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Evaluation on the Effect of Zinc Oxide Addition to Aging Rate of Asphalt and Performance of Resilience Modulus in Asphalt Concrete–Wearing Course

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Abstract This study discussed the effect of the addition of the antioxidant Zinc Oxide (ZnO) on the aging rate of AC-WC coated asphalt and found out the effect of the addition of ZnO antioxidant on the stiffness of the asphalt layer. The aging of asphalt can be caused by two main factors, namely evaporation of light oil fractions contained in asphalt and oxidation. In this study, it showed that, compared to the addition of 5% and 15% ZnO to asphalt, the addition of 10% ZnO provided the most effective results on the asphalt base affecting the rheological properties of asphalt, namely reducing the penetration value by 1 dmm, increasing the softening point of asphalt by 0.5°C but reducing the ductility by 10 cm. In the resilience modulus test which was carried out after aging at 135°C for 0, 24, 48, 72, 96, and 120 hours, the modulus value containing ZnO was always smaller than that of asphalt without ZnO content. The addition of antioxidant Zinc Oxide (ZnO) antioxidant to asphalt had a positive effect on the aging rate of asphalt and the performance of the open-graded AC-WC resilience modulus of asphalt mixture was effective at an additional 10% level.

Keywords Aging Asphalt, Antioxidant, Zinc Oxide

1. Introduction

Roads as one of the transportation infrastructures are the lifeblood of people who have an important role in the development of life. Pavement is constructed to serve traffic during its design life. The frequency of excessive traffic loads can cause rapid damage to the pavement. Asphalt pavement is one whose surface layer is made of an asphalt mixture. The asphalt mixture can be used as a surface course, either as a wearing course, a binder course, or a basic course, while the type of material that can be used in these layers depends on the function of the material in the pavement structure during its service life and the surrounding environmental conditions [1].

In asphalt pavement, the damage that occurs can be in the form of cracks or deformation. In addition, as an unprotected structure, the environment also has a significant influence on pavement durability. Raveling, asphalt aging, washboard, and permanent deformation are the types of damage caused by the main environmental factors in the form of ultraviolet light, water, and changes in the humidity and temperature conditions day and night. The type of damage that occurs in the paved pavement is generally not one type but is a combination of all types of damage.

The damage to the road surface can be caused by traffic factors, the environment, the original plan, the quality of the work, or a combination of these factors. Of these four factors, traffic, environment, and the interaction between them are the main causes of damage to the surface layer of asphalt pavement structures [2]. For example, the damage in the form of rutting, subsidence, and crocodile cracks is the type of damage caused by the traffic. Meanwhile, the types of damage caused by the environment or not caused by the influence of traffic are transverse and longitudinal cracks as well as the grains scattering on the surface of the asphalt layer.

The tropics show that the failure model of the asphalt layer in the tropics is different from that usually occurs in sub-tropical areas [3]. This difference indicates that the climate greatly affects the performance of the asphalt mixture. Due to the high heat, asphalt hardening due to aging occurs faster in tropical areas than in sub-tropical areas. This hardening mainly occurs on paved surfaces that are directly exposed to the environment. Therefore, the cracks in the asphalt surface layer in the tropics will occur quickly before cracking in other areas occurs [4].

The aging of asphalt is a good parameter to find out the durability of asphalt mixtures. Two main factors can cause asphalt aging, namely evaporation of light oil fractions contained in asphalt and oxidation. There are several external factors that also can cause asphalt aging include plant type, mixing temperature, and silo storage time during short-term aging, in-field conditions (i.e., temperature, ultraviolet (UV) ray, and rainfall), and time during long-term aging. The rate and extent of aging also depend on mixture properties, such as source and type of asphalt, aggregate gradation and absorption, void content/ permeability, and the thickness of asphalt binder film over the aggregate. A recent study by Morian et al. [5] reports that mixtures' effective binder content has provided the strongest indicator of the aging characteristics of asphalt mixture, irrespective of the type of granular aggregate**.** Aging can cause hardening of the asphalt and will further increase the stiffness of the asphalt mixture, so that the asphalt mixture becomes brittle and will make it susceptible to cracking and reduce its resistance to repeated loads (fatigue).

Based on the problems above, the antioxidant Zinc Oxide was chosen as the additive in this study. The selection of ZnO additives as antioxidants in this study is not only because ZnO is easily available in the market, but also because studies on the addition of ZnO as an asphalt modifier have been carried out in other countries to find out the effect of ZnO particle size on the modified asphalt properties produced. The previous study was conducted in China. Xu et al. (2019) on Physical Properties and Anti-Aging Characteristic of Asphalt Modified with Nano ZnO Powder showed that a dose of ZnO can affect the softening point and stability of modified asphalt. When the dose of ZnO exceeds certain doses, the stability of modified asphalt will be reduced. Then significantly ZnO can increase the value of rheology asphalt. ZnO can strongly absorb ultraviolet radiance with a percentage over 95% showing their primacy as the changing of anti-aging UV for asphalt. The absorption intensity for UV from modified asphalt with ZnO will be upgraded fewer times than the basic one; and when the dose is 3.0%, the absorption intensity can gain the maximum value and show significant changes because of the increasing of ZnO doses [6].

The previous study for Anti-Aging Characteristics with different antioxidants conducted by Ibrahim et al. (2020) on The Effect of Addition of Antioxidant 1,2-dihydro-2,2,4-trimethyl-quinoline on Characteristics of Crepe Rubber Modified Asphalt in Short-Term Aging and Long-Term Aging Conditions shows that the best-modified asphalt product was the addition of 10% crepe rubber and 2% TMQ. The best-modified asphalt characteristics have penetration of 68.70 dmm, softening point of 55.45°C, weight loss only 0.0579%, and penetration after RTFOT 59.60, Marshall stability of 1403.96 kg with optimum asphalt content of 5.50%, and rutting factor (G*/Sinδ) 6.91 kPa and 16.1 kPa before and after RTFOT. Overall, the modified crepe rubber asphalt can improve the performance of the asphalt in terms of durability. Simultaneously, the antioxidant TMQ works very well in increasing the resistance of bitumen to aging in the conditions of short-term aging and long-term aging [7].

Meanwhile, this study focused on the effective content of the addition of ZnO to the modified asphalt properties and the modulus of the mixture in Indonesia based on Indonesia's asphalt, environment, and temperature. In addition, the dose on ZnO was changed from the previous one. This study aimed to find out the effect of the addition of antioxidant Zinc Oxide (ZnO) on the rheological properties of asphalt, the aging rate of asphalt, and the modulus of resilience of the asphalt mixture due to the aging in the asphalt mixture. The AC-WC used the Universal Testing Apparatus Asphalt (UMATTA) tool.

2. Materials and Methods

This study used research methods. The materials used in this study were asphalt, aggregate, cement, sand, rock ash, and zinc oxide (ZnO) as an antioxidant additive.

2.1. Aggregate

According to the Indonesia National Standard (SNI) 1737-1989, aggregates are grains of crushed stone, gravel, sand, or other minerals, both natural and artificial, in the form of solid minerals in large or small sizes or fragments. The aggregate is the largest part of an asphalt mixture. It must be in good shape, clean, hard, strong, and of good gradation. Aggregate with good gradation has an arrangement of grains from fine to coarse regularly.

According to the clarification, the aggregate is divided into 2 types, namely coarse aggregate, and fine aggregate. Both types were tested first according to the SNI testing standard. There were 5 tests carried out, namely bulk density, saturated surface dry (SSD) density, apparent density, water absorption, and bulk density. The results of the aggregate test are presented in Table 1 for the coarse aggregate test and Table 2 for the fine aggregate test.

Based on the results of testing the characteristics of coarse aggregate shown in Table 1, the results obtained were 2.579 bulk specific gravity, 2.515 SSD density, 2.541 apparent density, 0.69% of water absorption, and 1.346 bulk density. The results of this test already met the requirements specified in the General Specifications of Bina Marga Indonesia 2018 Revision 1.

Based on the results of testing the characteristics of fine aggregates as shown in Table 2, the obtained results were 2,591of bulk specific gravity, 2,629 of SSD density, 2,694 of apparent density, 1.1% of water absorption, and 1.337 of bulk density. The results of this test already met the requirements specified in the General Specifications of Bina Marga Indonesia 2018 Revision 1.

2.2. Asphalt

Asphalt is a solid or semi-solid material, black to dark brown in color, and adhesive which will soften and melt when heated. The asphalt is composed mainly of bitumen, all of which is present in a solid or semi-solid form from nature or petroleum refining, or is a mixture of bituminous materials with petroleum or its derivatives [8]. The asphalt is a thermoplastic material, that is, its consistency or viscosity will change according to changes in temperature that occur. The higher the asphalt temperature, the lower the viscosity is.

Natural asphalt is asphalt that is formed naturally in nature. This asphalt has varying hardness and purity. Asphalt oil is the result of residues of the crude oil processing process. While bioasphalt is asphalt obtained from the pyrolysis of plants containing lignin. Of these three types of asphalt, the most oil asphalt (85%-95% of the world's asphalt needs) is used either generally as a binder in paved mixtures or as a waterproof layer on the roof of buildings or dams [9]. The asphalt used in this study was the most widely used in Indonesia as a binder for asphalt mixtures, namely Pertamina's Pen 60 asphalt. The properties of the asphalt used obtained from the test results are summarized in Table 3.

Table 3 shows that the Pen 60 asphalt used in this study meets the properties as required in the General Specification of Bina Marga Indonesia 2018 Revision 1. Therefore, the asphalt can be declared to be still good and can be used as a binder for asphalt mixtures.

2.3. Ash Rock

Ash rock is a mineral filler (<0.075 mm). It consists of fine particles, and the gradation and fineness of coal ash can meet the grading requirements for mineral fillers. Stone ash is obtained from the by-products of cement plants or stone crushers. This material is needed for the road pavement process. There are 6 types of rock ash characteristic tests, namely: bulk density, SSD density, apparent density, water absorption, bulk density, and sand equivalent value. Table 4 shows the test results.

Table 1. Coarse Aggregate Characteristic Test Results

No	Characteristics	Testing Standard		Results	Condition	Note.
		SNI	AASHTO			
1.	Bulk specific gravity	SNI 1969:2016	AASHTO T85-14	2,579	Min. 2.5	Fulfill
2.	SSD density	SNI 1969:2016	AASHTO T85-14	2,515	Min. 2.5	Fulfill
3.	Apparent density	SNI 1969:2016	AASHTO T85-14	2,541	Min. 2.5	Fulfill
4.	Water absorption	SNI 1969:2016	AASHTO T85-14	0.69%	Max. 2%	Fulfill
5.	Bulk density	SNI 03-4804-1998	AASHTO T19M/T19-14	1.346	-	-

Table 2. Test Results for Fine Aggregate Characteristics

No	Characteristics	Testing Standard		Results	Condition	Note.
		SNI	AASHTO			
1.	Bulk specific gravity	SNI 1969:2016	AASHTO T85-14	2,591	Min. 2.5	Fulfill
2.	SSD density	SNI 1969:2016	AASHTO T85-14	2,629	Min. 2.5	Fulfill
3.	Apparent density	SNI 1969:2016	AASHTO T85-14	2,694	Min. 2.5	Fulfill
4.	Water absorption	SNI 1969:2016	AASHTO T85-14	1.1%	Max. 2%	Fulfill
5.	Bulk density	SNI 03-4804-1998	AASHTO T19M/T19-14	1.337	-	-

Table 3. Properties of Pertamina's Pen 60 Asphalt

No.	Test Type	Testing Standard		Test result	Specification	Unit
		SNI	AASHTO			
1.	Penetration at 25°C, 100 g, 5 seconds	SNI 2456:2011	AASHTO T49-15	61.4	60 -7 0	0.1 mm
2.	Softening point	SNI 2434:2011	AASHTO T53-09(2013)	49.5	48	°C
3.	Ductility at 25°C, 5 cm/min	SNI 2432:2011	AASHTO T53-09(2013)	> 140	100	cm
4.	Flash point	SNI 2433:2011	AASHTO T48-06(2015)	311	232	°C
5.	Burn point	SNI 2433:2011	AASHTO T48-06(2015)	320		°C
6.	Specific gravity	SNI 2441:2011	AASHTO T228-09(2013)	1.031	1	-

Table 4. Test Results of Ash Rock Characteristics

No	Characteristics	Testing Standard		Test Results	Condition	Remarks
		SNI	AASHTO			
1.	Bulk specific gravity	SNI 1970:2016	AASHTO T84-13	2,548	Min. 2.5	Fulfil
2.	SSD density	SNI 1970:2016	AASHTO T84-13	2,583	Min. 2.5	Fulfil
3.	apparent density	SNI 1970:2016	AASHTO T84-13	2,639	Min. 2.5	Fulfil
4.	Water absorption	SNI 1970:2016	AASHTO T84-13	1.36%	Max. 2%	Fulfil
5.	Bulk density	SNI 03-4804-1998	AASHTO T19M/T19-14	0.371	-	-
6.	Sand equivalent value	SNI 03-4428-1997	AASHTO T176-08(2013)	88.1%	Min. 50%	Fulfil

Based on the results of testing the characteristics of rock ash as shown in Table 5, the results obtained were 2.548 of specific gravity, 2.583 of SSD gravity, 2.639 of apparent density, 1.36% of water absorption, 0.371 of Bulk density and 88.1% of sand equivalent value. The results of this test already met the requirements specified in the General Specifications of Bina Marga 2018 Revision 1.

2.4. Cement

Cement is a filler in asphalt mixtures. There are 2 cement tests, namely passing the No. 200 sieve and the specific gravity of the filler. Table 5 presents the results of cement testing.

The results of testing the characteristics of the filler presented in Table 5 show that the test results are the percentage of passing the No. sieve. 200 by 100%. They already met the requirements of SNI M-02-1994-03 and SNI 15-2531-1991.

2.5. Zinc Oxide (ZnO) As Antioxidant Ingredients

Zinc oxide is an inorganic compound with the chemical formula ZnO. It is a white powder that is insoluble in water but will dissolve in most acids, like hydrochloric acid and base. Pure ZnO occurs as a rare mineral zincite, which usually contains manganese [10]. ZnO as an antioxidant acts as a substitute that is sacrificed to oxidize [11].

The choice of ZnO additive as an antioxidant in this study was not only because ZnO is easily found in chemical stores but it's very commonly used in small- and large-scale chemical industries in Indonesia and its purchase does not require a special permit.

3. Result and Discussion

3.1. Effect of ZnO on Asphalt Rheology

Many properties of asphalt can be modified better. Important properties of asphalt that affect the performance of paved mixtures that are generally modified include durability, connective power to aggregates, resistance to permanent deformation, resistance to fatigue, ductility, elasticity, and sensitivity to temperature [9].

The additive used in this study is the antioxidant Zinc Oxide (ZnO). The levels of ZnO used were 5%, 10%, and 15%, but not all levels were tested; only the best ZnO levels were used in this study. So before further testing, the asphalt was tested for rheological properties to find out the best content for further testing. Table 6 shows the results of rheological testing of asphalt mixed with ZnO with levels of 5%, 10%, and 15%.

Table 5. Test Results of Filler Characteristics (Cement)

No	Characteristics	Testing Standard		Test Results	Condition	Note.
		SNI	AASHTO			
1.	Pass Filter No. 200	SNI M-02-1994-03	AASHTO T11-90	100%	Min. 70%	Fulfil
2.	Filler Specific Gravity	SNI 15-2531-1991	AASHTO T-133-98	3.15	-	

Table 6. Comparative Results of Asphalt Rheological Testing with 5%, 10%, and 15% ZnO

No.	Test Type	Testing Standard		Specification	5%	10%	15%
		SNI	AASHTO				
1.	Penetration at 25°C, 100 g, 5 seconds	SNI 2456:2011	AASHTO T49-15	60 -70 mm	61	60	58
2.	Softening Point	SNI 2434:2011	AASHTO T53-09(2013)	48°C	49.7	50.0	50.7
3.	Ductility at 25°C, 5 cm/min	SNI 2432:2011	AASHTO T51-09(2013)	100 cm	120	130	95
4.	Penetration Index	SNI 2456:2011	AASHTO T49-15		-0.809	-0.761	-0.675
5.	Specific Gravity	SNI 2441:2011	AASHTO T 228	≥ 1,0	1,049	1,120	1,162
6.	Kinematic Viscosity	SNI 7729:2011	AASHTO T44-14	≥ 300	476	326	495
7.	Solubility Asphalt	SNI 2438:2015	AASHTO T 44-03(2011)		97	93	90

Table 6 shows that asphalt with a mixture of 15% ZnO will cause a decrease in the value of penetration and ductility that does not meet the specification value. Consequently, the use of asphalt mixtures with 15% ZnO content could not be done. The ZnO addition levels meeting the standards were 5% and 10%, but viewed from the softening point and ductility values, the best ZnO addition content was 10% with a minimum softening point value of 50°C. Therefore, in this study, the level used was ZnO level of 10%.

3.2. Effect of ZnO on Asphalt Performance

Asphalt modification is not something new because this asphalt has been used since the last century. Currently, modified asphalt has become the main need as a bonded mixture binding material because it has a positive influence on its resistance to fatigue, rutting, peeling, and thermal cracking paved pavement [12]. The asphalt binder properties can be improved by using modifiers. The stiffness of hot mix asphalt at high temperatures may be decreased by using some modifiers which help in laying down and compaction during construction [13].

To see the effects of aging oxidation in asphalt, asphalt aging was carried out by heating it in an oven at 135°C temperature with various heating times carried out as a simulation of short-term aging. In this study, we looked at the effect of adding ZnO antioxidants to Pen 60 asphalt, the process of aging oxidation on asphalt was carried out both on asphalt which contains and doesn't contain ZnO.

Asphalt factors, gradation, temperature, and loading time influence the resilience modulus. The higher the temperature, the smaller the value of the resilience modulus is. It is because asphalt is visco-elastic; it can change from viscous to elastic or vice versa due to the influence of temperature.

There are differences in properties between AC – WC asphalt using 10% ZnO and without using ZnO as an additive. The different properties of AC-WC can be seen from the results of the Marshall test, which are stability, meltdown, and Marshall Quotient (MQ). The differences in the properties of the asphalt are presented in Table 7.

Table 7 shows that the value of stability and MQ in KAO AC – WC with the mixture of 10% ZnO is greater than the value for AC – WC without the mixture of ZnO. This indicates that AC – WC using 10% ZnO mixture has a more stable pavement ability and better resistance to deformation than the AC – WC which does not use ZnO.

3.3. Effect of ZnO on the Aging of Asphalt

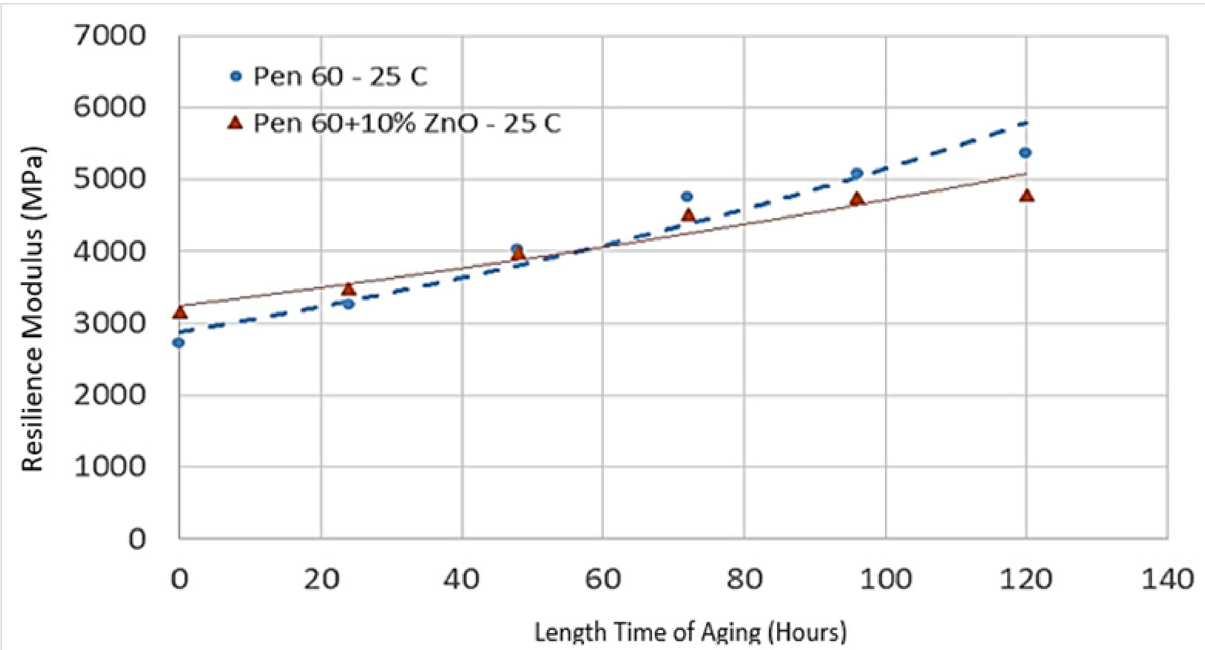
Changes in air temperature do not significantly affect the modulus of the subgrade and the material without a binder, except when freezing occurs, but greatly affect the resilience modulus of asphalt mixtures, especially asphalt mixtures used as a wear layer [14]. The aging process that occurs in asphalt will purify aromatics into asphalt [15]. As a result of this aging process, the hardness level of asphalt increases, its penetration value decreases, and its viscosity will increase.

Based on this, many researchers use the parameter of the asphalt mixture's resilience modulus to see the effect of aging of the asphalt mixture due to the temperature and then carry out further testing. In this study, the effect of temperature on the resilience modulus both before and after long-term oxidation aging of asphalt mixtures using asphalt binders containing or not containing ZnO is shown in Figure 1.

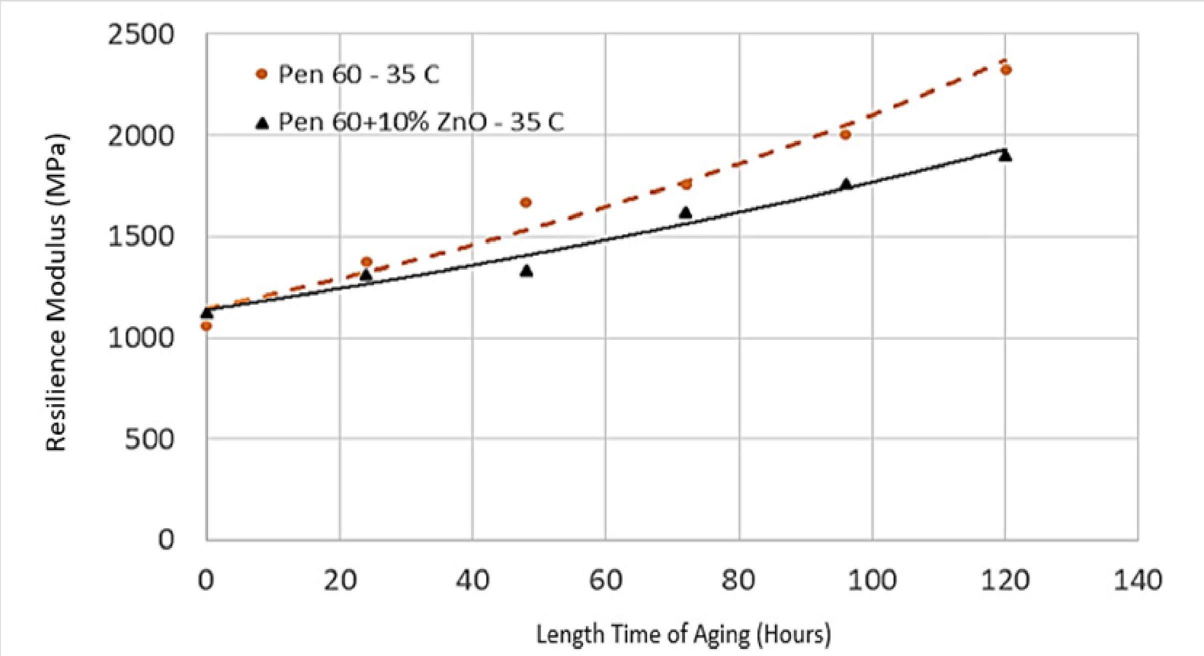
The resilience modulus of this mixture was tested using UMATTA set at a loading pulse width of 250 ms, pulse repetition period 3000 ms. The asphalt that has been made in mould with the dimension of 10,2 cm for the diameter and 7,62 cm for the height will be put to UMATTA and tested at temperatures of 25°C, 35°C, and 45°C. The tests at this temperature variation were carried out to see the sensitivity of the asphalt mixture without the addition of ZnO to changes and aging of the asphalt mixture due to heating at a temperature of 135°C for 24, 48, 72, 96 and 120 hours.

Table 7. Differences in AC – WC Value in KAO with and Without Using the Mixture of 10% ZnO

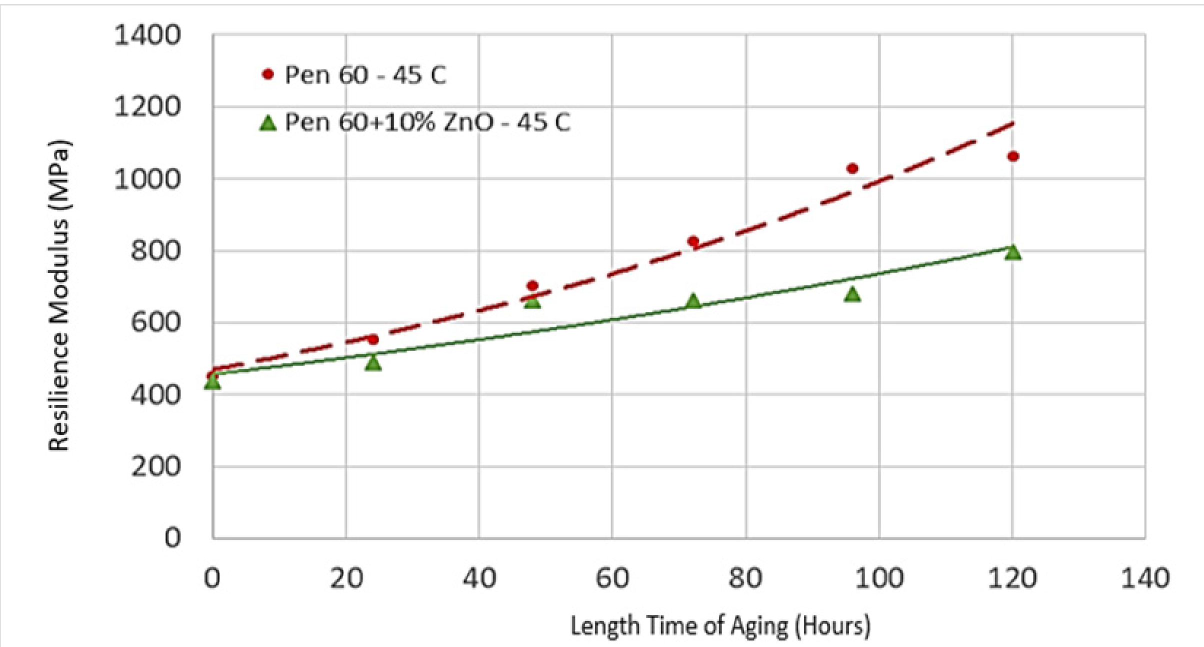
No.	Characteristic	AC - WC on KAO without The Mixture of ZnO	AC - WC on KAO with The Mixture of 10% ZnO
1.	Stability	988 kg	1431.2 kg
2.	Meltdown	3.65 mm	3.44 mm
3.	MQ	270.7 kg/mm	416 kg/mm



(a) 25°C



(b) 35℃



(c) 45℃

Figure 1. The Effect of Oxidation Aging on AC-WC Resistant Modulus on Temperature Tests of (a) 25°C, (b) 35°C, and (c) 45°C

Figure 1 concludes that the length of time of aging affects the value of the resilience modulus. However, the value of the resilience modulus without using a ZnO mixture will increase greater than that using a ZnO mixture. Although initially there was a modulus value using a ZnO mixture that was greater than the value without a ZnO mixture, but with the addition of aging time, the modulus value without using a ZnO mixture would be higher than that with a ZnO mixture.

The rate of aging that occurs on asphalt can be found out through visual observation, but more accurate and measurable information will be obtained only through laboratory testing on recovered asphalt extracted from paved mixtures that have undergone aging [16].

Due to the aging experienced, the asphalt will change in its hardness (penetration) and viscosity. This change in the degree of hardness and viscosity will affect the degree of rigidity of the paved mixture. Based on this, the asphalt aging indicates changes in hardness level (viscosity roof penetration value). The rate of asphalt aging (Aging Index, AI), can be expressed as a ratio between the rheological properties of asphalt (generally represented by the penetration value or viscosity of asphalt) after aging (recovery asphalt) with its early asphalt rheological properties [17] or as a ratio between the modulus of the rigidity of the resilient rigidity of paved mixtures poured with the modulus of the resilient rigidity of freshly paved mixtures [18].

Aging Index (AI) is an asphalt mixture that can be defined as the ratio between the resilience modulus of the mixture before and after the aging. The comparison of AI values for asphalt mixtures is made with asphalt containing 0% ZnO and 10% ZnO in which first the asphalt was already heated at 135°C. The Aging Index table can be seen in Table 8, Table 9 and Figure 2.

Based on the aging time, Table 8 and Table 9 show that the AI value of asphalt mixture has a downward trend. This resulted from the aging occurrence that there will be changes in the properties of asphalt. It can also be seen from Figure 2 that the AI value with 10% ZnO will always be higher compared to the asphalt mixture with 0% ZnO. This indicates that the addition of ZnO as an antioxidant in asphalt has a positive effect on the aging of the asphalt.

3.4. The Effect of ZnO on Asphalt Stiffness

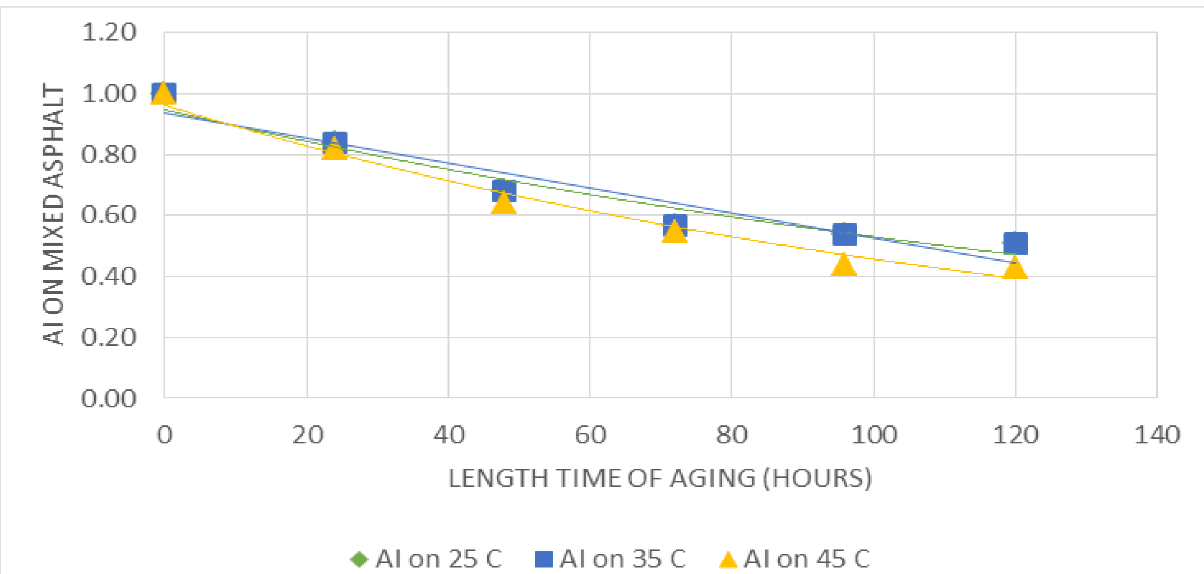
Table 10 shows the result of resilience modulus test. From the test, it can be shown that at a certain test temperature, initially the larger modulus value is the modulus value in asphalt pen 60 with a mixture of 10% ZnO compared to asphalt pen 60 without a mixture of ZnO. Both modulus values increased equally, but at a certain time, there was a change in the value of the resilience modulus. The value of the resilience modulus without ZnO mixture was greater than the value of the resilience modulus with ZnO mixture.

Table 8. The Effect of Oxidation Aging Time on AI Asphalt Mixed with 0% ZnO

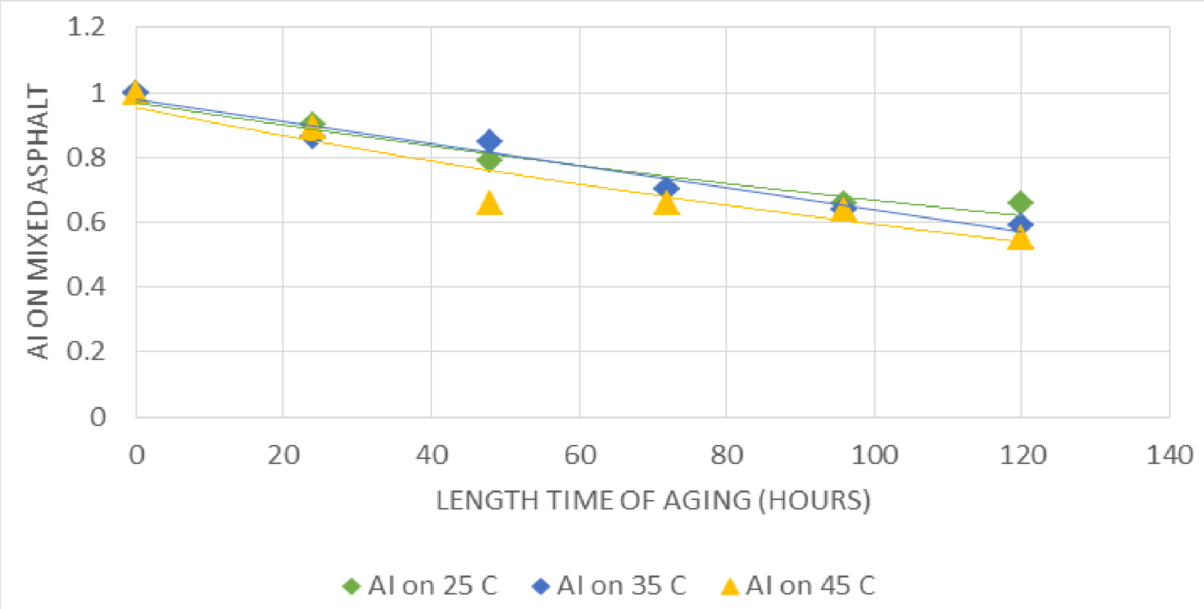
Testing Temperature	Aging Index					
	0 Hours	24 Hours	48 Hours	72 Hours	96 Hours	120 Hours
25°C	1.00	0.84	0.68	0.57	0.54	0.51
35°C	1.00	0.77	0.64	0.60	0.53	0.46
45°C	1.00	0.82	0.64	0.55	0.44	0.43

Table 9. The Effect of Oxidation Aging Time on AI Asphalt Mixed with 10% ZnO

Testing Temperature	Aging Index					
	0 Hours	24 Hours	48 Hours	72 Hours	96 Hours	120 Hours
25°C	1.00	0.90	0.79	0.70	0.66	0.66
35°C	1.00	0.86	0.85	0.70	0.64	0.59
45°C	1.00	0.89	0.66	0.66	0.64	0.55



(a) ZnO 0%



(b) ZnO 10%

Figure 2. AI Asphalt Mixture Due to Aging Oxidation on Asphalt with 0% and 10% ZnO

Table 10. Resilience Modulus of AC-WC Mixture with and Without Antioxidant ZnO

AC-WC Paved Mix	**Modulus Value (MPa)**		
	Testing Temperature (°C)		
	25	35	45
	Before Aging		
- Contains 0% ZnO	2727	1063	453
Contains 10% ZnO	3150	1127	436
	After Aging 135°C for 24 Hours		
Contains 0% ZnO	3252	1377	554
Contains 10% ZnO	3485	1311	490
	After Aging 135°C for 48 Hours		
Contains 0% ZnO	4027	1673	705
Contains 10% ZnO	3975	1333	662
	After Aging 135°C for 72 Hours		
Contains 0% ZnO	4763	1757	827
Contains 10% ZnO	4515	1618	664
	After Aging 135°C for 96 Hours		
Contains 0% ZnO	5074	2006	1028
Contains 10% ZnO	4747	1764	681
	After Aging 135°C for 120 Hours		
Contains 0% ZnO	5368	2327	1063
Contains 10% ZnO	4784	1900	796

Table 10 shows that the length of time of aging affects the value of the resilience modulus. However, the value of the resilience modulus without using ZnO mixture increased greater than that using ZnO mixture. Although initially there was a modulus value using a ZnO mixture that was greater than the value without ZnO mixture, but with the addition of aging time, the modulus value without using a ZnO mixture would be higher than that with ZnO mixture. This proves that the asphalt that does not contain ZnO can quickly change its stiffness characteristics compared to the asphalt containing ZnO.

4. Conclusions

In conclusion, all tests of asphalt rheological properties, compared by 0%, 5%, and 15%, the best ZnO content used as an antioxidant in AC – WC asphalt was at a level of 10%. The addition of ZnO up to 10% was very effective in inhibiting the aging rate of asphalt and prolonging the aging time of asphalt. In the resilience modulus test carried out after aging at 135℃ for 24, 48, 72, 96, and 120 hours, the modulus value containing ZnO was always smaller than asphalt without ZnO content. It indicates that the ZnO content may inhibit the rate of asphalt aging. Therefore, the addition of Zinc Oxide (ZnO) antioxidant additive to asphalt has a positive effect on the aging rate of asphalt and the performance of the open graded AC-WC resilience modulus of asphalt mixture was effective at an additional 10% level.

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