EVALUATION OF PETROLEUM RESIN EFFECTIVENESS ON ASPHALT BINDER VISCOSITY

by

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DEDICATION

I would like to dedicate this to my wife who stayed with me in all difficulties here abroad and my parents who always supported me.

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ABSTRACT

This study presents an experimental evaluation of viscosity changes in polymer modified asphalt binders due to the temperature changes. Petroleum Resin (PE) as one of the tackifier polymers in the market has been considered to conduct this viscosity measurement in asphalt binders. The modified binders were produced by two binders of PG 64-22 and PG 76-22 and were tested in temperature range of 120℃ to 180℃. The tests were carried out through the rotational viscometer to examine the viscosity changes depending on PE contents (0%, 5% and 10%).

1.INTRODUCTION

Background

Asphalt is the most common material as an organic chemical mixture to be applied in road pavement due to its good viscoelastic properties (Zhang et al 2009). The quality of the asphalt binders is one of the main concerns of engineers and contractors to avoid consequential defects, which result in further maintenance and related funding that are not desirable for any contractor. There are some parameters that affect the asphalt binder and cause defects such as rutting and cracking due to the changes in asphalt properties. Polymers might be applied (Li et al, 1998; Wekumbura et al, 2007) to improve the viscosity behavior of the asphalt binders and increase the adhesion of asphalt and aggregates (Zhang et al 2009).

Shell Co. has developed one of the most common polymers which is styrene-butadiene-styrene (SBS) and it has been used as a binder modifier for several decades (Lavin 2001; Beker et al, 2001). The application of SBS results three-dimensional network within virgin asphalt phase and consequences excellent bonding strength to aggregates which lead to a durable and long-lasting pavement (Adedeji et al, 1996; Kim 2003). However, the application of the SBS leads the preparation conditions to higher melting temperature and higher fuel consumption consequently which results higher cost. Another polymer which improves the asphalt binder resistance against permanent deformations is High-Density Polyethylene (HDPE) which normally obtains from waste material (Hnsloglu and Agar 2003). The application of scrap tires from wastes into the asphalt has been found as an effective way to improve the resistance against rutting and thermal cracking in addition of reducing the traffic noise (Lee et al 2007). The application of SIS polymer significantly improved the rutting and low temperature cracking properties of the asphalt binder (Mazumder at al. 2019).

Petroleum resin (PE) is known as a product of petroleum refineries which categorized in tackifiers' group, with low molecular weight thermoplastic hydrocarbon resins. PE is derived from cracked petroleum fractions (Zohuriaan and Omidian 2007). It can be obtained from high polymers like polypropylene and polystyrene which increases the tack of asphalt by improving wettability and compatibility of the components and altering the viscoelastic rheological properties of mass in terms of the design process or desired application (J.B. and Chu S.G 1985; Mildenberg 1993). Depending on crude oil and polymerization conditions, PE may physically range from viscous liquids to hard solids with softening points. The viscoelastic properties of PE are the evidence of its tackification (Zohuriaan & Omidian 2007).

Scope of Study

The objective of this study is to investigate a viscosity change in asphalt binders containing petroleum resin (PE) along a range of different temperatures. The viscosity properties for the binders were evaluated in the original state through rotational viscometer (RV) test using five testing temperatures of 120°C, 135°C, 150°C, 165°C and 180°C with period of 20 min. Two types of asphalt binders (PG 64-22 and PG 76-22) were used to compare the asphalt behavior in the range of mentioned temperatures.

2. LITERATURE REVIEW

Polymer Modified Asphalt Binder

Polymers with the repeated chain of molecules have been shown as an effective additive to asphalt pavement to improve the resistance against rutting and cracking (Yildrim et al 2005). For decades PMAs have been used with high efficiency at locations of high stress, such as intersections of busy streets, airports, vehicle weigh station and racetracks (King et al 1999). PMAs have desirable characteristics such as greater elastic recovery, a higher softening point, greater viscosity, greater cohesive strength, and greater ductility (Bates R and Worch R 1987). The process of asphalt modification consists of natural and synthetic polymers were found as early as 1843 (Thompson 1979). In the late 1970s, Europe was using more PMAs rather than of the United States because of contractors, who had to give warranties, motivated a greater interest in decreased life cycle costs, even at higher initial costs. The high preliminary expenses for PMA limited its use in the US (Terrel R and Walter J 1986). During 1980s newer polymers tend to be applied in Europe and the United states. The United States Federal Highway Administration (FHWA) issued a life cycle cost analysis, which can be applied to evaluate the life cycle costs of pavement containing asphalt rubber binders as well as other treatments. The findings indicated that the polymers application in asphalt binders is cost effective (Yildrim 2005). A survey in 1997 shows among the state departments of transportation in the United States, 47 states out of the 50, reported that they would be using modified binders and 35 of them saying that they would use greater amounts of polymers as an additive (Bahia et al 1997) as we consider it nowadays, they are the important part of the asphalt pavement industry.

Petroleum Resin

Petroleum resins are used literally in thousands of applications, specially the low-cost hot-melt adhesive market. Three main types of petroleum resins may be distinguished depending on the nature of the starting material which come from the deep cracking of petroleum distillates, such as aliphatic, aromatic, and dicyclopentadiene (DCPD) (Zohuriaan-Mehr and Omidian 2000). According to the established applications of the PE, it can be applied in different purposes in the market specially as a tackifier in asphalt pavement industry (Zohuriaan-Mehr and Omidian 2000). the purpose of PE application in this study is to increase the viscosity of the binders in different range of temperatures to modify the characteristics of them to avoid the routine defects of rutting and cracking beside increasing the adhesion of the binders to have a reasonable and efficient performance with contact of aggregates. Depending on the starting materials and polymerization operational conditions, PE may physically range from viscous liquids to hard solids with softening points up to 180°C–190°C. Resin colors may vary from pale yellow to dark brown and special water-white types. Solubility and compatibility characteristics are functions of the special resin type. Figure 1 shows the petroleum resin which applied this study.

Figure 1. Petroleum resin

3. EXPERIMENTAL DESIGN

Methods

Chapter 3 provides the description of the materials which are included in this study as well as the experimental procedure used to accomplish the research objectives. Figure 2 shows the flow chart of the experimental design which was applied in this study. This chart provides a holistic research process to evaluate the viscosity of two asphalt binders (PG64-22 and PG76-22) in different range of temperatures. This experimental plan was selected to examine the effects of temperature as an important variable on asphalt binders containing PE. The summary below shows full names and the abbreviation used in this study.

PG: Performance Grade

64-22: The binder meets the high temperature properties up to 64°C and low temperature properties down to -22°C

76-22: The binder meets the high temperature properties up to 76°C and low temperature properties down to -22°C

RV: Rotational Viscometer

PMA: Polymer Modified Asphalt

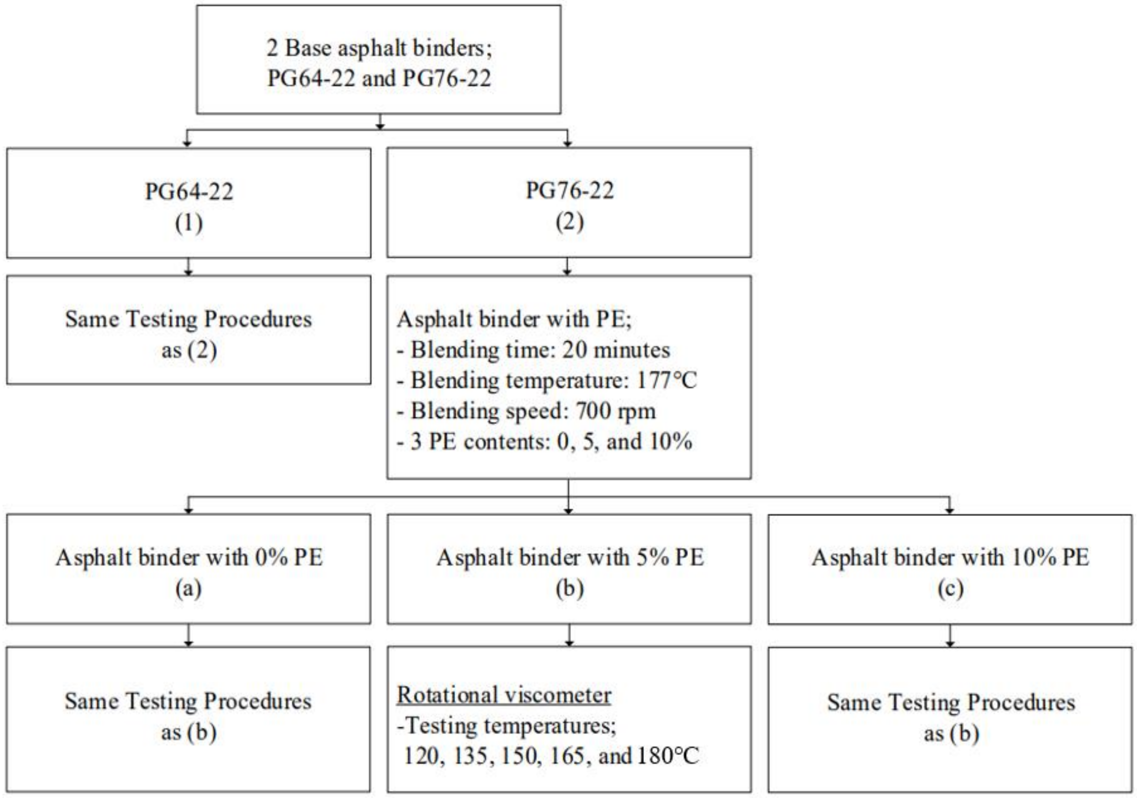

Figure 2. Experimental design

Material

PG 64-22 and PG 76-22 were used as a base binder. SUKOREZ SU-420 was considered as PE and mixed with asphalt binder at different contents of 5% and 10% by the weight of the base binder. The PE characteristics are shown in Table 1. The mentioned PE is water white thermoplastic resin obtained from polymerizing of C5/Cyclic/Aromatic and hydrogenation. Due to the good heat resistance of the PE and suitable compatibility, most of the applications is as a tackifier for hot mix asphalt (HMA) and hot melt pressure sensitive adhesive (HMPSA).

Table 1: PE characteristics

Specifications	Value	Standard
Softening Point (Ring & Ball, °C)	115-125	ASTM E 28
Color (50% Toluene Solution, HAZEN)	Max 50	ASTM D 1209
Specific Gravity (20/20 °C)	1.08	ASTM D71
Softening Point (Ring & Ball, °C)	120	ASTM E28
Color (50% Toluene Solution, HAZEN)	30	ASTM D 1209
Acid Value (KOHmg/g)	0.04	ASTM D 974
Molecular Weight (GPC, Mw)	680	G.P.C

The properties of base binder are shown in Table 2.

Table 2: Base asphalt binder properties

Aging states	Test properties	PG 64-22	PG 76-22
Unaged binder	Viscosity @ 135°C (cP)	531	1438
	G*/sin δ @ 64°C (kPa)	1.4	-
	G*/sin δ @ 76°C (kPa)	-	1.9

Asphalt binder with Petroleum Resin

Petroleum resin of SU-420 was added to PG 76-22 and PG 64-22 in certain condition which was involving the 5% and 10% of base binder weight, followed by 20 min agitating via motorized actuator mixer with speed of 700 rpm at 177 °C. Table 3 shows the arrangement used in this study.

Table 3: Designation of binders and description

Base binder type	Designation
PG 64-22	64-22
	64-22 + 5% PE
	64-22 + 10% PE
PG 76-22	76-22
	76-22 + 5% PE
	76-22 + 10% PE

Experimental Procedure

Rotational viscometer (RV) test

A Brookfield rotational viscometer was utilized to determine the viscosity of both base binders including PE at 120°C, 135°C, 150°C, 165°C and 180°C. The viscosity is determined by measuring the torque required to maintain a constant rotational speed of a cylindrical spindle, while it is submerged in an asphalt binder sample at a constant temperature. Reference weight of 10.5g binder sample was tested with a number 27 cylindrical spindle (10.5 mL) rotated with constant speed (20 rpm) for asphalt binders. The control binders without PE were tested in accordance with the same procedure. The period of 20 minutes was considered for all samples to evaluate the viscosity change in different testing temperatures.

According to the Superpave binder test, the maximum viscosity of unaged asphalt binder is 3.0 Pa-s (3000 cP). Figure 3 shows a picture of a rotational viscometer.

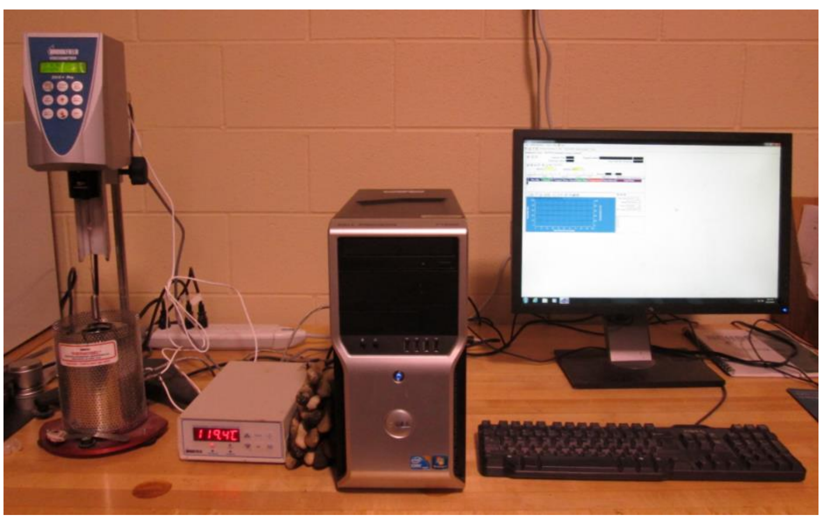

Figure 3. Rotational viscometer

4. STATISTICAL ANALYSIS

A statistical analysis was performed using the Statistical Analysis System (SAS) program to conduct an analysis of variance (ANOVA) and Fisher's Least Significant Difference (LSD) comparison with an $\alpha = 0.05$. The primary variables included the PE Contents (Control, 5%, and 10%) and the binder types (PG 64-22 and PG 76-22).

The ANOVA was performed first to determine whether significant differences among sample means existed. In the analyses of this study, the significance level was .95 ($\alpha = 0.05$), indicating that each finding had a 95% chance of being true. Upon determining that there were differences among sample means using the ANOVA, the LSD was then calculated. The LSD is defined as the observed differences between two sample means necessary to declare the corresponding population means difference. Once the LSD was calculated, all pairs of sample means were compared. If the difference between two sample means was greater than or equal to the LSD, the population means were declared to be statistically different [Ott, 2001].

5. RESULTS

Rotational viscosity

In high temperature, the asphalt binder viscosity plays an important role to decide working temperature because it reflects the binder ability to be pumped through an asphalt plant, thoroughly coat aggregate in HMA mixture and be placed and compacted to form a new pavement surface (Asphalt Institute, 2003). The results show how the temperature increase affects the viscosity and the behavior of asphalt binder. The viscosity measurements were conducted in different temperatures which are described in following sections.

Viscosity at 120°C

The viscosity values of both PG 64-22 and PG 76-22 binders containing three PE contents of 0%, 5% and 10% were measured at 120°C. Figure 4 shows the viscosity of the binders. The viscosity values of 0% PE recorded 1,239 cP and 3,543 cP for PG 64-22 and PG 76-22, respectively. The addition of 5% PE increased the viscosity of PG 64-22 and PG 76-22 by 19% and 17%, respectively. It is worth to note that the further addition of 10% PE is observed to slightly decrease the viscosity of both binders. The viscosity of PG 64-22 and PG 76-22 is found to be decreased by 1.3% and 5.6%, respectively, compared to the viscosity values of asphalt binders with 5% PE.

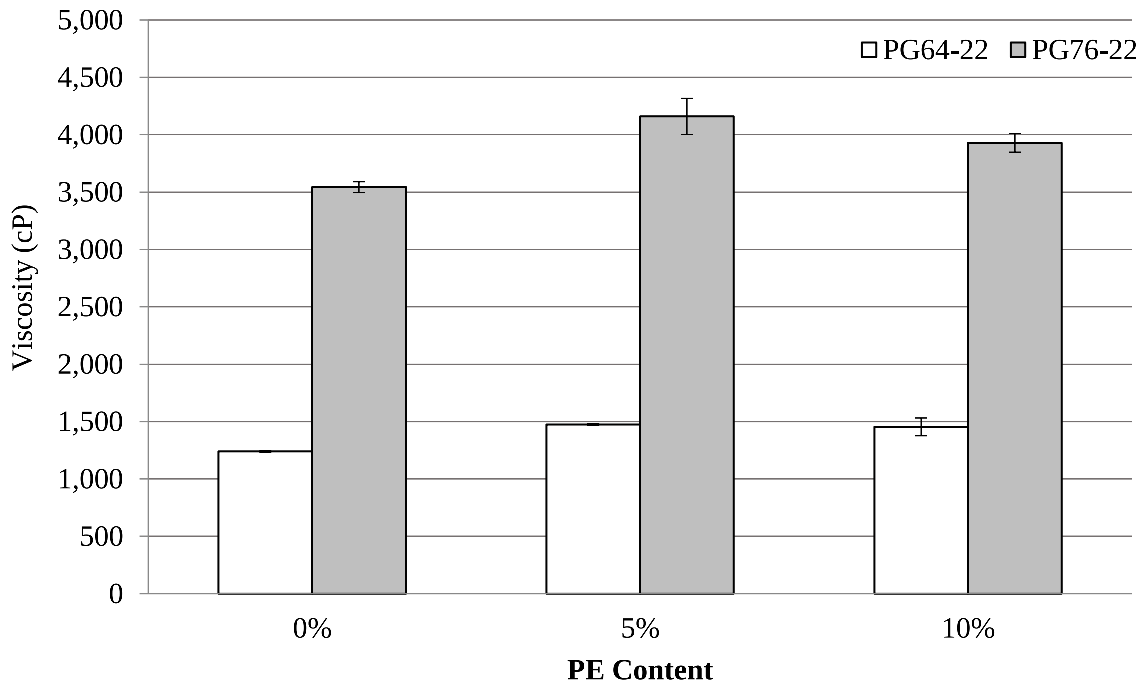

Figure 4. Viscosity at 120°C

The statistical change in viscosity as a function of PE content is examined and the results are shown in Table 4. The data indicated that PE content has a significant effect on the viscosity values at 120°C. In general, the results showed that within each binder type (PG 64-22 and PG 76-22), the binders have a significant difference in the viscosity depending on the PE content.

Table 4. Statistical analysis results of the viscosity at 120°C (α=0.05)

Viscosity at 120°C		PE contents		
		0%	5%	10%
PG 64-22	0%	-	S	S
	5%		-	N
	10%			-
PG 76-22	0%	-	S	S
	5%		-	S
	10%			-

N: non-significant; S: significant

Viscosity at 135°C

Figure 5 shows the viscosity of the binders at 135°C. The viscosity values of 0% PE are found to be 548 cP and 1,438 cP for PG 64-22 and PG 76-22, respectively. The addition of 5% PE increased the viscosity of PG 64-22 and PG 76-22 by 13% and 14%, respectively. Like the results at 120°C, the addition of 10% PE resulted in decreasing the viscosity of PG 76-22 binder.

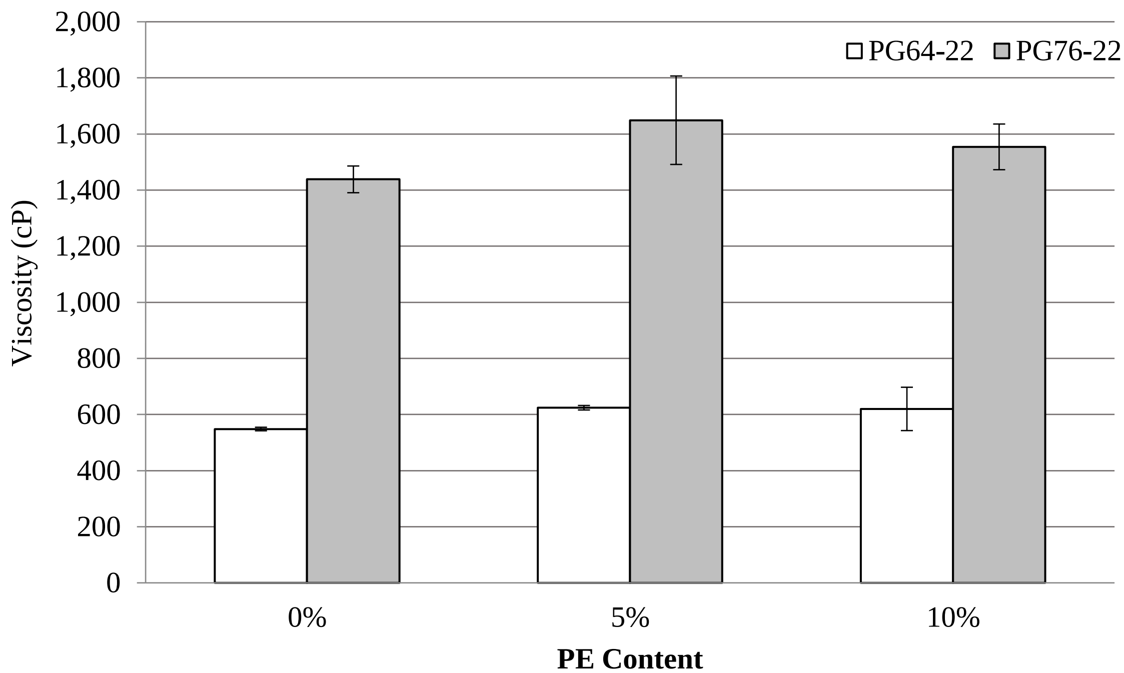

Figure 5. Viscosity at 135°C

Table 5 shows the statistical change in viscosity at 135°C depending on PE content. The data indicated that PE contents have a significant effect on the viscosity values of PG 76-22 binder. In addition, there is no statistical difference of viscosity values between 5% PE and 10% PE for PG 64-22 binder.

Table 5. Statistical analysis results of the viscosity at 135°C (α=0.05)

Viscosity at 135°C		PE contents		
		0%	5%	10%
PG 64-22	0%	-	S	S
	5%		-	N
	10%			-
PG 76-22	0%	-	S	S
	5%		-	S
	10%			-

N: non-significant; S: significant

Viscosity at 150°C

The viscosity values of the binders with three PE contents were illustrated at Figure 6. The viscosity values of 0% PE are observed to be 345 cP and 733 cP for PG 64-22 and PG 76-22, respectively. The viscosity of PG 64-22 was decreased by 2% due to the addition of 5% PE while the viscosity of PG 76-22 was increased by 4% with addition of 5% PE. The 10% PE addition seemed to decrease the viscosity of PG 76-22 binder, compared with the PG 76-22 with 5% PE. This trend is consistent with the results at the lower temperatures of 120°C and 135°C.

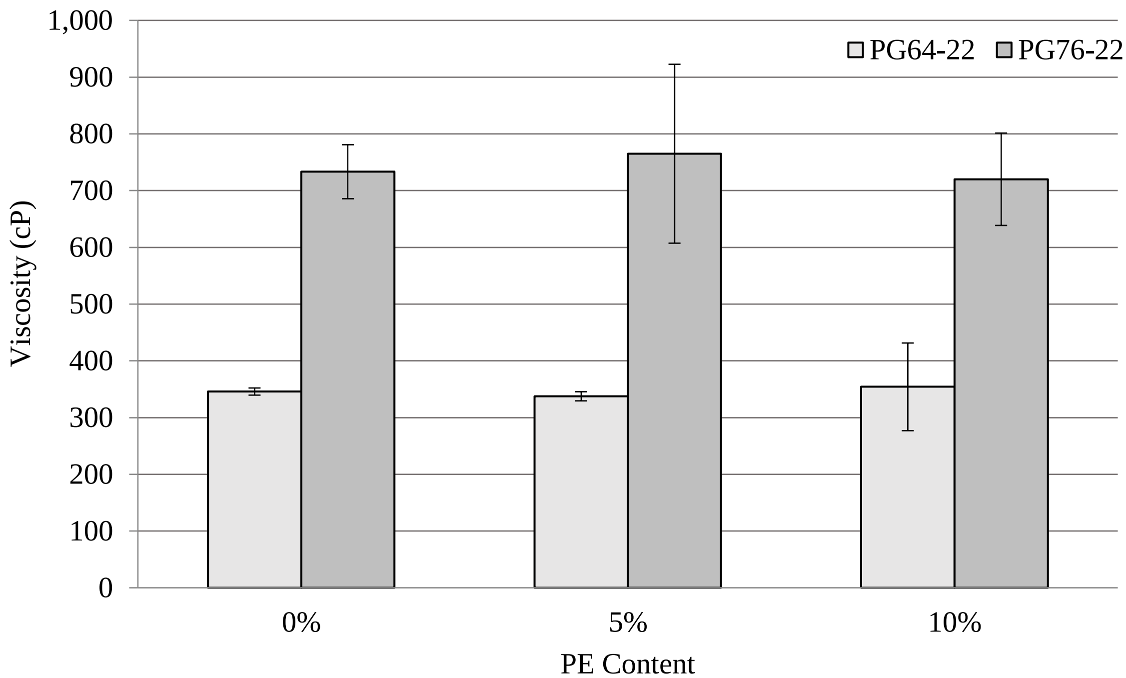

Figure 6. Viscosity at 150°C

The statistical change in viscosity as a function of PE content are shown in Table 6. The data indicated that within each binder type (PG 64-22 or PG 76-22) the PE content does not have significant effect on the viscosity values at 150°C. It is considered that the effect of adding PE was not shown in statistical viewpoint due to the low viscosity values of the binders at 150°C.

Table 6. Statistical analysis results of the viscosity at 150°C (α=0.05)

Viscosity at 150°C		PE contents		
		0%	5%	10%
PG 64-22	0%	-	N	N
	5%		-	N
	10%			-
PG 76-22	0%	-	N	N
	5%		-	N
	10%			-

N: non-significant; S: significant

Viscosity at 165°C

The viscosity values of PG 64-22 and PG 76-22 binders with PE were measured and illustrated at Figure 7. The viscosity values of 0% PE are found to be 137 cP and 410 cP for PG 64-22 and PG 76-22, respectively. The addition of 5% PE increased the viscosity of PG 64-22 and PG 76-22 by 5% and 8% respectively. Adding 10% PE resulted in slightly decreasing the viscosity of PG 64-22 binder, compared with the PG 64-22 with 5% PE.

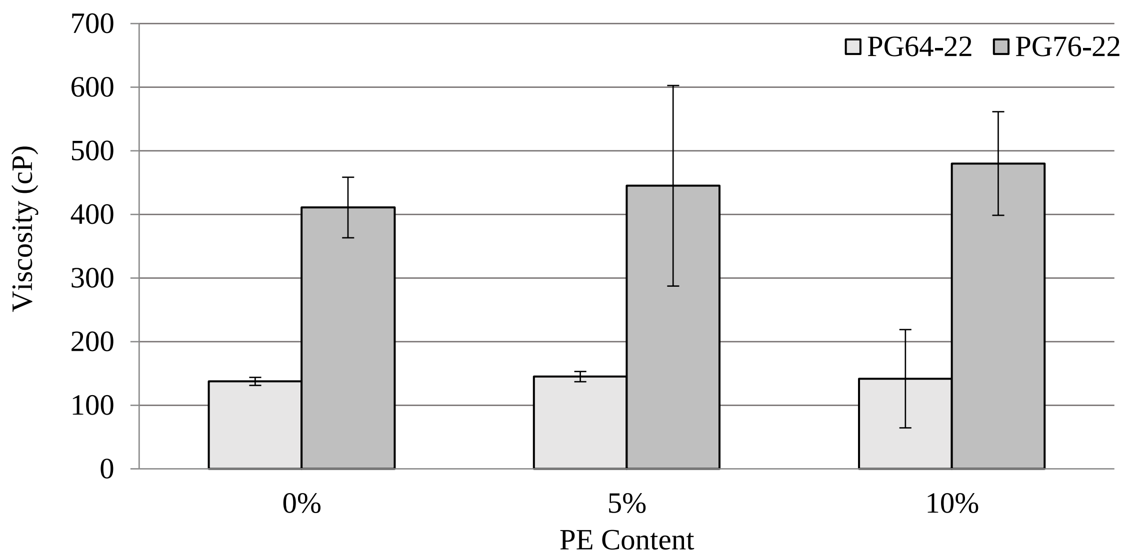

Figure 7. Viscosity at 165°C

The statistical change in viscosity as a function of PE content are shown in Table 7. The data indicated that within each binder type (PG 64-22 or PG 76-22) the PE content does not have significant effect on the viscosity values at 165°C. Similar to the statistical results at 150°C, it is observed that PE addition did not statistically change the viscosity properties at 165°C.

Table 7. Statistical analysis results of the viscosity at 165°C (α=0.05)

Viscosity at 165°C		PE contents		
		0%	5%	10%
PG 64-22	0%	-	N	N
	5%		-	N
	10%			-
PG 76-22	0%	-	N	N
	5%		-	N
	10%			-

N: non-significant; S: significant

Viscosity at 180°C

Figure 8 illustrates the viscosity of the binders at 180°C. The measured viscosity values of the binders with 0% PE were 83 cP and 290 cP for PG 64-22 and PG 76-22, respectively. The viscosity of PG 64-22 was decreased by 8% due to the addition of 5% PE while the viscosity of PG 76-22 was increased by 11% with 5% PE addition. The addition of 10% PE showed decrease in viscosity value of PG 76-22 binder by 16%, compared with PG 76-22 binder with 5% PE. Adding 10% PE led to increase the viscosity of PG 64-22 binder by 22%, compared with the PG 64-22 with 5% PE.

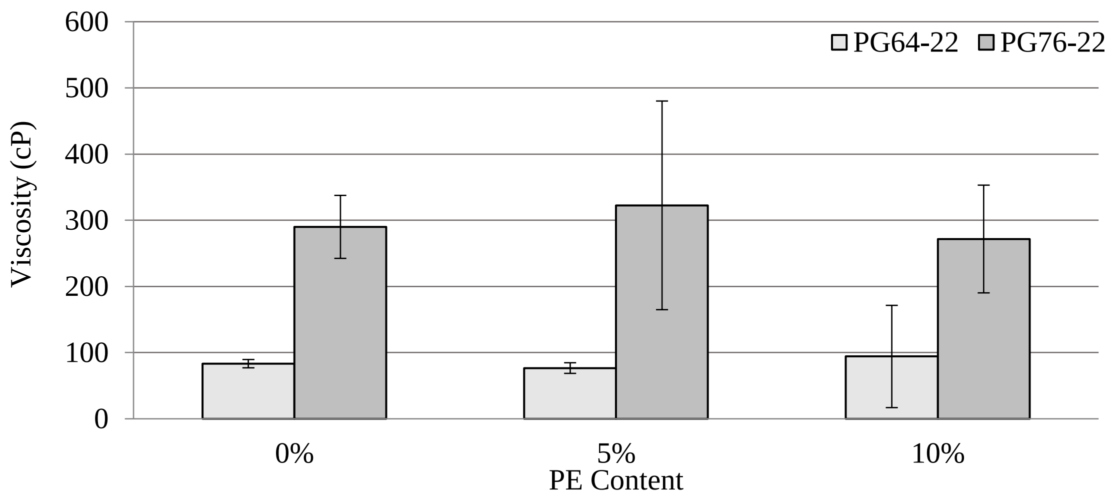

Figure 8. Viscosity at 180°C

The statistical change in viscosity as a function of PE content are shown in Table 8. The data revealed that the viscosity values at 180°C were not statistically different as a function of PE contents. At 180°C, the viscosity of the asphalt binders came out too low, so it was difficult to statistically show the effect of adding PE with the sensitivity of the rotational viscometer used in this study. However, since the asphalt binder containing a high content of modifier shows a high viscosity value even at 180°C, it would be good to evaluate the possibility of improving workability by checking the viscosity change due to PE addition.

Table 8. Statistical analysis results of the viscosity at 180°C (α=0.05)

Viscosity at 180°C		PE contents		
		0%	5%	10%
PG 64-22	0%	-	N	N
	5%		-	N
	10%			-
PG 76-22	0%	-	N	N
	5%		-	N
	10%			-

N: non-significant; S: significant

6. SUMMARY AND CONCLUSIONS

The viscosity properties of PG 64-22 and PG 76-22 binders with PE were studied by application of rotational viscosity test. The 5% PE and 10% PE were considered to investigate the PE influences on asphalt binders. The test results are shown in Figure 9. The binder viscosity decreased as the temperature increased in range of 120℃ to 180℃, as expected.

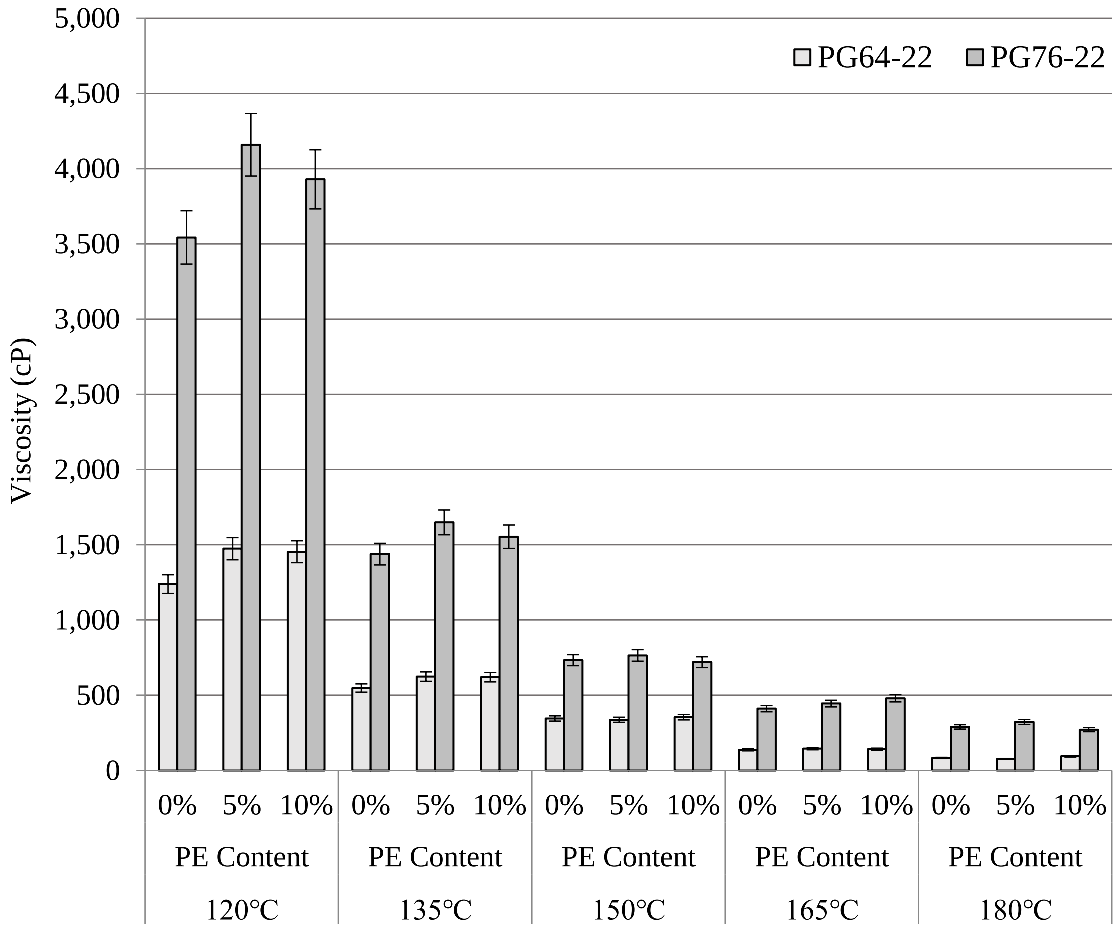

Figure 9. Viscosity in temperature range of 120℃ to 180℃

1. Regardless of PE contents, it was observed that the higher of measuring temperature, the lower of binder viscosity.

2. At lower temperatures of 120℃ and 135℃, the 5% PE resulted in increasing the viscosity of PG 64-22 and PG 76-22 binders.

3. The 10% PE showed to decrease the PG 76-22 viscosity at the temperatures of 120℃, 135℃ and 150℃.

4. At higher temperatures of 150℃, 165℃ and 180℃, the PE addition led to demonstrate little influence on the viscosity behavior of both binders (PG 64-22 and PG 76-22).

5. From a statistical point of view, the PE effect on binder viscosity was verified at the lower temperature. At relatively high temperature, the binder viscosity was so low that it was difficult to statistically check the effect of PE addition.

6. It is recommended to conduct laboratory evaluation by including higher PE contents such as 15% and 20% to further investigate the viscosity along with other rheological properties.

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