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A Study on fly ash Geopolymer Modified Asphalt Binder

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Abstract: Asphalt has widely been used as road pavement all over the world. But the most crucial part was, asphalt pavement must be able to withstand various of problem. Realizing these facts, asphalt modified must be evaluated to achieve certain types of improvement. The objective of this research is to conduct a comparative study of the physical properties of different asphalt binder penetration prepared with various fly ash geopolymer content. This study focuses on the strength and hardness of asphalt binder with modified by fly ash geopolymer. In this study, asphalt binder grade penetration 60/70 and 80/100 with 0%,3%, 5%, 7%, 9%, 11% fly ash geopolymer by mass of asphalt binder. The physical test of asphalt binder such as, penetration test, softening point test, ductility test and rotational viscosity test was conducted. The best strength and hardness of asphalt binder modified by fly ash geopolymer was 60/70 grade penetration with 9% fly ash geopolymer. This can be shown by lesser penetration and ductility result, while higher softening point timer and rotational viscosity test result.

Keywords: Asphalt Binder, Fly Ash, Penetration Test, Softening Test, Ductility, Rotational Viscosity

1. Introduction

The damage to roadway pavement has risen annually in Malaysia. A major issue faced by highway engineers is the challenge of pavement roads such as cracks, fatigue and rutting roads. It is important to fix the maintenance work caused by improvement of road users and the number of vehicles in order to solve the issue by reducing damage or defects on the roadway. As the road user increases, the road loading will be increased and if the pavement does not accommodate the high loading, the pavement will damage the curlier [1]. There are two factors that cause problems with cracking and rutting, the first is temperature and weather and the second is the rising number of vehicles on the roads that are too heavy. The asphalt binder on the road surface is difficult and brittle due to the reaction of the ageing process caused by hot weather.

Asphalt is soft at average temperatures in tropical nations but appears to flow at high temperatures like viscous liquid. Here, the absence of asphalt's rheological and viscoelastic properties can cause

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deformation on the road surface, i.e., rutting damage that occurs along the part of the wheel [2]. Otherwise, asphalt changes its properties at low temperatures to become hard solid causing brittleness and contributing to failure of fatigue cracking [3]. This demonstrates that asphalt binder is very sensitive to vehicle temperatures and loading speeds. The changes made to the quality of asphalt for road construction are also realistic in order to extend road life and save maintenance costs [4].

The rising cost of asphalt binder and polymer modifiers and the lack of available capital have prompted highway engineers to pursue options for new road construction. To solve this problem, organic geopolymer which is fly ash to be used as a modified binder. Several previous research on these chemicals and additives have been carried out and the findings of the asphalt binder properties are satisfying. In Malaysia, the research about fly ash additive as a mix material in asphalt in the road need to be developed. Fly ash is produced by coal-fired electric and steam generating plants has been used for paving as a binder additive. The use of this waste material will help to address the issue of waste management and would also promote economic sustainability by reducing road construction costs and also the selection of material of fly ash as additive in the hot mix asphalt using the additives to observe the change of properties physical of the modified asphalt binder and benefit against in the pavement [5].

Since so much modified asphalt binder is required in road building, the cost of the modifying agent must be considered. Fly ash is a waste product from the electric power industry that can be recycled and utilized as a road construction material. The cost of this modifying agent is low, and the fact that it is made from recycled materials makes it much cheaper [6]. Based on [7], Fly ash is currently produced in large quantities, and there is a great need for dumping locations to dispose of it. According to the Malaysian Department of Environment (DoE), the country generates over 2 million metric tons of fly ash per year. Alternative ingredients, such as fly ash, would increase the characteristics and durability of asphalt binder while also being cost-effective and environmentally beneficial.

2. Fly ash geopolymer

Geopolymer is a kind of new asphalt binder materials that has gained considerable international attention in recent years due to its industrial use and lower CO_2 emissions during the processing of material [14]. Mn(-(Si-O2-)z-Al-O-)n-wH2O is the general structural formula of geopolymer polycondensation molecules, where M means sodium (Na) or potassium (K), n means the degree of polycondensation, z means the silicate to aluminium ratio, and w means the volume of crystalisation water. Silicon-oxygen tetrahedron and aluminium-oxygen tetrahedron connected by the oxygen atom are the basic structure of the geopolymer [14]. In addition, several pores and channels are present in the geopolymer microstructure, resulting in a large specific surface area that absorbs free water and hydrated metallic ions [8]. At a temperature range of 90-140C, the water is then slowly released and evaporated into a steam [8].

Alkali activators and aluminosilicate raw materials are used to make geopolymer, an inorganic polymer. Scientists and engineers have been increasingly interested in geopolymer in recent years because of its safe and environmentally friendly properties, which can help reduce greenhouse gas emissions [15, 16, 17]. Because coal fly ash is the most common source of geopolymer preparation material, promoting geopolymer uses is a safe strategy to mitigate environmental imbalances. investigated the Life Cycle Assessment (LCA) of a Geopolymer Concrete (GC) from a laboratory to an industrial scale. According to the findings, the Global Warming Potential (GWP) of GC is 64 percent lower than ordinary concrete [18]. Photolysis of 2-Butanone as a Volatile Organic Compound (VOC) can also be utilised to regulate interior and outdoor air pollution [19].

[20] was also looking at the geopolymerization activity of size fractioned fly ash. The findings revealed that different size fractions of fly ash obtained from various hoppers had significant differences in chemistry, mineralogy, particle size distribution, and glass concentration, resulting in variable geopolymer characteristics. A polymer backbone comprising aluminium and silicon atoms was produced during the geopolymerization reaction process [21]. The amorphous X-ray equivalent of the tetrahedral alkali aluminosilicate structure has also been proposed for the geopolymer backbone matrix [22]. The compressive strength and microstructural characteristics of Class F fly ash geopolymer were

investigated [17]. As a result, the use of geopolymer based on Class F fly ash was found to be both energy efficient and environmentally benign.

In addition, earlier research has indicated that geopolymers have a high fire resistance and thermal stability due to their inorganic structure. [23] assessed the thermal cycle stability of Class F fly ash-based geopolymeric mortars at extreme temperatures. The results revealed that the geopolymeric specimens were stable and had an appropriate compressive strength. [24] investigated the thermal properties of geopolymer specimens made from Class F fly ash. These results showed that geopolymer had excellent thermal performance, indicating that it was a unique, ecologically beneficial material. They find that the geopolymer specimens had no severe macroscopic damage and kept their structural integrity after the fire assessment. The curing temperature had an impact on phase transformation, microstructure change, and strength production in geopolymer materials [25].

3. Materials and Methods

3.1 Materials

The binder used in this study has a 60/70 penetration grade asphalt binder brand Chevron and 80/100 penetration grade asphalt binder brand Dorotech. This asphalt was provided by the University Tun Hussein Onn, Malaysia. The fly ash was provided by the Power Station Malaysia and based on the ASTM C 618, is a class F fly ash.

3.2 Geopolymer Binder Modification

In this study, 60/70 and 80/100 grade binder were the base asphalt binder used. The 400 g base asphalt binder was heated until it became liquid, then the geopolymer was applied to the base asphalt mix with doses of 0%, 3%, 5%, 7%, 9%, and 11% from the total mass of the asphalt binder. The percentage of fly ash geopolymer used were adopted based on studied by [8] as published in literature review. The blends were subsequently blended for 120 minutes using a mechanical shear mixer at a speed of 2000 r/min at a temperature of 150 °C± 5 to create a homogeneous blend.

3.3 Asphalt binder test

The grade of binder use is 60/70 and 80/100 was supplied by Petronas. The specification of the binder was shown at Table 1.

Table 1: The specification of the binder

No.	Type of test	Method	Specification
1.	Softening Point (C)	ASTM D36-2005	-
2.	Penetration at 25ºC (dmm)	ASTM D5-2005	60/70, 80/100
3.	Rotational Viscosity (RV)	ASTM D4402-2005	Min 100
4.	Ductility	ASTM D113	-

3.3.1 Penetration test

The use of the penetration test, which is conducted in accordance with ASTM D5-2005, is to determine the consistency of the sample binder. Based on normal conditions such as loading, duration, and temperature, it measured the depth to which a standard needle of 0.1 mm pierced the asphalt. A sample of binder was placed into the penetration cup and left for one hour in a temperature-controlled environment. The sample was shielded from the elements and allowed to cool. The sample and transfer plate were then immersed in a water bath at 25ºC for 1.5 hours prior to the test. The specimen was subjected to six tests. For each determination, a new needle was utilised. The needle tip was set at least 10 mm from the side of the container and at least 10 mm apart in repeat determinations.

3.3.2 Softening point test

The objective of softening point test is to determine the softness of the binder depend on the temperature applied on sample. The samples are heated at temperature of 100ºC until it becomes pouring consistency and stirred thoroughly until there is no air bubbles and water, it is then poured into standard brass rings and cools in the air 30 minutes. A standard ball and a stir were placed in the beaker. Distilled water of 5ºC was filled into the beaker with height of 105 mm and the temperature was kept maintained for 15 minutes. The water bath was heated, and the asphalt should be softening, and the balls sink through the ring and touch the bottom plate, records the temperatures reading. Figure 3.6 show the total average reading needed the nearest 0.5ºC is reported as the softening point according to ASTM D36-2005.

3.3.3 Ductility test

Ductilometer was used to determine the bituminous ductility, that is the distance to which a briquette of molten binder can be extended under controlled conditions, before breaking. This test was according to ASTM D113. The Ductilometer basically consists of a moving carriage travelling along guide ways as shown in Figure 3.8. The carriage is driven by an electrical motor, inside a large tank fitted with digital thermostat, immersion electric heater, cooling coil for cold water circulation and pump unit. The binder was poured into briquette mould and was placed in water bath of 25ºC.

3.3.4 Rotational viscosity test

The rotational viscometer test measures the viscosity of the original binder at high temperatures range from 60ºC to 200ºC. It is to ensure that it is fluid enough for the mixing operation. The basic RV test measures the torque required to maintain a constant rotational speed 20 rpm of a cylindrical spindle while submerged in an asphalt binder at a constant temperature. The RV is more suitable than the capillary viscometer for testing modified binders because it can clog when use the capillary viscometer and cause error readings the data.

The equipment that used to measured rotational viscosity is Brookfield rotational viscometer. The preparation of this method with 30 g approximately of binder was heated in an oven so that it is sufficiently fluid to pour. The sample should be heated above 120ºC. The sample occasionally must stir for remove entrapped air during heating binder. Asphalt is weighed into the sample chamber.

The amount of asphalt was varies based on the spindle. A larger spindle means that less asphalt can be placed in the chamber. The sample chamber containing the binder sample was placed in the thermos container and is too ready for stabilizes, the digital display was the set to show viscosity information which includes test temperature, spindle number and speed. In 1 minute, interval, three reading were recorded and this test was according to ASTM D4402-2005.

4. Results and Discussion

In this experiment research, asphalt binder of penetration grade 60/70 and 80/100 from Chevron Company and Dorotech Company was mixed with fly ash of 0%, 3%, 5%, 7%, 9%, 11% by mass of binder. The asphalt binder was blend with fly ash using the high shear mixer to obtain a dispersive mixing of asphalt and fly ash. The mixing of the sample was conducted at mixing speed 2000 rpm, for duration of two hours at range 145ºC to 155ºC. Table 2 summarizes the blending procedure's mixing parameters.

Table 2: Blending binder protocols for both grade asphalt binders

Asphalt Weight (g)	Percent of Asphalt (%)	Fly ash weight (g)	Mixing time (hrs)	Mixing speed (rpm)	Mixing temp. (ºC)
400	0%	0	2	2000	±150
400	3%	12	2	2000	±150
400	5%	20	2	2000	±150

400	7%	28	2	2000	±150
400	9%	36	2	2000	±150
400	11%	44	2	2000	±150

4.1 Penetration test

Penetration test is a measure of the hardness of the binder material, the lower the value of penetration indicates that the stiffness of the binder is improved while higher value of penetration indicate softer consistency [9]. For this test, six penetration cones have been prepared for 2 different grade asphalt binder which are 60/70 and 80/100 with different percentage of fly ash additive in order to improve the consistency of the results. The results of the penetration grade for the grade of asphalt binder was as shown below.

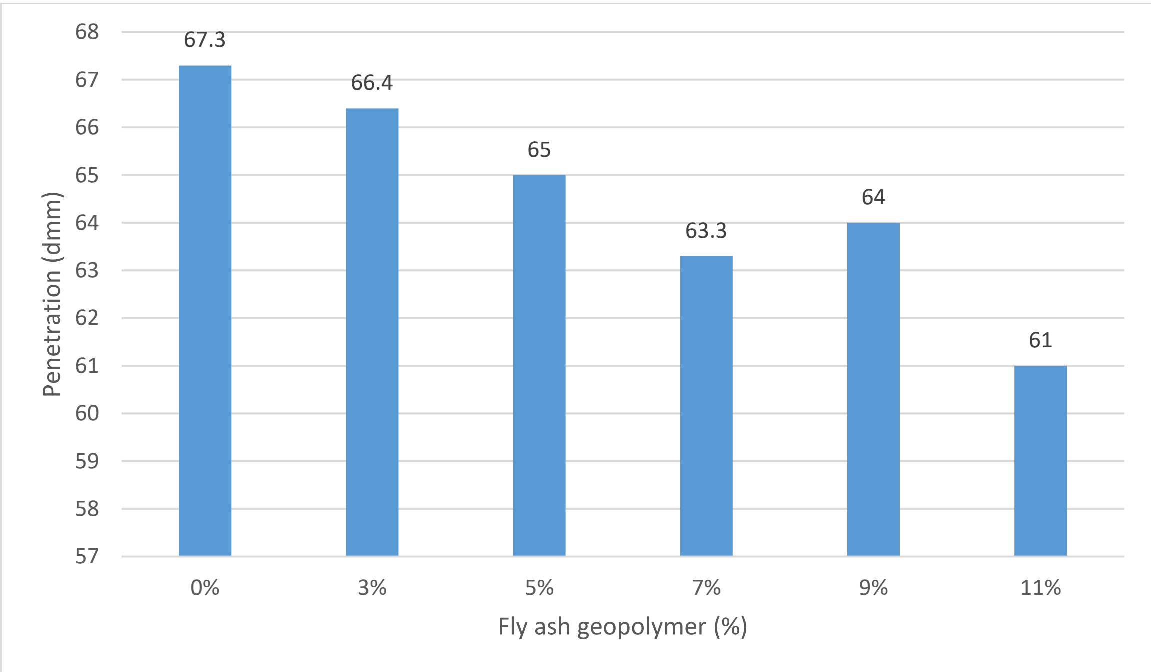

Figure 1: Result of penetration test for asphalt binder grade 60/70

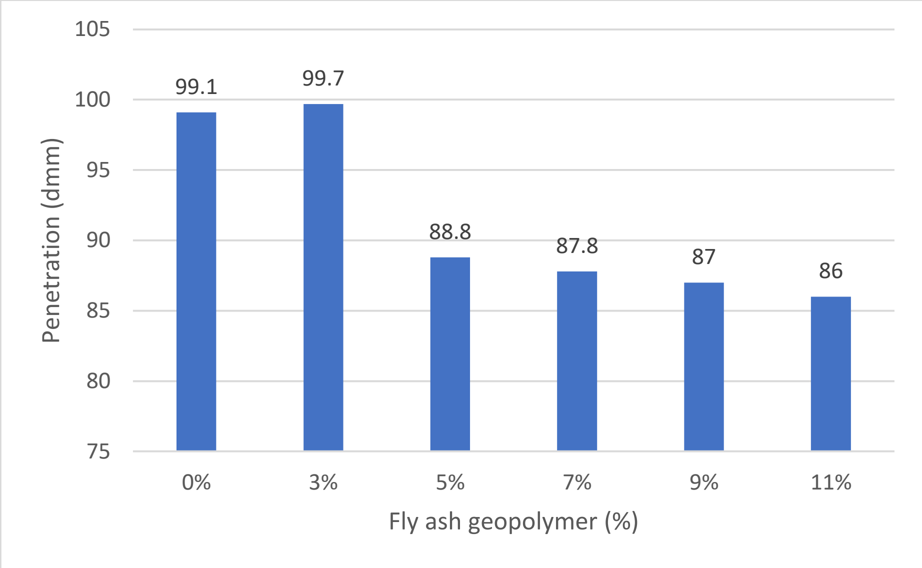

Figure 2: Result of penetration test for asphalt binder grade 80/100

The results of the penetration for the original, and fly ash modified asphalt binders for both grade of asphalt binder is shown in appendix A, Figure 1 and Figure 2. The chart shows the relationship between the percentage of fly ash additive and penetration grade. The original binder for grade 60/70 has an average penetration value 67.3 mm. The penetration value for 3% FA is 66.4 mm, 5% FA is 65.0 mm, 7% FA is 63.3, 9% is 64.0 mm and 11% FA is 61.0 mm. while, for asphalt binder grade 80/100 the original binder has average penetration value 99.1 mm. The penetration value for 3% FA is 99.7 mm, 5% FA is 88.8 mm, 7% FA is 87.8, 9% is 87.0 mm and 11% FA is 86.0 mm. Based on the result, the penetration values gradually decrease as the additive content increases [13]. The attributed from the decrease in penetration values due to increase in the viscosity and stiffness. Adding of fly ash to asphalt binders can improve their stiffness which may also has a potential to improve it rutting resistance.

4.2 Softening point test

Softening point test is a measure of the temperature at which phase change occurred in asphalt material [10]. Higher softening point indicates stiffer asphalt binder and lower temperature susceptibility at high temperature, which is more preferred in hot climates. Asphalt mixtures made with this binder are more likely to resist rutting [11]. The test was conducted in accordance with ASTM D36. For this test, every sample has been successfully obtained. Note that 6 sets of experiment have been conducted for each asphalt binder grade; the results were shown below.

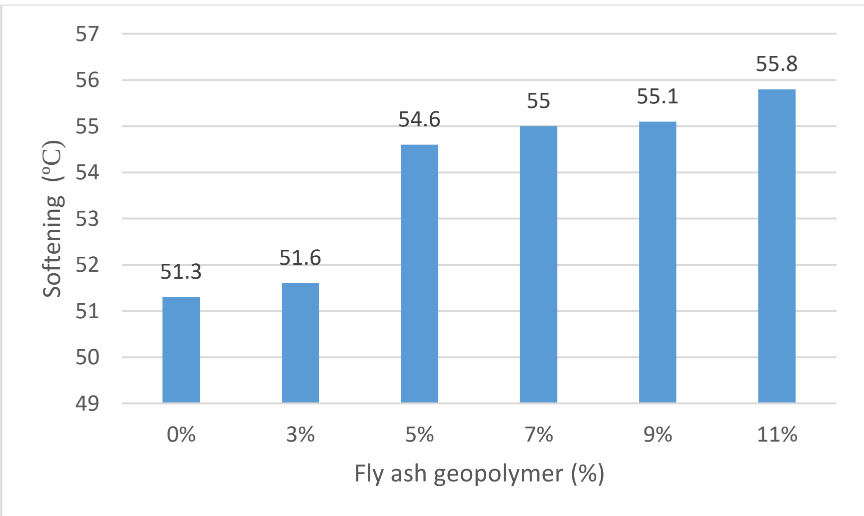

Figure 3: Result of Softening test for asphalt binder grade 60/70

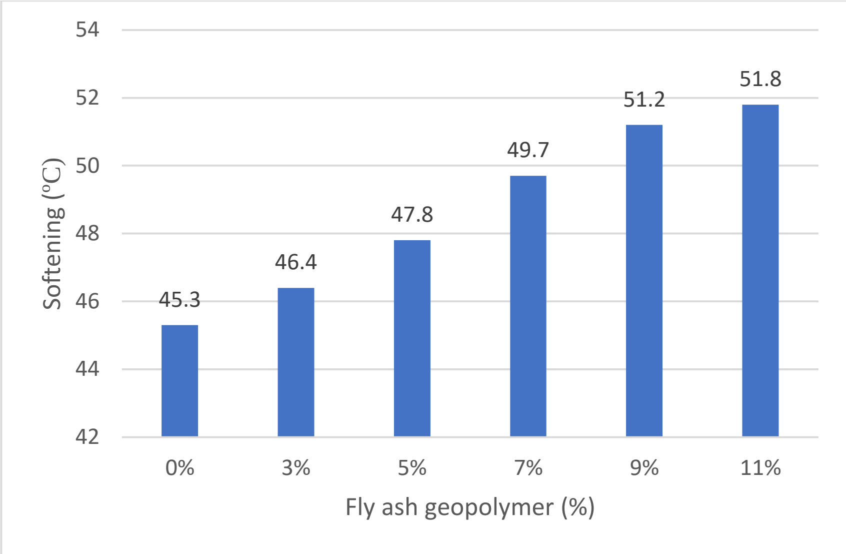

Figure 4: Result of Softening test for asphalt binder grade 80/100

The softening point of the original binder for asphalt binder grade 60/70 is 51.3ºC as shown in Figure 3, while the modified asphalt binders are; 51.6ºC, 54.6ºC, 55.0ºC, 55.1ºC and 55.8ºC for 3%, 5%, 7%, 9%, 11% FA. While for asphalt binder grade 80/100 the result of the original binder is 45.3ºC can be shown in Figure 4 and appendix A. The modified asphalt binders are; 46.4ºC, 47.8ºC, 49.7ºC, 51.2ºC and 51.8ºC for 3%, 5%, 7%, 9%, 11% FA addition accordingly. Based on the result for both asphalt binder grade, the softening point is slightly higher than the original binder. There was a general increase in softening point values with additive incorporation for grade of asphalt binder. Therefore, fly ash additive has significant effect on improving softening point that can increased stiffness of the binder which is desirable in asphalt industry.

4.3 Ductility test

The ductility test determines the asphalt binder's cohesion and elasticity. asphalt binder is a pavement binder that binds particles by forming very thin layers around them. This serves as a perfect binder for increasing the aggregate physical interlock. The binder material would crack if it had adequate ductility and exposing the preceding pavement surface [10]. For asphalt binder grade 60/70 the original binder, the ductility result is >150 cm while 98 cm, 128 cm, 108 cm, 89 cm, 73 cm for 3%, 5%, 7%, 9%, 11%. While the ductility result for asphalt binder grade 80/100; >150 cm, 143 cm, 101 cm, 138 cm, 106 cm, 87 cm for 0%, 3%, 5%, 7%, 9%, 11%. Referring to the result shown on Figure 5 and Figure 6, the ductility values decreased as the fly ash addition increased to the binder. Generally, asphalt binder with both grade penetration has the ductility value of 100 cm. As the fly ash modified binder get harder and stiffer, the reduction of ductility values is predictable. Addition of fly ash to asphalt binder composite binder fulfills the requirement and can be applied for pavement usage.

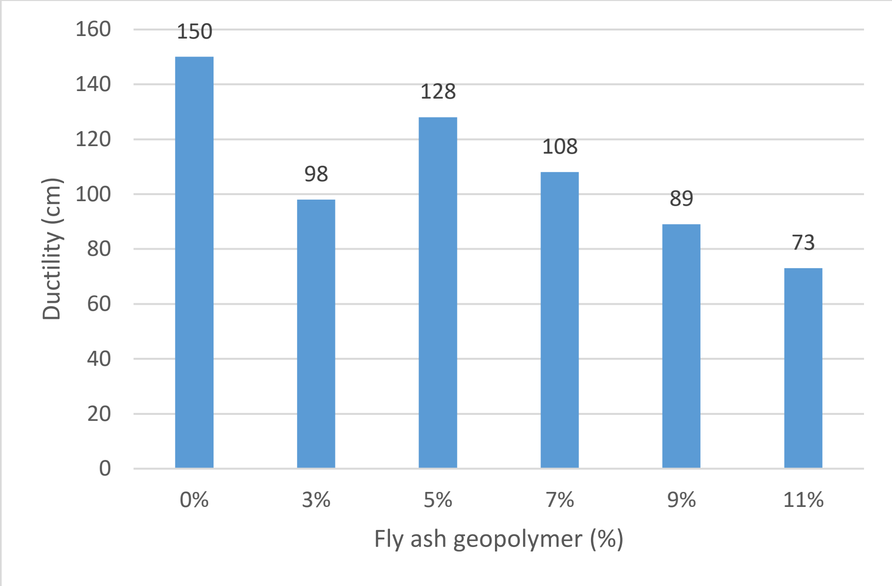

Figure 5: Result of Ductility test for asphalt binder grade 60/70

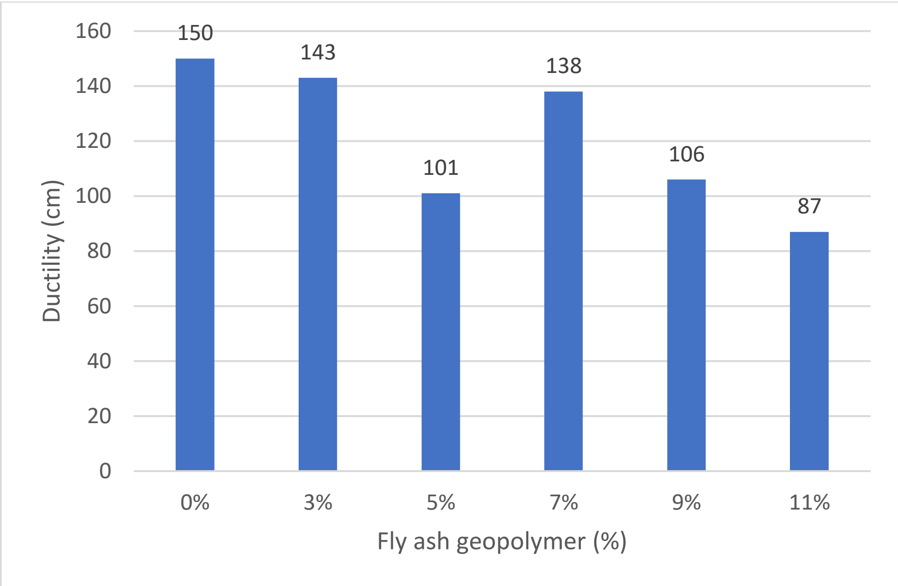

Figure 6: Result of Ductility test for asphalt binder grade 80/100

4.4 Review of rotational viscosity

Over the working temperature of pavement under normal traffic loads, asphalt is a typical viscoelastic material that exhibits both viscous and elastic properties. A Brookfield viscometer was used to assess the flowing resistance of asphalt materials in a rotational viscosity (RV) test. Higher viscosity often means higher mixing and compaction temperatures. It is used to calculate the temperature of asphalt binders during pumping, mixing, and compaction. Rutting can occur as a result of permanent deformation in asphalt surfaces. This is one of the most aggravating mechanisms that can occur in asphalt surfaces. In practically all climate circumstances, it is regarded as a major problem. The pavement's service life is substantially reduced in high-temperature zones [12].

The base asphalt binder used was PG 59-28, according to [12]. The geopolymer was added to the base asphalt blend at doses of 3%, 6%, and 9% by mass of the base asphalt binder after the 300g base asphalt binder was heated until it became fluid. The rotational viscosity of asphalt binder is recognized as a significant factor for defining its workability, according to the study [12]. As a result, the amount of geopolymer in an asphalt binder has a big influence on the mixing temperature and compaction. The amount of geopolymers in the asphalt binder affects its viscosity significantly [8]. The virgin binder had the lowest viscosity, but the modified asphalt binder sample with 9 percent geopolymer had the highest, showing that 9 percent geopolymer had greater rutting resistance. The viscosity of virgin binder and binder containing 9% geopolymer at temperatures ranging from 90°C to 165°C was compared using the statistical T-test, which revealed an insignificant difference with a P-value of 0.126 at the 95 percent confidence level. The 9 percent modified binder had a viscosity that was 51 percent higher than the virgin binder at 90°C. Figure 7 depicts the effect of temperature on asphalt binder viscosity.

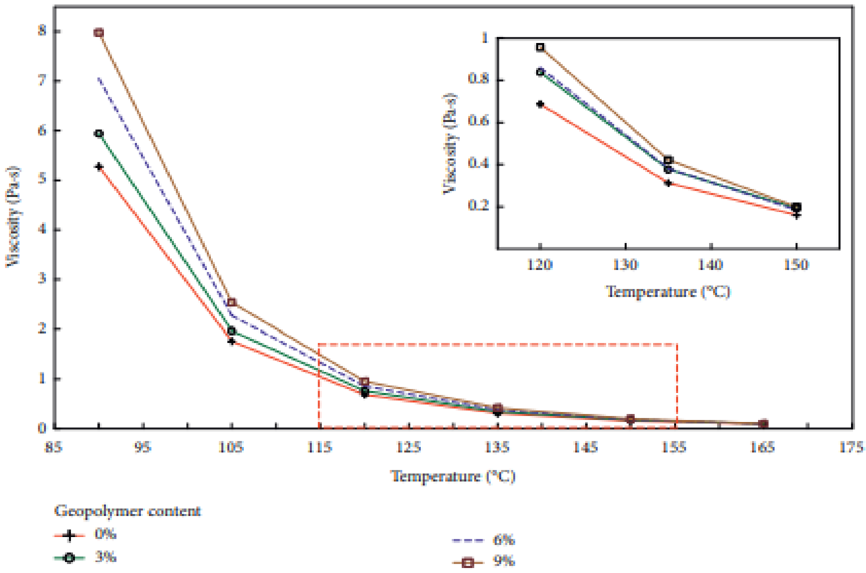

Figure 7: Asphalt binder viscosity change with the temperature [12]

Asphalt binder grade 80/100 was utilised, as well as five samples of asphalt binders containing various amounts of geopolymer fly ash of 0%. The effects of asphalt binder concentrations of 3%, 5%, 7%, and 9% by weight were investigated [7]. Figure 8 shows the results of the rotating viscosity test on virgin asphalt and geopolymer modified asphalt. The viscosity of all types of asphalt binders decreased as the temperature was raised from 135 to 165 °C, as expected. Figure 8 also shows that geopolymer-modified asphalt binders increased the binder's viscosity. GMA with 5% geopolymer has the maximum viscosity (135°C: 0.460 mPa.s, 165°C: 0.169 mPa.s). The viscosity of asphalt binders determines their flow qualities. At high temperatures, asphalt binders must be sufficiently fluid to be pumped and handled easily during the manufacture and installation of asphalt mixtures for paving structures. When a large amount of geopolymer (5%) was applied to virgin asphalt binder, the outcome revealed that mixing and compaction temperatures were greater than usual. Furthermore, at high pavement service temperatures, higher viscosity resulted in greater stiffness, which could be advantageous in improving rutting resistance. The effect of putting geopolymer on observed viscosity values is shown in Figure 8.

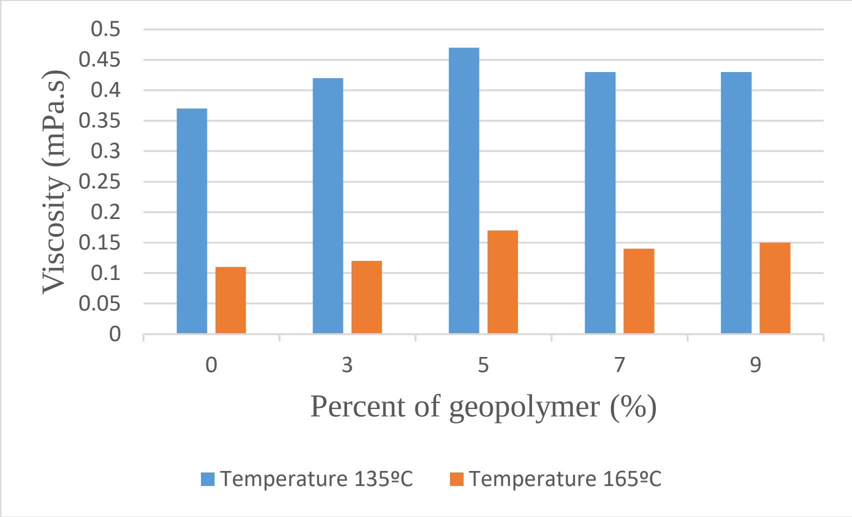

Figure 8: Effect of adding geopolymer on measured viscosity values [7]

5. Conclusion and Recommendation

In this study, the characteristic of fly ash geopolymer modified asphalt were investigated using tests as stated in ASTM. Amounts of 0%, 3%, 5%, 7%, 9%, 11% of geopolymer fly ash were added to asphalt binder. Based on the test results presented, the following conclusion were drawn. Softening point and penetration values improve as fly ash geopolymer is used to modify the asphalt binders, and reasonably stiffer binders could offer good resistance against effect of temperature (rutting) as suggested by previous research that lower penetration and or higher softening point value of asphalt binders is required to resist rutting. While the ductility test shown that, as the fly ash modified binder get harder and stiffer, the reduction of ductility values is predictable. Addition of fly ash to asphalt binder composite binder fulfills the requirement and can be applied for pavement usage. Furthermore, the review on rotational viscosity test shown that increased the percentage of fly ash geopolymer will increased viscosity that can increased stiffness at high pavement service temperatures, which could be useful in enhancing rutting resistance. High viscosity asphalt binders provide great weather resistance and strong binding forces between particles. Furthermore, asphalt binders with a high viscosity withstand water displacement better than those with a low viscosity.

In conclusion, the result of this study proves that the use of fly ash geopolymer suitable as asphalt binder modifier. The limited laboratory research conducted revealed that adding geopolymer to virgin asphalt binder increased the asphalt binder's hardness. Furthermore, this research may help to reduce the size of dumping grounds for the disposal of fly ash, which would protect the environment. As a consequence of this research, the best outcome was obtained with asphalt binder containing 9% geopolymer. The laboratory tests conducted also shows asphalt binder with fly ash geopolymer grade penetration 60/70 got lower penetration and higher softening test result than 80/100. Thus, asphalt binder grade penetration 60/70 with 9% geopolymer fly ash has the best result and suitable for pavement. This concentration is thought to be the best for asphalt binder

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