CIVED
Journal of Civil Engineering and Vocational Education

EISSN: 2622-6774
Vol 11 No.2 June 2024
http://cived.ppj.unp.ac.id/index.php/CIVED

Viscous Elastic Asphalt Characteristics of Cariphalte Modification with Addition of Gilsonite Viewed from Phase Angle Value

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Received 15th April 2024; Revision 25th May 2024; Accepted 28th June 2024

ABSTRACT

Performance Grade (PG) Bitumen is bitumen that is graded based on its performance at different temperatures. In the Superpave grading system, asphalt binders are classified according to their performance in extreme hot and cold temperatures and are referred to as performance grade (PG) asphalt. The main objective of assessing and selecting asphalt binder using the PG system is to ensure that the binder has properties suitable for the environmental conditions in the field. Cariphalte is a premium grade polymer modified bitumen used in road and airport construction and other similar applications. Cariphalte is a Styrene Butadine Styrene (SBS) modified bitumen. The SBS in Cariphalte ensures the formation of a 3-dimensional network in the bitumen thereby reducing the temperature susceptibility and increasing the stiffness modulus at high temperatures. Cariphalte is also resistant to oxidation, reducing deformation and slowing secondary solidification. To get an idea of the improvement in rheological properties due to the addition of gilsonite, tests were carried out on a mixture of cariphalte and gilsonite asphalt with 6 variations of gilsonite content. The tests carried out include basic rheological properties testing and mechanistic rheological properties testing. From this research, the test results showed that at the same temperature, asphalt with the addition of 0% gilsonite had the smallest phase angle (δ) compared to asphalt using the addition of gilsonite. This explains that the addition of gilsonite can increase the phase angle (δ) value of PG-76 asphalt, which makes the asphalt material have thicker characteristics.

Keywords: *Cariphalte; Gilsonite; Performance Grade; Phase Angle.*

INTRODUCTION

Lack of penetration and viscosity-based assessment systems The Strategic Highway Research Program in the United States conducted a Project between 1987 and 1993 to address the deficiencies of the empirical system. One of the consequences of this project is a performance-based fastener specification with a new set of tests. The final product of the SHRP bitumen research program was a new system called SUPERPAVE, which stands for Pavement Asphalt Performing Superior and is referred to as a binder specification because it is intended to work equally well for modified and unmodified bitumen [1]. Performance Grade (PG) Bitumen is bitumen that is graded based on its performance at different temperatures. In the Superpave grading system, asphalt binders are classified according to their performance in extreme hot and cold temperatures and are referred to as performance grade (PG) asphalt. The main objective of assessing and selecting asphalt binder using the PG system is to ensure that the

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binder has properties suitable for the environmental conditions in the field.

PG asphalt binder is selected to meet expected climatic conditions as well as traffic speed and volume adjustments. Therefore, PG systems use a series of common tests to measure the physical properties of binders that can be directly related to the field performance of the pavement at its service temperature by engineering principles. This is one of the most important changes introduced in Superpave that the acceptance limits are the same but must be met at specific pavement temperatures and traffic conditions. Long Term Pavement Performance has provided a specific algorithm to calculate the pavement temperature based on the above air temperature. From here, the highest and lowest temperatures of the pavement are calculated and asphalt that performs well in that temperature range is selected [2]. Penetration grading and viscosity grading are somewhat limited in their ability to fully characterize asphalt binders for use in Hot Mix Asphalt (HMA) pavements. Therefore, as part of Superpave's research efforts, new binder tests and specifications were developed to more accurately and fully characterize asphalt binders for use in HMA pavements. These tests and specifications are specifically designed to address HMA pavement performance parameters such as rutting, fatigue cracking, and thermal cracking. Superpave performance Grade (PG) Bitumen is based on the idea that the properties of HMA asphalt binder should be related to the conditions in which it is used. For asphalt binders, this involves expected climatic conditions as well as aging considerations [3].

Cariphalte is a premium grade polymer modified bitumen used in road and airport construction and other similar applications. Cariphalte is a Styrene Butadine Styrene (SBS) modified bitumen. The SBS in Cariphalte ensures the formation of a 3-dimensional network in the bitumen thereby reducing the temperature susceptibility and increasing the stiffness modulus at high temperatures. Cariphalte is also resistant to oxidation, reducing deformation and slowing secondary solidification [4].

METHOD

Research on asphalt mixtures uses testing methods on several test objects tested at the Balai Besar Peralatan Jalan Nasional (BBPJN) IV Cikampek Laboratory. The additional ingredient used in the asphalt mixture is gilsonite.

Mixing cariphalte asphalt was carried out with 7 variations of gilsonite mixture content, namely (0%, 4%, 5%, 6%, 7%, 8%). Mixing was carried out by mixing hot cariphalte asphalt and gilsonite in a container and mixing at 5000 rpm for 1 hour in the laboratory. Basic asphalt rheological testing includes asphalt penetration testing, softening point testing, flash point testing, asphalt kinematic viscosity testing, ductility testing, and solubility testing in trichloroethylene. For mechanistic rheology testing, each variation of asphalt mixture will be conditioned in 2 test conditions. Firstly, the asphalt will be conditioned using the RTFOT (Rolling Thin Film Oven Test) test, while secondly the asphalt will be conditioned using the PAV (Pressure Aging Vessel) test. After conditioning the asphalt in RTFOT and PAV conditions, the asphalt will be tested for its mechanistic rheology using the DSR (Dynamic Shear Rheometer) testing tool. The entire test can be seen in the flow diagram below.

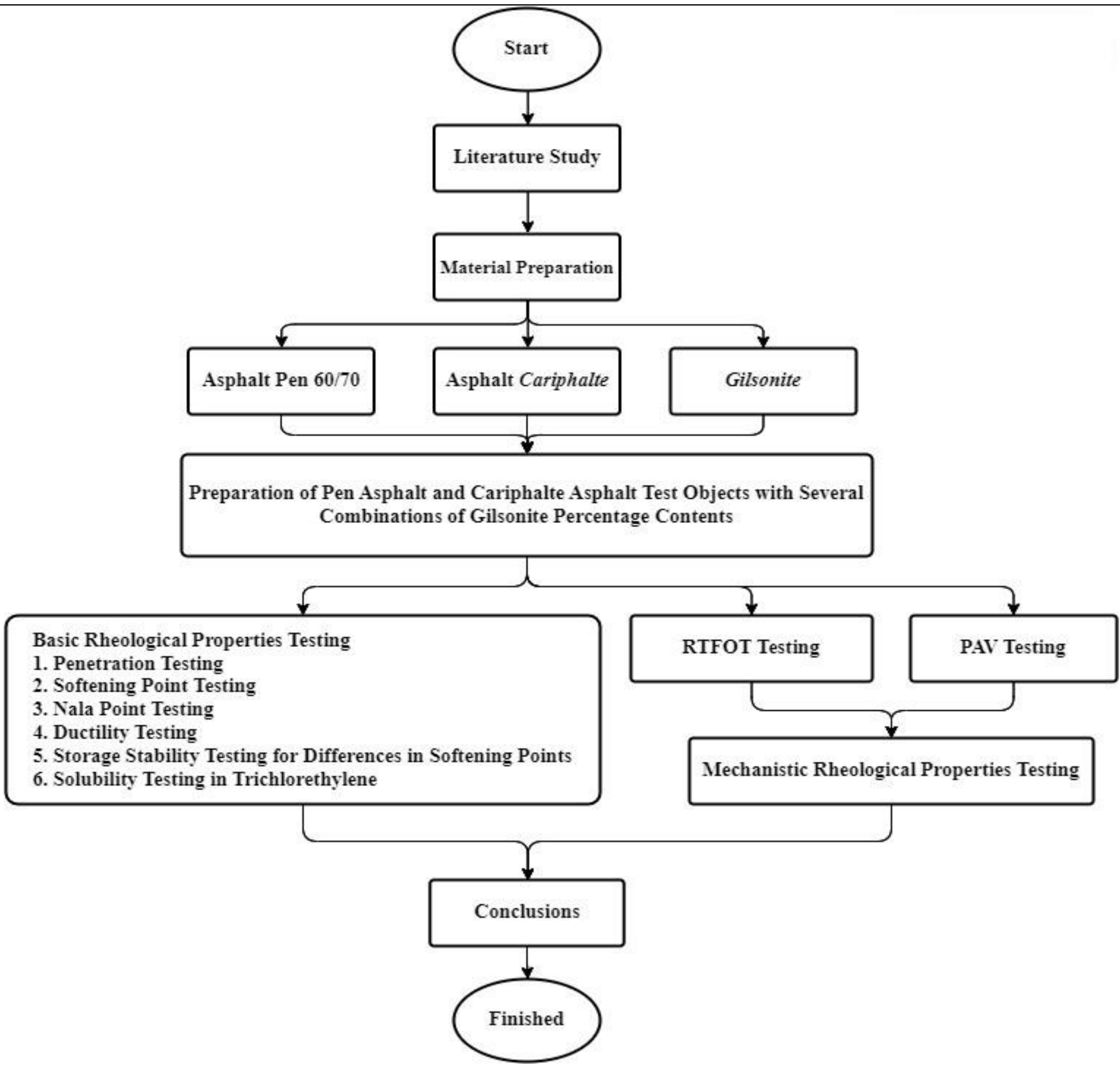

Figure 1. Research Flowchart

RESULTS AND DISCUSSION

Asphalt Characteristics

The asphalt used in this research was Cariphalte PG-76 which was obtained from PT Buntara Megah Inti, a Shell Bitumen distributor in Indonesia operating in Tangerang. Cariphalte is a Styrene Butadine Styrene (SBS) modified bitumen. The SBS in Cariphalte ensures the formation of a 3-dimensional network in the bitumen thereby reducing the temperature susceptibility and increasing the stiffness modulus at high temperatures. This is why cariphalte was used as a binder for the mixture in this research. The characteristics of asphalt can be determined by carrying out laboratory tests to obtain several parameters required in the asphalt mixture. The overall test results for PG-76 asphalt can be seen in Table 1. The next stage was testing modified asphalt using added gilsonite with a mixture percentage of 0%, 4%, 5%, 6%, 7% and 8%. The test results can be seen in Table 1.

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Table 1. PG-76 + Gilsonite Asphalt Properties Results

Number	Test Type	Test Method	PG76 Modified Asphalt	Test Result					
				0% Gs	4% Gs	5% Gs	6% Gs	7% Gs	8% Gs
1	Penetration at 25°C (0,1 mm)	SNI 2456:2011	Reported (1)	49	36	34	33	32	29
2	Soft Point (°C)	SNI 2434:2011	Reported (2)	81.1	81.4	82.6	84.4	85.2	85.8
3	Flash point (°C)	SNI 2434:2011	≥ 230	319	324	328	322	324	328
4	Mixing Temperature (°C)	SNI 7729:2011	Reported (2)	189.5 - 196.5	191.5 - 197.5	192 - 197	193 - 197	193.5 - 197	193.5 - 198
5	Compaction Temperature (°C)	SNI 7729:2011	Reported (2)	175.5 - 181	178.5 - 185.5	181 - 186	181.5 - 186	181.5 - 186	181.5 - 187
6	Solubility in Trichlorethylene (%)	AASHTO T44- 14	≥ 99	99.66	99.8	99.63	99.74	99.67	99.73
7	Storage Stability Softening Point Difference (°C)	ASTM 5976-00 Part 6.1 dan SNI 2434:2011	≤ 2,2	1.4	0.6	0.1	2.5	1.8	3
Residue Testing TFOT Results (SNI-06-2440-1991) or RTFOT (SNI-03-6835-2002) :									
8	Weight Lost (%)	SNI 06-2441-1991	≤ 0,8	0.016	0.069	0.018	0.021	0.048	0.05
9	Penetration at 25°C (% beginning)	SNI 2456:2011	≥ 54	84	85.2	83	84.2	87.5	87.1
10	Ductility on 25°C, (cm)	SNI 2432:2011	≥ 25	114.5	112.5	95.5	92.25	81.2	78

Based on Table 1, it can be seen that each variation in gilsonite content has different characteristic values. From the penetration test results, it was found that the penetration value of PG-76 asphalt decreased along with increasing gilsonite content. Asphalt with the addition of 4% gilsonite had a decrease of 26.5%, while with the addition of 8% gilsonite the penetration value decreased by 40.8%. From the results of the penetration value, it can be concluded that the higher the gilsonite content in the asphalt, the more the asphalt penetration value will decrease. Thus, the lower the penetration value, the harder the asphalt properties are [5]. This shows that asphalt with a greater percentage of gilsonite will show a smaller penetration value, which means that the asphalt becomes harder. Therefore, the harder the asphalt, the lower the deformation and rutting values.

Next, asphalt ductility testing is carried out to determine the flexibility of the asphalt which is expressed by the length of asphalt that can be reached before the asphalt breaks. Ductility properties are also used to determine the resistance of asphalt to cracking when used as a pavement structural layer. Asphalt with low ductility will experience cracks during use [6]. The ductility value of the mixture also influences the strength of the asphalt in binding the aggregate in the test object. Ductility testing was carried out using residual asphalt samples after TFOT according to the 2018 Bina Marga specifications. From the ductility test results, it was found that the ductility value of PG-76 asphalt with the addition of gilsonite still met the requirements, namely ≥ 25. However, there was a decrease in the ductility value as the percentage of gilsonite content increased.

The softening point test is carried out to determine the temperature at which the asphalt starts to soften. The softening point can be an indication of the asphalt's tendency to soften due to increasing temperatures on the road pavement. The effect of adding gilsonite to asphalt causes changes in physical properties in terms of penetration rate and softening point. The penetration rate decreased with increasing gilsonite content. This indicates that the asphalt becomes harder and conversely the softening point of the asphalt increases which indicates that the sensitivity of the asphalt to temperature decreases [7]. Of the three test parameters for asphalt testing characteristics above, namely penetration value, softening point value and ductility value, for the 2004 AAPA specifications, these requirements are not written. However, the results based on the 2018 Bina Marga requirements can be seen in full in Table 1.

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Performance Grade (PG)

Dynamic Shear Rheometer (DSR) is used to test the visco elastic characteristics of asphalt at medium and high temperatures. DSR measures the asphalt shear complex modulus (G*) and phase angle (δ). The shear complex modulus (G*) can be considered as the resistance of asphalt to deformation when repeated shear stresses are applied, while the phase angle (δ) is the distance between the applied shear stress and the resulting shear strain. The greater the phase angle, the thicker the material characteristics [8]. G* and δ are used as predictors of rutting and fatigue cracking of asphalt concrete mixtures. At the beginning of the pavement's life, rutting is the main concern, while during the remainder of the pavement's life fatigue cracking is the main concern. To resist rutting, asphalt must be stiff and elastic (it must be able to return to its original shape after load deformation). Therefore, the complex shear modulus of the elastic part, G*/sinδ must be large. Intuitively, the higher the G* value, the greater the stiffness of the asphalt (able to resist deformation) and the lower the δ value, the greater the elastic portion of G* (able to recover its original shape after being deformed by load).

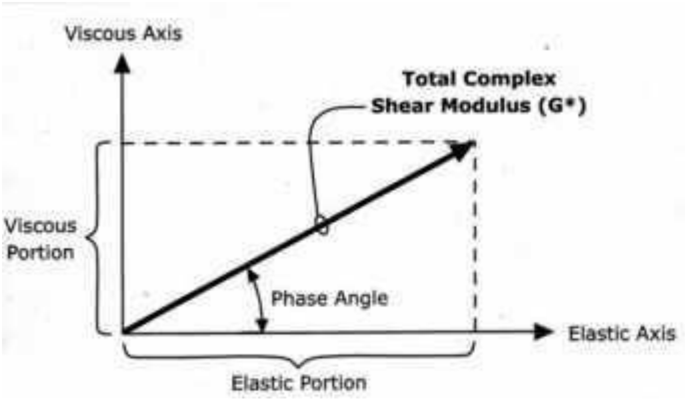

Figure 2. Complex Shear Modulus and Phase Angle

To simulate asphalt aging to achieve short term aging which occurs due to the mixing and construction process, the Rolling Thin Film Oven Test (RTFOT) is carried out. In this research, RTFOT testing was carried out on original PG-76 asphalt and PG-76 asphalt mixed with gilsonite. The standard RTFOT testing procedure refers to ASTM D 2872-04 (Effect of Heat and Air on a Moving Film of Asphalt). Furthermore, to simulate long-term aging of asphalt, which conditions the asphalt to undergo oxidation during the service life of the road, a Pressure Aging Vessel (PAV) test is carried out on RTFOT asphalt residue. In this study, PAV testing was carried out on original RTFOT PG-76 residual asphalt and PG-76 asphalt mixed with gilsonite. Testing the phase angle (δ) of asphalt is carried out with three asphalt conditions, namely pure asphalt (original binder), RTFOT residual asphalt and PAV residual asphalt.

Based on research conducted [9], to observe the effect of temperature on the behavior of the phase angle (δ) and short-term aging in the conditioning of pure asphalt (original binder) and RTFOT residual asphalt, the temperature variations used start from 58 °C, 64 °C , 70°C, 76°C with an increase every 6°C until it reaches a temperature of 82°C, according to the condition of the PG value of the asphalt used, namely Performance Grade 76. Meanwhile, for long-term aging carried out in conditioning PAV residue asphalt, the temperature variations required used starting from 31°C, 28°C, 25°C with a decrease every 3 °C until reaching a temperature of 22°C, in accordance with research conducted by [10], Phase Angle Value (δ) with Original PG-76 Asphalt Conditioning.

Phase Angle Value (δ) with Original Asphalt Conditioning

Based on pure asphalt samples (original binder) with the addition of gilsonite starting from 4%, 5%, 6%, 7%, and 8%, the phase angle value (δ) is then tested using DSR with the ASHTO T 315 or ASTM D 7175-test standard. 08 (Determining the Rheological Properties of Asphalt Binder Using a Dynamic Shear Rheometer). From the test results, at the same temperature, asphalt with the addition of 0% gilsonite has the smallest phase angle (δ) compared to asphalt using the addition of gilsonite. This explains that the addition of gilsonite can increase the phase angle (δ) value of PG-76 asphalt which makes the asphalt material have thicker characteristics [10].

The largest increase in the phase angle (δ) value occurred until the gilsonite content was added to 6% and there was a decrease in the phase angle (δ) value at 7% and 8% gilsonite percentages. Likewise, with the effect of increasing temperature, in the same sample there is an increase in the phase angle (δ) value along with increasing temperature, which means the elastic part of PG-76 asphalt decreases. The relationship between temperature variations and phase angle (δ) in pure asphalt conditions can be seen in Table 2 and Figure 3.

Table 2. Phase Angle (δ) of Original PG-76 + Gilsonite Asphalt DSR Test Results

Temperature (°C)	Angle Phase (δ) (Degree)					
	0% Gs	4% Gs	5% Gs	6% Gs	7% Gs	8% Gs
58	63.6	64.4	64.4	65.1	65.5	63.8
64	63.3	64.4	64.5	65.7	65.7	63.6
70	63.3	65.0	65.7	67.3	66.4	64.1
76	63.4	65.1	67.7	69.4	67.3	65.7
82	63.7	65.7	70.5	72.1	68.6	68.6

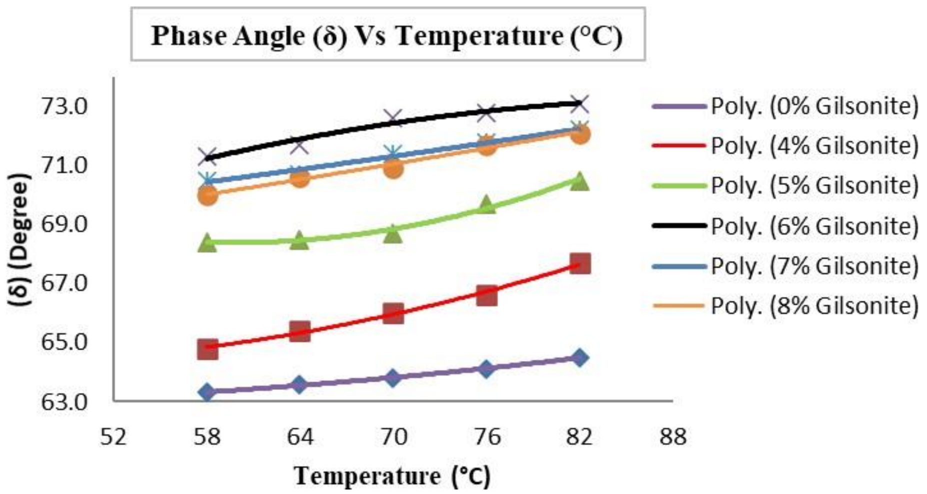

Figure 3. Phase Angle (δ) Vs Temperature (°C) of Original Asphalt

Phase Angle Value (δ) with RTFOT Residue Asphalt Conditioning

The phase angle (δ) value in RTFOT residual asphalt conditioning is intended to determine the visco elastic characteristics of asphalt at the beginning to the middle of the pavement life. To simulate asphalt in this condition, RTFOT testing is carried out on pure asphalt. For pure asphalt and RTFOT residual asphalt, the tendency is to have relatively the same change in phase angle (δ). These two asphalts have relatively the same visco elastic behavior. At the same temperature, asphalt with the addition of 0% gilsonite has the smallest phase angle (δ) compared to asphalt with the addition of gilsonite.

The largest increase in the phase angle (δ) value occurred until the gilsonite content was added to 6% and there was a decrease in the phase angle (δ) value at 7% and 8% gilsonite percentages. Likewise, with the effect of increasing temperature, in the same sample there is an increase in the phase angle (δ) value along with increasing temperature, which means the elastic part of PG-76 asphalt decreases. The relationship between temperature variations and phase angle (δ) in pure asphalt conditions can be seen in Table 3 and Figure 4.

Table 3. Phase Angle (δ) of PG-76 Asphalt Residue RTFOT + Gilsonite DSR Test Results

Temperature (°C)	Angle Phase (δ) (Degree)					
	0% Gs	4% Gs	5% Gs	6% Gs	7% Gs	8% Gs
58	63.8	64.5	64.3	65.1	65.2	64.0
64	64.2	64.6	64.2	65.2	65.2	64.6
70	65.6	65.5	65.2	65.9	65.2	64.4
76	67.6	67.5	67.1	68.1	67.5	66.8
82	69.8	70.2	70.1	71.7	70.1	70.5

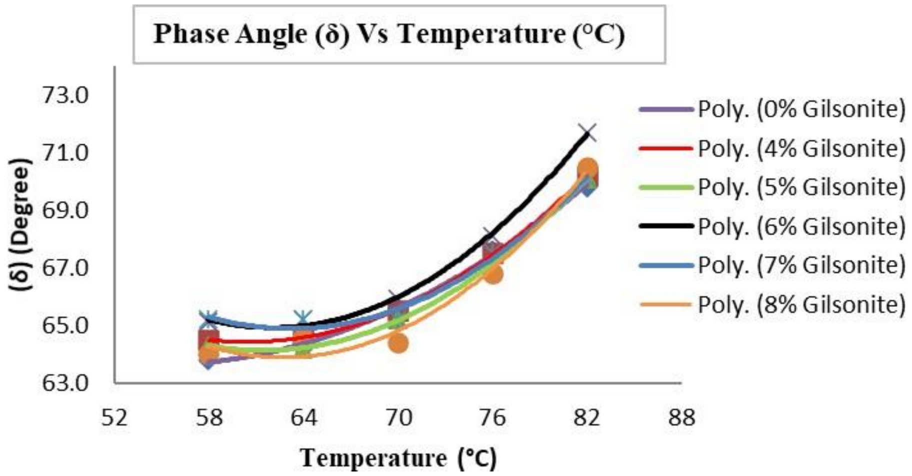

Figure 4. Phase Angle (δ) vs Temperature (°C) of RTFOT Residue Asphalt

Phase Angle Value (δ) with PAV Residue Asphalt Conditioning

The viscous elastic characteristics of asphalt at the end of the pavement life can be seen from the phase angle (δ) value with PAV residual asphalt conditioning. To simulate asphalt in this condition, a PAV test was carried out on RTFOT residual asphalt. For pure asphalt, RTFOT asphalt residue, and PAV residue have a relatively similar tendency to change the phase angle (δ). The difference is only visible in the temperature used. For pure asphalt and RTFOT residue, the temperature starts from 58°C-82°C with a temperature increase of 6°C in each phase. Meanwhile, for PAV residue, the temperature starts from 31°C-22°C with a temperature decrease of 3°C in each phase, all of which is based on the AASHTO T 315 (2008) standard regarding the visco-elastic behavior of asphalt. The relationship between temperature variations and phase angle (δ) in PAV residual conditions can be seen in Table 4 and Figure 5.

Table 4. Phase Angle (δ) of Asphalt PG-76 PAV + Gilsonite Residue DSR Test Results

Temperature (°C)	Angle Phase (δ) (Degree)					
	0% Gs	4% Gs	5% Gs	6% Gs	7% Gs	8% Gs
31	62.6	60.6	59.8	58.4	57.5	61.7
28	59.4	57.1	56.9	54.5	53.5	56.9
25	56.2	53.6	53.6	50.5	50.2	52.2
22	52.7	50.0	50.2	46.8	46.6	48.0

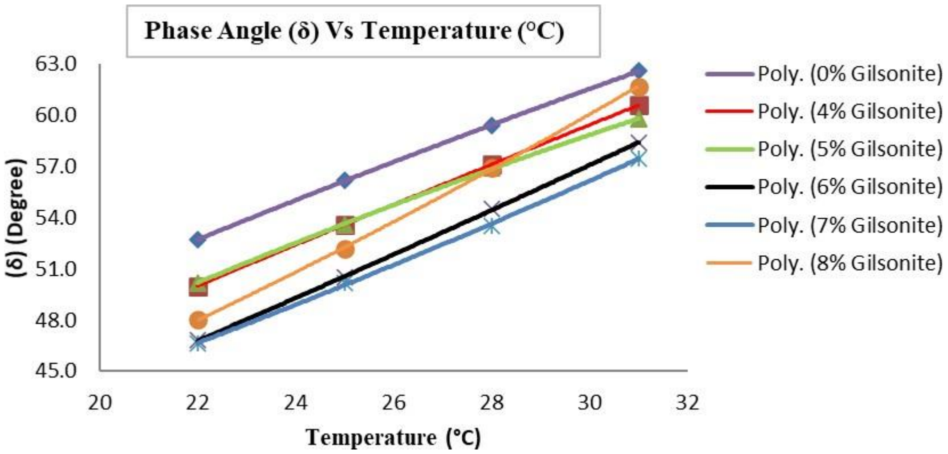

Figure 5. Phase Angle (δ) vs Temperature (°C) of PAV Residue Asphalt

Aging Factor Value (G*/sinδ) of PG-76 Asphalt from DSR

To determine the level of asphalt aging, it can be seen from the aging factor, namely the ratio between the G*/sinδ parameters after the RTFOT process and the original G*/sinδ [11]. This is to determine the deformation resistance at the initial age of the pavement. Table 5 shows the aging factor values for PG-76 asphalt with or without gilsonite in pure condition, RTFOT residue and PAV residue. The results show that the aging factor value for the asphalt mixture with a 4% gilsonite percentage is smaller than the aging factor value for asphalt with other gilsonite percentages. This value is even smaller in all conditions, be it pure asphalt (Original Binder), RTFOT asphalt residue, or PAV residue. A lower aging factor indicates better pavement life because asphalt aging occurs more slowly over the service life of the road [12].

Table 5. Aging Factor Value (G*/sinδ) of PG-76 Asphalt from DSR in Original Condition, After TFOT, and After PAV

Condition	Temperature (°C)	0% Gs	4% Gs	5% Gs	6% Gs	7% Gs	8% Gs
Original binder G*/sinδ,(≥ 1,0 kPa)	58	19.5	11.3	19.7	20.0	24.3	31.1
	64	10.4	6.47	10.8	10.9	12.7	16.2
	70	5.8	3.83	6.14	6.23	6.99	9.0
	76	3.35	2.35	3.6	3.65	3.98	5.18
	82	2.00	1.47	2.15	2.22	2.37	3.05
	58	12.8	10.8	23.3	26.6	28.2	30.9

RTFOT G*/sinδ, (≥ 2,2 kPa)	64	9.07	8.20	12.7	14.0	14.5	16.6
	70	7.05	6.28	7.15	7.64	7.88	9.23
	76	2.43	3.67	4.18	4.26	4.44	5.25
	82	1.53	2.23	2.5	2.42	2.61	3.01
PAV G*sinδ, (≤ 5000 kPa)	31	175	162	331	430	316	241
	28	279	246	512	612	445	328
	25	433	364	788	880	619	446
	22	674	532	820	930	881	608

Phase Angle Parameter Value (δ) from DSR Testing to see the durability of asphalt during the pavement service period

It is hoped that good asphalt will continue to function well as a binding material during the asphalt concrete pavement service period in the field. Asphalt that is easily damaged, for example easily oxidized, during the service period in the field can cause damage to the asphalt concrete pavement before the service period ends. In the Pen asphalt specifications, there are no requirements intended to prevent asphalt damage during the service period.

In PG asphalt specifications, to predict the properties of asphalt during the service period in the field, PAV (Pressure Aging Vessel) testing is used. PAV testing is considered to be able to simulate asphalt conditions for 5-10 years of service in the field. Conditioning is carried out by first conditioning the asphalt with TFOT (Thin Film Oven Test) to simulate asphalt conditioning during mixing at AMP until spreading and then TFOT residual asphalt is conditioned with PAV, namely being given a certain pressure and temperature for 20 hours.

Table 6. Phase Angle Value (δ) of PG-76 Asphalt and PAV Pen Residue Asphalt

Temperature (°C)	**Angle Phase (δ) (Degree)**	
	Asphalt Pen 60 (Agus Ariawan Research 2017)	**Asphalt PG-76 (Current Research Results)**
31	59,58	62,6
28	55,33	59,4
25	51,79	56,2
22	48,33	52,7

Asphalt characteristics that are influenced by asphalt aging can be seen from the Phase Angle (δ) value. From the results of the DSR test with PAV conditioning, it produces a phase angle value that is greater than Pen asphalt. A larger phase angle value indicates better pavement life because the aging of the asphalt or pavement progresses more slowly during the service life of the road [12].

CONCLUSION

1. The test results show that at the same temperature, asphalt with the addition of 0% gilsonite has the smallest phase angle (δ) compared to asphalt using the addition of gilsonite. This explains that the addition of gilsonite can increase the phase angle (δ) value of PG-76 asphalt, which makes the asphalt material have thicker characteristics.
2. At the same temperature, asphalt with the addition of 0% gilsonite has the smallest phase angle (δ) compared to asphalt with the addition of gilsonite. For pure asphalt and RTFOT

residual asphalt, the tendency is to have relatively the same change in phase angle (δ). These two asphalts have relatively the same visco elastic behavior.
3. Original asphalt, RTFOT asphalt residue, and PAV residue have relatively the same tendency to change the phase angle (δ). The difference is only visible in the temperature used. For pure asphalt and RTFOT residue, the temperature starts from 58°C-82°C with a temperature increase of 6°C in each phase, while for PAV residue the temperature starts from 31°C-22°C with a temperature decrease of 3°C in each phase.

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