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Physical Characterization of Modified Asphalt Binder with Differing Fly Ash Geopolymer Contents

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Abstract: Nowadays, the use of waste material product widely used in the asphalt mixtures industry production due to a cost-effective method of pavement construction that can decrease the consumption of natural resources and to reduce environmental pollution. This research aimed to investigate the possibility of using waste and by-product material namely fly ash geopolymer additive to influence the physical properties of asphalt binder. A series of asphalt binder laboratory tests were carried out to evaluate the properties of the 60/70 and 80/100 asphalt binder incorporating 3%, 5%, 7%, 9% and 11% of fly ash geopolymer additive. The physical properties of the binders were determined using the penetration, softening, penetration index, ductility, and rotational viscosity respectively. The results indicated that, the fly ash geopolymer modified binder had improved the physical properties over base binder. The thermal susceptibility also improved by referring to the Penetration Index value. Overall research conclusions are that geopolymer application resulted in a potential enhancement of some of the properties of the asphalt binder and increase the performance of asphalt binder in the pavement application.

Keywords: Additive, fly ash geopolymer, asphalt binder, binder properties

1. Introduction

Countries around the world face challenges to maintain their existing road networks with the increasing development of the transportation industry in the past few decades. In Malaysia, dense graded asphalt has been paved extensively in most of the major road network. The performance of asphaltic pavement has a significant relationship with the properties of asphalt binder and aggregate used. The weakness of conventional asphalt binder rheology has proved many studies considered in the use of the modifiers to improve and enhance their properties performance. In the past few decades, the research has been focused and establishment of modified asphalt binder material to improve the overall pavement performance. The use of additive materials or environmentally production processes in pavement construction without compromising its performance was one of the sustainability movements in this direction. Recently, geopolymer modified asphalt binder is a new method to maximise on the use of waste and by-product materials in paved roads.

According to Tang et al. [1], the first geopolymer concept was introduced in 1978. The general structural formula of polycondensation molecules of geopolymer is M_n [-(Si-O_2-)$_z$-Al-O-)$_{n.}$w$H_2$0, wherein M means sodium (Na) or potassium (K), n means the number of waters of crystallization. The basic structure of geopolymer is silicon-oxygen tetrahedron

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and aluminum-oxygen tetrahedron that are connected by oxygen atom [2]. In addition, many industry wastes can be used as the raw materials for the geopolymer preparation, such as coal gangue, fly ash, tailings, and slag. The use of by-product materials such as fly ash and geopolymer interacts with asphalt binder properties to reduce the binder viscosity and increase binder stiffness thus promoting results increasing of aggregate-binder bonding [3]. Geopolymer is an inorganic material that forms a long-range, covalently bonded non-crystalline skeleton. According to Tang et al. [1], the applications of geopolymer can reduce the viscosity of the asphalt binder and provide for the complete coating of aggregates at low temperatures. Thus, asphalt binder mixture can lower production temperature, minimize energy consumption, and reduce emissions.

The need for new additive with high properties is in continuous growth to enhance the asphalt binder properties. The use of by-product materials such as fly ash enhances the sustainability of pavement mixtures and reduces the emission of CO_2. Fly ash can be divided into three classes, N, F and C, based on its composition and sources of origin [4]. The concentration of calcium in fly ash has an effective influence on the polymerization process which was noted that fly ash with a low amount of calcium such as Class F is better for the formation of geopolymers that fly ash with high amount of calcium such as Class C. Xu et al. [5] noted that the addition of sodium hydroxide solution to the sodium silicate solution as the alkaline liquid improved the reaction with fly ash.

The primary objective of this study is to evaluate the modified asphalt binder in enhancement the performance of the pavement. Thus, this paper presents the potential of fly ash geopolymer asphalt additive in enhance the physical properties of modified asphalt binder.

2. Material and Methods

2.1 Materials and Sample Preparation

In this study, geopolymer additive was prepared by mixed the fly ash materials with the alkali activator. The alkali activator that was employed is sodium solution (Na_2SiO_3) and sodium hydroxide (NaOH) pallet diluted in water to produce 8 Molar (8M) NaOH solution. A mixture of sodium silicate solution and sodium hydroxide solution was prepared to activate the alumina-silicate precursors in fly ash. The fly ash was provided by the Kapar Power Station located in Selangor, Malaysia and accordance on ASTM C 618 [6], is a class F fly ash. The chemical composition compositions of fly ash are listed in Table 1. The asphalt binder used in this study has a 60/70 and 80/100 penetration grade provided by PETRONAS, Malaysia. Geopolymer additives were prepared using the alkaline medium as the chemical activator and fly ash as the aluminosilicate source. Firstly, the alkaline medium was prepared using sodium hydroxide (8M) and sodium silicate solution with percentages of 100: 50% by mass respectively. Secondly, 200 grams of fly ash powder were mixed with 80 grams of the alkaline medium for 6 minutes. Afterwards, the formed slurry was transfer to the molds in dimensions were 20mm × 20mm × 20mm. The sample needs to be cured for 24 hours at room temperature (25ºC) followed by the oven at 60ºC for 24 hours. Finally, all the samples were milled into powders form, which was then sieved to remove particles with the diameter above 0.15 mm [7].

Table 1 - Chemical composition of the fly ash (%)

Constituent	Fly ash
SiO_2	57.20
Al_2O_3	23.50
Fe_2O_3	3.80
CaO	9.3
MgO	1.0
SO_3	0.20
Na2O	2.43

The fly ash geopolymer additive and asphalt binder was blended together using Silverson mechanical mixer. The base asphalt binder was heated in the oven at a temperature 110ºC before the fly ash based geopolymer is blend into the binder. Difference percentage of additive was added in range 0%, 3%, 5%, 7%, 9% and 11% by mass of binder at a rotational speed of 2000 rpm for 120 minutes at 150ºC constant temperature to produce a homogenous blend. To obtain a uniform temperature distribution, the asphalt binder was stirred approximately 2 minutes before adding the additives.

2.2 Test Methods

2.2.1 Penetration Test

The penetration test was used to determine the consistency of the asphalt binder. This penetration test was conducted according to ASTM D5-97 [8] procedures with allowed a needle of specified dimensions to penetrate a sample of asphalt binder under a 100g load at 25ºC temperature for 5 seconds. The specimens were prepared in sample container and place in water bath at 25ºC for 1 to 1.5 hours before the test. Loading of 100g is brought to the surface of the specimen at right angles and at least three determinations on the specimen at the different area of penetration, while the temperature of specimen was maintained at 25ºC.

2.2.2 Softening Point Test

The softening point is carried out in accordance with ASTM D36-95 [9] procedures. The objective is to determine the softening point of the asphalt binder within the range of 30ºC to 157ºC by using of ring and ball softening apparatus. Specimens were prepared with placing 3.5 g steel ball on the surface of an asphalt binder disc that has been moulded into a tapered brass ring. The temperature must maintain at not be less than 10ºC at least 30 minutes before the test. Then place two ball bearings in a liquid bath and allowed to increase the temperature at 5ºC per minutes until the weight of ball stretches the asphalt binder and fall onto a base plate. At the moment the asphalt binder and the steel ball touch a base plate 25mm below the ring, the temperature was recorded. The mean temperature of the two specimens was record as the softening point. The temperature was used in conjunction with the penetration value to obtain the Penetration Index (PI).

2.2.3 Ductility Test

A ductility test was used to determine the amount asphalt binder would stretch without breaking under a standard testing condition below its softening point. The ductility test was carried out according to ASTM D113 [10] procedure. It is generally considered that asphalt binder with a very low ductility was having poor adhesive properties and thus poor performance in workability. Ductility values range from 0 to over 150 depending on the type of asphalt binder. The asphalt binder was heated and pours in the mold assembly place on a plate. Then, the samples with mold were cooled in the air and in water bath of the ductility machine at 25ºC temperature. The sides of the molds are removed the clips are hooked on the machine and operated the machine. The distance up to the point of breaking of thread is the ductility value was reported in cm.

2.2.4 Rotational Viscosity Test

A brookfield rotational viscometer (RV) was used to evaluate high temperature workability of binder to ensure the binder has sufficient pump ability, mix ability and workability. Rotational viscosity (RV) test was conducted accordance to ASTM D4402 [11] for evaluate high temperature workability of asphalt binder. RV test were evaluated using Brookfield rotational viscometer at 120ºC up to 180ºC with every 15ºC interval. Higher temperature binder viscosity is measured to ensure that the asphalt is sufficiently fluid when pumping and mixing. During the test, were preheated the sample holder and spindle to 120ºC and load the sample then wait for temperature stabilize approximately 30 minutes. Then, set the viscometer speed at 20 rpm/min and the weight of asphalt binder used for the test was 15g. Allow the asphalt binder sample to equilibrate for 10 minutes before record the viscosity at 1 mm intervals. Two readings were taken for each temperature and the mean value was recorded as the final result.

3. Results and Discussion

3.1 Penetrations and Softening Point

Fig. 1 illustrates the relationship between penetration and fly ash geopolymer content for asphalt binder grade 80/100 and 60/70. General trend shows that every content of fly ash geopolymer added on the asphalt binder are significantly reduces the penetration value for both asphalt binder grades 80/100 and 60/70 compare to virgin binder. The results indicates that the specimens incorporating 9% fly ash geopolymer experiences the lowest penetration value compared to control binder and other percent of fly ash geopolymer modified binders. Adding 9% of fly ash geopolymer in asphalt binder grade 80/100 and 60/70, the penetration value reduces from 86.6 d-mm to 77.0 d-mm and 68.0 d-mm to 55.6 d-mm respectively. Meanwhile, asphalt binder modified with 3% fly ash geopolymer is found as the highest penetration value compared to other modified binders for both asphalt binder grade. Overall, the penetration value of fly ash geopolymer modified binder for both asphalt binder grades are lower than control binder regardless of fly ash geopolymer dosage.

Fig. 2 illustrates the presence of fly ash geopolymer on softening point of asphalt binder. Overall, softening point for fly ash geopolymer modified binders are slightly higher than the base binder for both asphalt binder grade. Based on the bar chart, asphalt binder grade 80/100 containing 9% fly ash geopolymer depicts the higher softening point followed by 5%, 3%, 7%, 11% and 0%. Meanwhile, same trends are observed for asphalt binder grade 60/70 where 9% of fly ash geopolymer had increase the softening point compared to base binder from 51.1ºC to 56.7ºC. Incorporating 9% fly ash geopolymer results in 13% and 11% increases over base binder for both asphalt binder grades. The findings are constant with the previous study which claim that addition of fly ash geopolymer does not significantly influence the softening point [12]. According to Elkholy et al. [13], asphalt binder with high softening point may be less susceptible to permanent deformation.

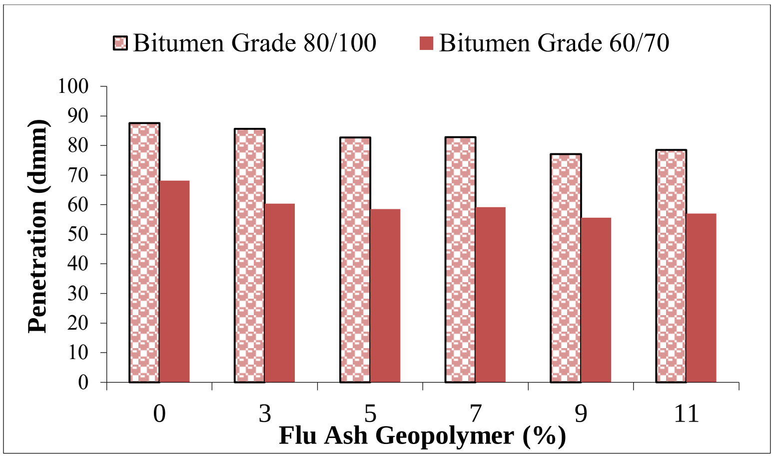

Fig. 1 - Relationship between fly Ash geopolymer content and penetration for asphalt binder grade 80/100 and 60/70

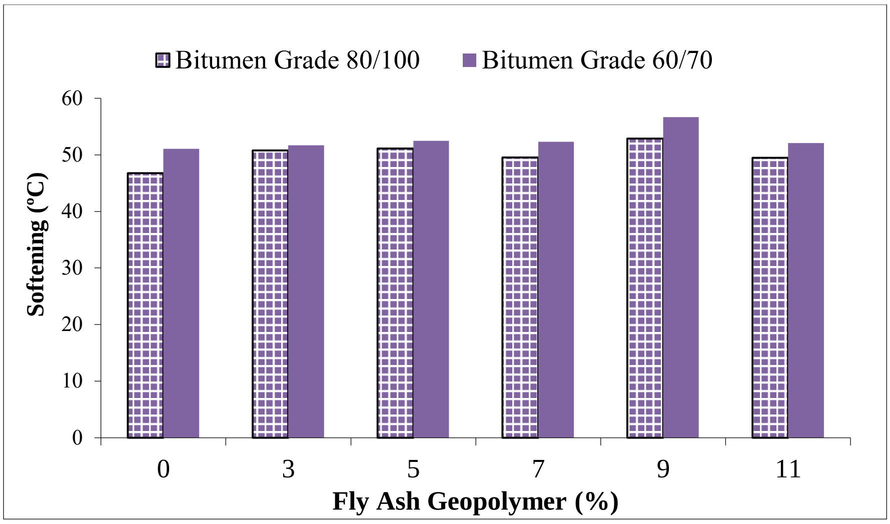

Fig. 2 - Relationship between fly ash geopolymer content and softening point for asphalt binder grade 80/100 and 60/70

3.2 Penetrations Index

The penetration index (PI) is a quantitative indicator that measures asphalt binder responses to change in temperature. The penetration test is a common and simple way to evaluate asphalt binders thermal susceptibility [14]. The penetration index for all modified binders is depicted in Fig. 3, which shows the effect of fly ash geopolymer content on penetration index. Overall trend found that, the addition of fly ash geopolymer increases the PI for both asphalt binder 80/10 and 60/70 respectively compared to the base binder. The result indicates that adding 9% fly ash geopolymer into both asphalt binder grade depicts the highest value of PI. Incorporating 9% fly ash geopolymer increases the PI from -0.65 to 0.63 and -0.17 to 0.60 for asphalt binder 80/100 and 60/70 respectively compared to the base binder. This indicates the asphalt binder susceptibility to temperature is lesser which means it become less sensitive i.e., change its properties hence improve the problem such as rutting and fatigue problem in hot climate region. Therefore, the outcome of this study is to obtain PI value of higher than PI value for virgin asphalt binder and agrees by Geckil [15], asphalt mixture containing asphalt binder with higher PI is more resistant to low temperature cracking as well as permanent deformation.

Further analysis was performed using One Way ANOVA to determine the effect of fly ash geopolymer for asphalt binder grade 80/100 on PI at 95% confidence level (α=0.05). Table 2 shows that fly ash geopolymer has a significant effect on increasing PI due to increases in softening point and penetration test with *p*-value less than 0.05.

Table 3 summarize the analysis results for asphalt binder grade 60/70 on PI using One Way ANOVA at 95% confidence level. It can be seen that the fly ash geopolymer content has a significantly affected the penetration index (PI), with *p*-value less than 0.05. According to Teltayev et al. [16], binder with higher PI are more resistant to low temperature cracking as well as permanent deformation.

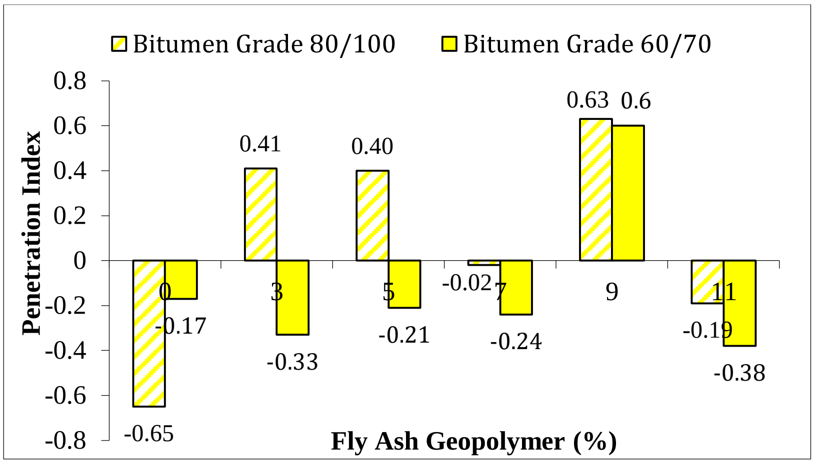

Fig. 3 - Effect of fly ash geopolymer on penetration index

Table 2 - One Way ANOVA effects of fly ash geopolymer for asphalt binder grade 80/100 on PI

Source	DF	SS	MS	F	*p*-value
Between Groups	1	98.728	98.728	12.046	<0.05
Within Groups	10	81.961	8.196		
Total	11	180.689			

Table 3 - One Way ANOVA effects of fly ash geopolymer for asphalt binder grade 60/70 on PI

Source	DF	SS	MS	F	*p*-value
Between Groups	1	106.386	106.386	13.055	<0.05
Within Groups	10	81.488	8.149		
Total	11	187.874			

3.3 Ductility

Fig. 4 shows the results of ductility test conducted at temperature 25ºC for all modified binders. Overall trend found that, the addition of fly ash geopolymer decreases the ductility value for both asphalt binder grades 80/100 and 60/70. The result indicates that by adding 9% fly ash geopolymer into both asphalt binder grades depicts lowest value of ductility. Incorporating 9% fly ash geopolymer decrease the ductility value from 150 mm to 103 mm and 150mm to 89mm for asphalt binder grade 80/100 and 60/70 respectively compared to the base binder.

3.4 Effect Fly Ash Geopolymer on Mixing and Compaction Temperature

The asphalt binder viscosity is considered an important value to assess the workability of asphalt binder during mixing and compaction operations. Fig. 5 shows the viscosity test results for conventional asphalt binder grade 80/100 and 60/70. The binder viscosity decreases sharply as the temperature increase. At 120ºC, the viscosity for asphalt binder grade 80/100 and 60/70 are 914 and 1362 Pa.s respectively. As the temperature rises to 180ºC, the asphalt binder grade 80/100 and 60/70 binder viscosity decreases by 89.5% and 90.7% respectively. The results also show that the asphalt binder grade 60/70 binder viscosities are constantly highest compared with the asphalt binder grade 80/100 binder viscosities. According to Rahman [17], bitumen grade 60/70 is more brittle and hardened asphalt binder.

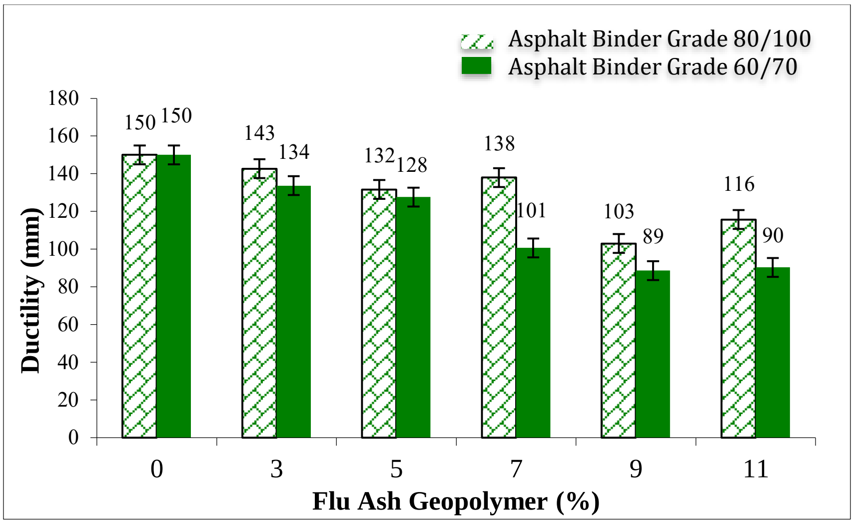

Fig. 4 - Relationship between fly ash geopolymer content and ductility for asphalt binder grade 80/100 and 60/70

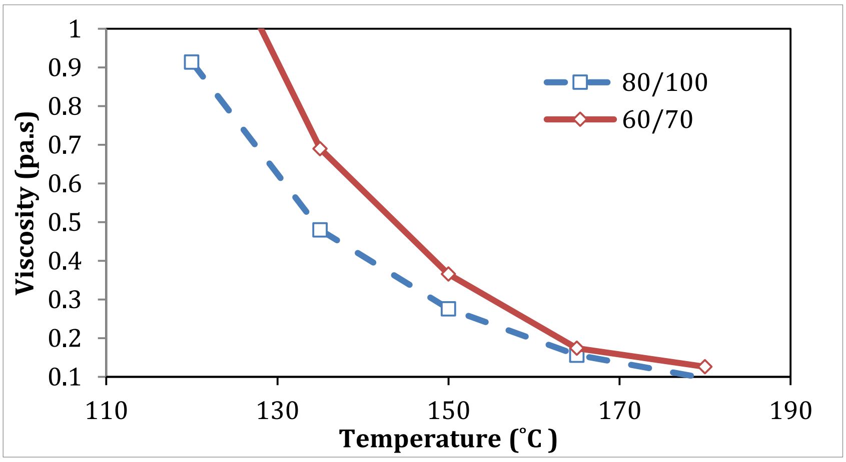

Fig. 5 - Viscosity versus temperature in asphalt binder grade 80/100 and 60/70

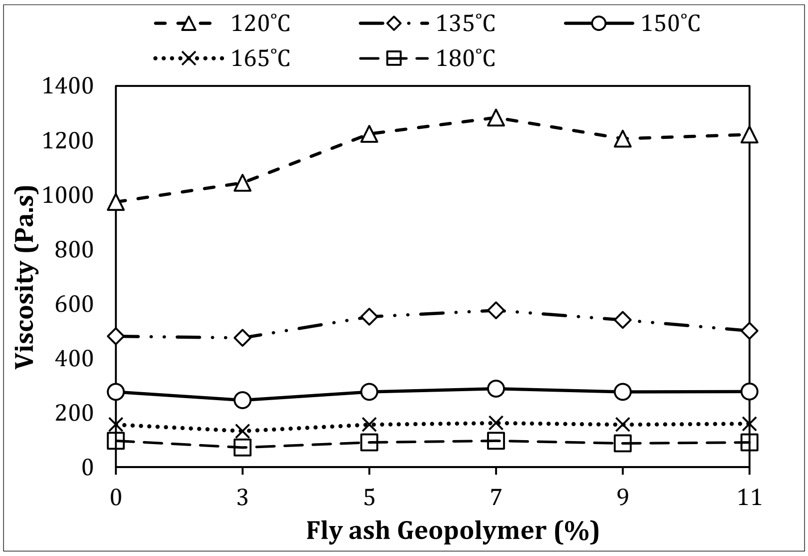

Fig. 6 - Relationship between viscosity and fly ash geopolymer content for asphalt binder grade 80/100

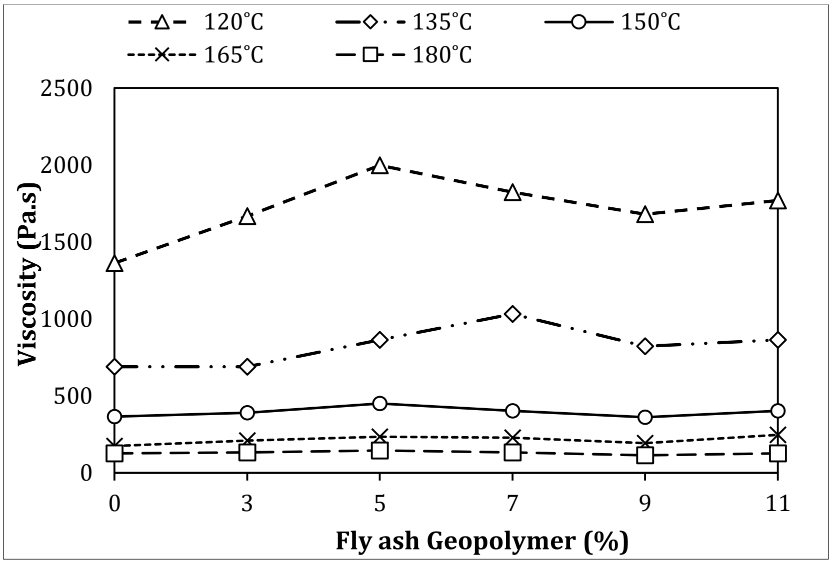

Fig. 7 - Relationship between viscosity and fly ash geopolymer content for asphalt binder grade 60/70

It is shows that, the adequate asphalt mixing temperature and compaction significantly impacted by the geopolymer content. The additional of geopolymer has significantly affects the viscosity of asphalt binder [1]. Fig. 6 and Fig. 7 show the relationship between fly ash geopolymer content and binder viscosity at different temperature. The result indicates a general trend where binder viscosity decreases as fly ash geopolymer content increase for asphalt binder grade 80/100 and 60/70 at stipulated testing temperature. The viscosities of bitumen were observed at peak when temperature equivalent to 120ºC for both asphalt binder grade 80/100 and 60/70. At the similar temperature, the asphalt binder modified by fly ash geopolymer is higher for grade asphalt binder compared to the base binder.

By incorporating 3% fly ash geopolymer, the viscosities for asphalt binder grade 80/100 and 60/70 binder tested at 120ºC increases by 7.2% and 22.5% respectively. At 180ºC, the corresponding reduction is 25% for asphalt binder grade 80/100 but increases 5% for asphalt binder grade 60/70. Thus, adding fly ash geopolymer cause a steady increase in binder viscosity, whiles increasing the fly ash geopolymer content increases the binder viscosity for both asphalt binder grades. On the other hand, the viscosities of asphalt binder grade 80/100 with 0% fly ash geopolymer tested at 120ºC and 180ºC are equivalent to 914 and 96 Pa.s respectively. However, by increased fly ash geopolymer content up to 3% records viscosities equalled to 1044 and 72 Pa.s tested at similar temperatures. For bitumen grade 60/70 binder, the recorded viscosities are 1362 and 126 Pa.s (0% fly ash geopolymer at 120 ºC and 180 ºC) and 1668 and 132 Pa.s (3% fly ash geopolymer at 120 ºC and 180ºC), respectively. It can be seen that binder viscosity increased as fly ash geopolymer content increased for all testing temperature. Binder viscosity also obviously decreased as the testing temperature increased. The asphalt binder grade 60/70 exhibit higher viscosity compared with the asphalt binder grade 80/100.

4. Conclusion

This study evaluated the effects of fly ash geopolymer on the physical properties of asphalt binder grade 80/100 and 60/70. Materials were characterised to ensure fulfilling the standard and specifications. Results showed that fly ash geopolymer causes increase in softening point and reductions in penetration [18]. All in all, it was found that the optimum of fly ash geopolymer is 9% and further additional of fly ash geopolymer slightly affected the penetration and softening properties of modified asphalt binder, respectively. These results indicate that fly ash geopolymer could improve the consistency and hardness of asphalt binders which considered the first indicator for the possibility of using such additives for improving the asphalt binder pavement performance.

The addition of fly ash geopolymer into the asphalt binder increases the viscosity of the binder at lower temperature. In addition, asphalt binder grade 60/70 exhibits higher viscosity due to binder hardened. According to rotational viscosity results, the addition of fly ash geopolymer increased the viscosity, therefore raising the mixing and compaction temperatures. It can be concluded that incorporation of fly ash geopolymer in asphalt binder has a strong potential to be an effective additive in the enhancement of asphalt binder properties. The optimization results showed that 9% of fly ash geopolymer can be recommended for modification of the asphalt binder as optimum contents.

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References

[1] Tang N., Deng Z., Dai J. G., Yang K., Chen C. & Wang Q. (2018). Geopolymer as an additive of warm mix asphalt: Preparation and properties. Journal of Cleaner Production, 192, 906-915.

[2] Davidovits J. (2011). Geopolymer Chemistry and Applications. Geopolymer Institute.

[3] Hamid A., Alfaidi H., Baaj H. & El-hakim M. (2020). Evaluating fly ash-based geopolymers as a modifier for asphalt binders. Advances in Materials Science and Engineering, 1-11.

[4] Hamid A., H., Baaj H. & El-hakim M. (2019). Enhancing asphalt cement properties using geopolymer based on fly ash and glass powder. Annual Conference - Canadian Society for Civil Engineering, 1-10.

[5] Xu J., Yang E., Luo H. & Ding H. (2020). Effects of warm mix additives on the thermal stress and ductile resistance of asphalt binders. Construction and Building Materials, 238, 1-12.

[6] ASTM C 618 (2019). Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete, Vol.04.03, Road and Paving Materials; Vehicle Pavement Systems. American Society for Testing and Materials.

[7] Bujang H., Aman M Y., & Taher M N M. (2022). Volumetric properties of asphalt mixture containing fly ash geopolymer. Conference Series: Earth and Environmental Science, 1-8.

[8] ASTM D5 (2005). Standard Test Methods for Penetration of Bituminous Materials, Vol.04.03, Road and Paving Materials; Vehicle Pavement Systems. American Society for Testing and Materials.

[9] ASTM D36 (2005). Standard Test Method for Softening Point of Bitumen (Ring and Ball Apparatus). American Society for Testing and Materials.

[10] ASTM D113 (2015). Standard Test Method for Ductility of Asphalt Materials. American Society for Testing and Materials.

[11] ASTM D4402 (2006). Standard Test Method for Viscosity Determination of Asphalt at Elevated Temperatures Using a Rational Viscometer, Vol. 14.03, Temperature Measurement. American Society for Testing and Materials.

[12] Rosyidi S. A. P., Rahmad S., Yusoff N. I. M., Shahrir A. H., Ibrahim A. N. H., Ismail N. F. N. & Badri K. H. (2020). Investigation of the chemical, strength, adhesion and morphological properties of fly ash based geopolymer-modified bitumen. Construction and Building Materials, 255, 1- 9.

[13] Elkholy S.A., Rahman A.E., Shafie E. & Shanab A. Z. L. (2018). Physical and rheological properties of modified sulfur asphalt binder. International Journal of Pavement Research and Technology, 11, 838-845.

[14] ASTM D7175 (2008). Standard Test Method for Determining the Rheological Properties of Asphalt Binder Using a Dynamic Shear Rheometer. American Society for Testing and Materials.

[15] Geckil T. (2019). Physical, chemical, microstructural and rheological properties of reactive Terpolymer-modified bitumen. Materials, 12(6), 1-21.

[16] Teltayev B. B., Rossi C. O., Izmailova G. G., Amirbayev E. D. & Elshibayev A. O. (2019). Evaluating the effect of asphalt binder modification on the low-temperature cracking resistance of hot mix asphalt. Case Studies in Construction Materials, 1-13.

[17] Rahman M. R. (2019). A comparative study on properties of different grade bitumen used in the transportation projects in and around Dhaka City. Trends in Civil Engineering and Its Architecture, 3(2), 1-7.

[18] Taher M N M., Aman M Y. & Abdullah N F A. (2018). Physical properties and chemical bonding of Advera modified asphalt binder. MATEC Web of Conferences, 1-16.