can minimise emissions by 80%. Mainly due to the action of moisture, stripping is the physical separation between of bitumen and aggregate due to the loss of adhesion between the bitumen and the aggregate surface. According to Rosyidi *et al.*, (2020), the use of 0%, 3%, 5%, 7% and 9% by weight of bitumen can improve the mixture stability and increasing the resistance to moisture damage and decreasing the permanent deformation.

To determine the moisture-susceptible asphalt mixes, a generally acknowledged test method which is Modified Lottman test (AASHTO T283) was implemented, and this method was used in the Superpave system as well. Moisture Sensitivity Test is one of the most precise experimental tests for evaluating the moisture susceptibility of asphalt mixes. Improving aggregate interlock helps enhances the mixture's susceptibility to moisture damage (Foroutan *et al*., 2019). More Indirect Tensile Strength (TSR) values indicate that the specimens are less susceptible to moisture (Ameri *et al*., 2018). This method of testing considers not only the physical and mechanical features of the asphalt mixture, but also the impacts of pore pressure and traffic.

3. Materials and Methods

The laboratory work was conducted in Advance Highway Laboratory, Universiti Tun Hussein Onn Malaysia (UTHM). The first aspect determined in this research is the information related to the topic being discussed. The next step was started from the selection of material of aggregates, bitumen, and fly ash geopolymer. The type of aggregate used is granite. Aggregate testing used in this research is specific gravity and water absorption, flakiness index and elongation index and aggregate impact value (AIV). Then, the optimum bitumen content (OBC) was conducted based on Superpave mix design. Accordingly, moisture sensitivity test as performance evaluation was conducted to evaluate the bituminous mixes tensile properties and more in relation to the crack formation of properties of the pavement accordance AASHTO T283.

3.1 Material Selection

The selection of material in this study is aggregate and fly ash geopolymer. The aggregates used is granite which is the type of this aggregate have a different degree of water absorption and the aggregate gradation is the mid limit of a densely graded asphalt mixture. The penetration grade of bitumen was used in this study is 80/100 as it is commonly used as paving grade. The fly ash obtained from Kapar Power Plant was used as additive to minimize the moisture sensitivity in bitumen mixtures. The percentage of fly ash geopolymer were adapted in this study based on study by Rosyidi *et al.*, (2020) as published in literature review. The percentage in this study are used as 0%, 3%, 5%, 7%, 9% and 11% by weight of a total mixture.

3.2 Methodology

The aggregate testing was conducted to obtain the physical properties of aggregate that achieve the requirement. The standard method for aggregate evaluation was shown in Table 3.1. The optimum bitumen content (OBC) is aimed to accomplish the necessary strength, durability, and performance. The Superpave method was used to evaluate the bitumen content. The design of OBC ranges from 4.0% - 6.0% according to ACW14 mixture. Accordance AASHTO T283, the moisture sensitivity test was conducted to evaluate the effectiveness assessment of different percentage of fly ash geopolymer which is 0%, 3%, 5%, 7%, 9% and 11% in bitumen mixtures against moisture damage. The samples which are consists of 12 sample for wet and 12 sample of dry are prepared. Then, the sample are compacted to 7 $\pm$ 0.5% air void content. The failure load for each sample was recorded at 25°C and measure the force which is required to break the specimen and the indirect tensile strength (ITS) for each sample was calculated. In Figure 3.1 shows the flow chart of research in this study.

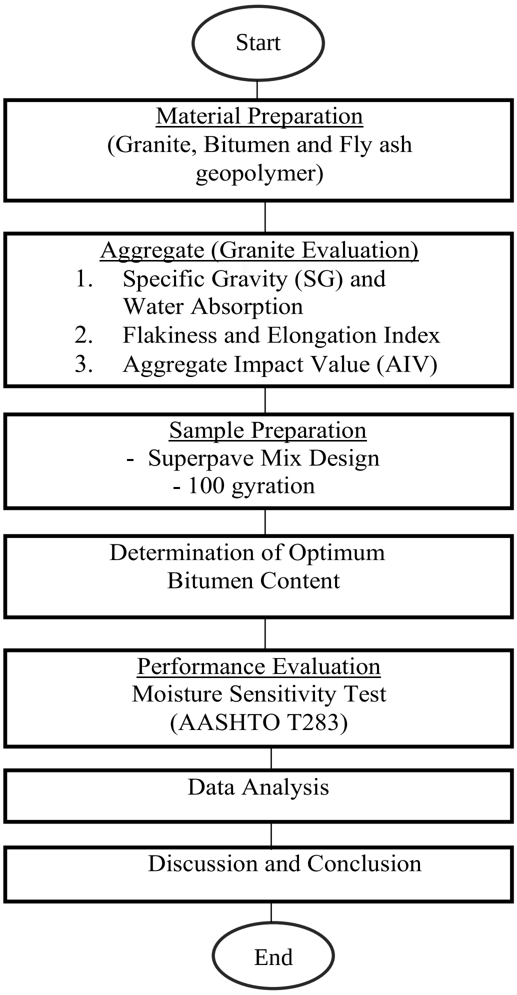

Figure 1: Research of the Flow Chart

Table 1: Standard method for aggregate evaluation

Aggregate Evaluation	Standard Method
Specific gravity and water absorption	AASHTO T85 (2002) & BS 812: Part 110:1990.
Flakiness and elongation index	MS30: Part 3 & 5: 1995
Aggregate impact value test (AIV)	MS 30: Part 10: 1995

4. Results and Discussion

4.1 Aggregate Testing

4.1.1 Specific Gravity and Water Absorption

The summary results for the specific gravity and water absorption are presented in Table 4.1 and Table 4.2. The data shows the specific gravity and water absorption for coarse aggregate is 0.620% and 2.509 respectively. Meanwhile, the data for water absorption and specific gravity of fine aggregate is 0.786% and 2.577. According to the findings, the smaller the aggregate size, the higher the specific gravity and water absorption and the value are satisfying the JKR specification requirement.

Table 2: Specific gravity and water absorption of coarse granite aggregate

Sample		Coarse aggregate
Saturated dry weight in air (g)	A	2017.5
Dry weight in air (g)	B	2030
Weight in water (g)	C	1226
Specific gravity (SG)	D	2.509
Absorption (%)	E	0.620

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

Sample		Fine aggregate
Saturated dry weight in air (g)	A	496.1
Dry weight in air (g)	B	500
Weight in water (g)	C	307.5
Specific gravity (SG)	D	2.577
Absorption (%)	E	0.786

4.1.2 Flakiness and Elongation Test

The shape of aggregate are important to be decided before it can be utilized in pavement construction because to its feasibility in terms of shape and size, which makes compacting easier. The results of flakiness and elongation index is shown in Table 4.3. For this study, the percentage value for flakiness index is 17.41% and less than 25%. It can conclude that the aggregate used in this studied are satisfying the JKR specification requirement regarding the flakiness index and elongation index.

Table 4: Flakiness and Elongation Index of aggregate

Properties	Requirement	Result
Flakiness Index	Less than 25%	17.41%
Elongation Index	Not stated	12.24%

4.1.3 Aggregate Impact Value (AIV)

The test was conducted to assess the toughness of aggregate and its ability to endure rapid loading or impact loading. Table 4.4 presents the result of the Aggregate Impact (AIV). The value of AIV obtained is 12.25%. The aggregate used in this studied are complies the requirement provided by JKR specification requirement which is more than 10% and less than 30%.

Table 5: Result Aggregate Impact Value test

Properties	Requirement	Result
AIV	10% < AIV < 30%	12.25%

4.2 Optimum Binder Content (OBC)

The aim of Superpave mix design is to determine the OBC and the value is used for specimen of performance test. The aggregate gradation was performed using nominal maximum aggregate size (NMAS) of 12.5mm. The trial bitumen content been used is 4.5%, 5.0%, 5.5% and 6.0%. For the trial blend, the air voids has been set 4%.

Bulk specific gravity, Gmb is used to determine air void value for asphalt mixture following AASHTO T166. Placed the sample at room temperature in 24 hours and bulk specific gravity, Gmb was described by weighing the sample in three different conditions: dry, wet, and saturated surface dry.

Figure 2: Procedure Bulk Specific Gravity (G_{mb})

The theoretical maximum specific gravity, G_{mm} is required to compute the air void percentage in each asphalt content. The maximum specific gravity can be determined by ASTM D2041. Corelok method was conducted in this method.

Figure 3: Procedure theoretical maximum specific gravity (G_{mm})

Table 4.5 shows the optimum bitumen content (OBC) used for mixture test. The result of air voids, VMA and VFA and dust proportion need fulfil the specification of Superpave mix design to achieve the OBC.

Table 6: Optimum Bitumen Content (OBC) used for mixture test

Mix Properties	0%	3%	5%	7%	9%	11%	Criteria	Status
Air Voids (%)	4.0	4.0	4.0	4.0	4.0	4.0	Criteria	Status
VMA (%)	18.5	18.7	18.8	19.8	18	19.5	4.0	COMPLY
VFA (%)	79	79	79	80	80	79	Min 14	COMPLY
Dust Proportion	0.65	0.61	0.62	0.61	0.62	0.65	65 -75	COMPLY
%Gmm @ Ndes = 100	96	97	96	94	94	95	0.6 – 1.2	COMPLY
OBC (%)	5.25	5.02	5.30	5.60	5.65	5.83		

4.3 Moisture Sensitivity Test

4.3.1 Effect of Percentage of Fly Ash Geopolymer (FAG) Content on Indirect Tensile Strength

Figure 4.1 illustrates the effect of fly ash geopolymer percentage as anti-stripping additives on asphalt mixture specimens prepared with different sample condition. The mean of ITS for wet specimens subjected to the water conditioning incorporating fly ash geopolymer ranges between 1045.5 kPa to 1346.9 kPa, in contrast, dry specimens were found to be between 1278.3 kPa to 1628.7 kPa, respectively. A water conditioning proved to have a lowest ITS in mixes compared to the dry specimens. The specimens prepared with 9% of fly ash geopolymer shows a highest of ITS for both sample conditioning. According to Behiry (2013), the additives containing in mixtures had a greater indirect tensile strength under loading condition indicating that mixtures could generate greater tensile stress leading up to trying to crack.

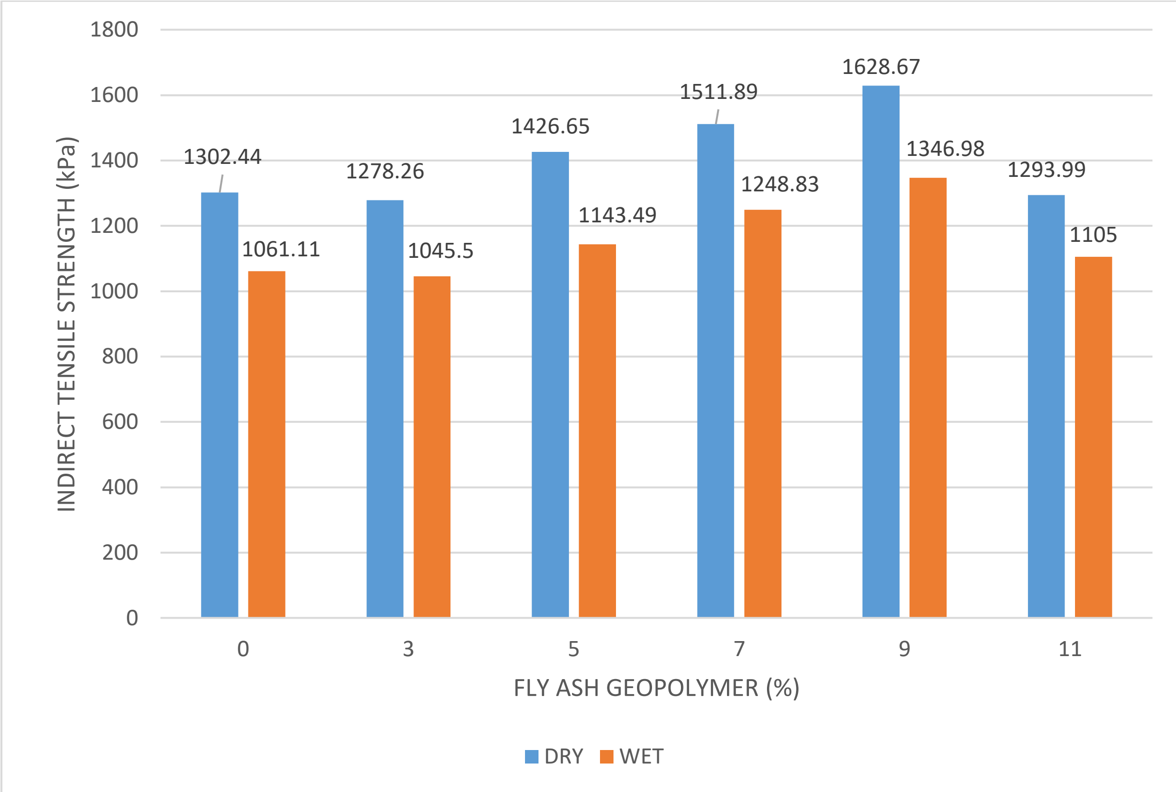

Figure 4: Effect of Fly Ash Geopolymer Content on Indirect Tensile Strength

4.3.2 Effect of Percentage of Fly Ash Geopolymer Content on Resistance of Moisture Sensitivity

Figure 4.2 presents the ITSR results at stipulated the effect of fly ash geopolymer percentage in asphalt mixtures. The ITSR of the asphalt mix containing 11% of fly ash geopolymer is consistently higher than that other specimen, while the specimens prepared with 5% of FAG shows lowest ITSR. The specimens incorporating PMD exhibit higher ITSR and greater resistance to water damage compared with the specimen containing 11% of FAG increasing the moisture resistance caused by a presence the higher of FAG to enhance and leading to the de-bonding of bitumen films from aggregate surface, which greater affinity of the aggregate from water than for bitumen. According to Dayal & Soundarapandian, (2018), application of fly ash-based geopolymer improves the coated aggregates in bituminous mixtures and lead to the improvement of the stability and longer service life of these mixtures.

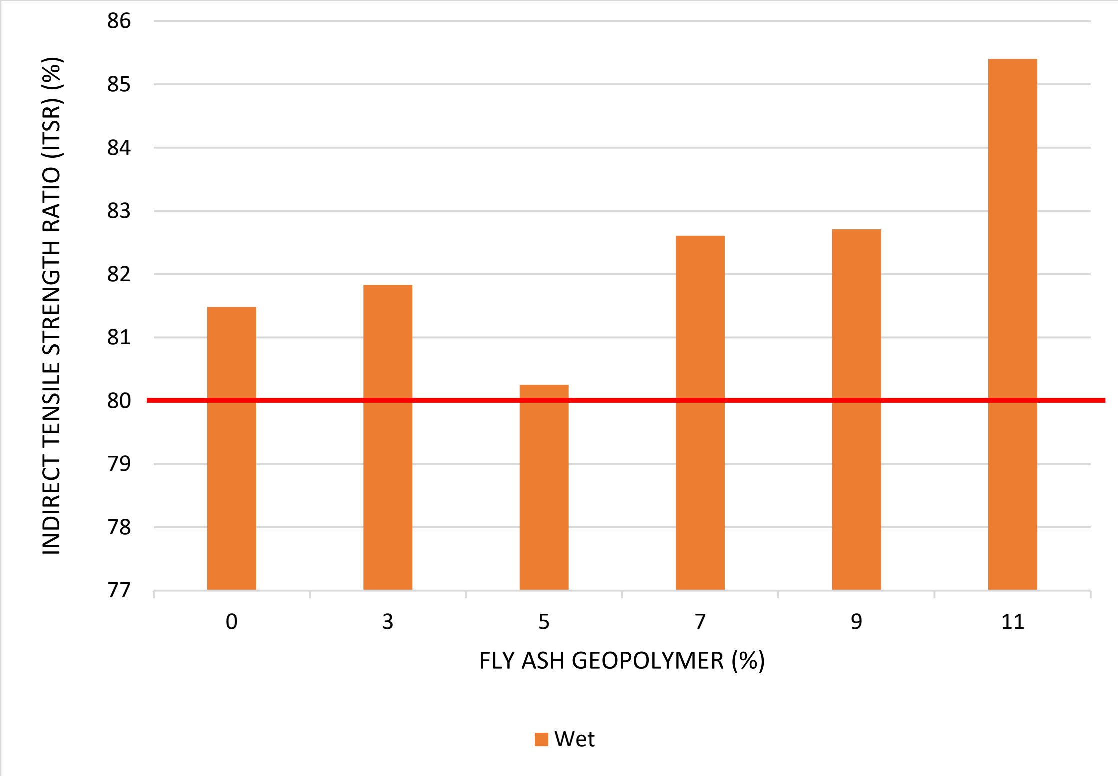

Figure 5: Effect of Fly Ash Geopolymer Content on Resistance of Moisture Sensitivity

5. Conclusion

The aggregate testing that conducted is satisfying the JKR specification requirement and allow to use in the preparation of specimen. Based on the testing conducted at the laboratory, the bitumen content of bitumen 80/100 penetration grade incorporating with different percentages of fly ash geopolymer also was successfully obtained for each bitumen content. The OBC obtained was 5.25% for 0% fly ash geopolymer, 5.02% for 3% fly ash geopolymer, 5.30% for 5% fly ash geopolymer, 5.60% for 7% fly ash geopolymer, 5.65% for 9% fly ash geopolymer and 5.83% for 11% fly ash geopolymer. The results of air voids, VMA, VFA and dust proportion are also fulfilling all of the requirement needed.

The result Indirect Tensile Strength (ITS) at 9% are higher with different 326.23% in dry condition and 285.87% in wet condition from sample virgin bitumen at 0%. Besides, the result of Indirect Tensile Strength Ratio (ITSR) for all samples contained 0%, 3%, 5%, 7%, 9% and 11% of fly ash geopolymer exceeding 80% which compliance with the AASHTO T283 limitation stated. The results showed 11% of fly ash geopolymer with 85.40% in ITSR testing is the higher compared to other percentage of fly ash geopolymer content, while the specimens prepared with 5% of FAG shows lowest ITSR.

The higher the ITSR value resulted in better performance of the bitumen mixture with a greater withstands to moisture damage. According to the analysis, it can be concluded that the use of fly ash geopolymer as additive were increase the stability and workability. As a result, the objective in this studied was achieved.

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