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To cite this article: Biruk Tadele & Emer Tucay Quezon (2021): Evaluation of waste engine oil rejuvenation for highly short term aged asphalt binder, Australian Journal of Civil Engineering, DOI: [10.1080/14488353.2021.1896124](https://doi.org/10.1080/14488353.2021.1896124)

To link to this article: <https://doi.org/10.1080/14488353.2021.1896124>



Published online: 14 Mar 2021.



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Evaluation of waste engine oil rejuvenation for highly short term aged asphalt binder

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ABSTRACT

The ageing property of the asphalt binder is time-dependent. A time-dependent short term ageing property of 80/100 penetration grade bitumen and the possibility of waste engine oil rejuvenation for the highly aged asphalt binder performance were investigated. Four specimens of equal weight from the penetration grade-80/100 bitumen are collected. The first specimen was checked for quality requirements. The other three specimens were aged using rolling thin film oven for 85, 115, and 145 minutes to simulate the delay during hot mix asphalt production, hauling, and compaction. The highly aged bitumen was rejuvenated with 2%, 5%, and 10% Waste Engine Oil by weight. Results indicated that as the ageing time increased, penetration and ductility decreased, softening point, flash point, fire point, and mass loss increased. A conventional test showed that highly aged bitumen from the trial period was 145 minutes and 10% waste engine oil obtained the optimum dosage. Further, multiple stress creep recovery analyses indicated the rejuvenated binder is prone to pavement rutting above 70°C and rejuvenation is effective for pavement temperature below 70°C. Hence, exposing the asphalt binder for temperature for a more extended period affects pavement performance.

ARTICLE HISTORY

Received 14 April 2020
Accepted 19 February 2021

KEYWORDS

Ageing; bitumen; dynamic Shear Rheometer; rejuvenation; rheology; waste engine oil

1. Introduction

The origin of bitumen as engineering material starts in Indus Vales and Euphrates by using surface seepage of natural bitumen as masonry and waterproofing from 3000 to 3800 (Glaser and Glaser 2016). Hot mix asphalt is a composite material that consists of aggregate, asphalt (bitumen), and air voids. Asphalt binder (Bitumen) is a petroleum distillation product, which has its own chemical and physical characteristics. Asphalt binder is a complex mixture composed of organic molecules (Abdulahi, 2016; Admas 2017).

Construction of road involves various stages starting with determining the properties of ingredients (bitumen and aggregates), whether they meet a given specification, mixing the ingredients at the controlled condition, and finally dumping the mixed asphalt and compacting with a truck at a specified temperature. Each procedure in the production, hauling, and compaction affect the lifetime properties of the constructed road.

Asphalt binders are considered one of the most expensive pavement material, and asphalt binders affect the various performance aspects of the asphalt mixture (Aziz et al. 2015), such as permanent deformation and fatigue cracking, and low-temperature cracking (ArafatYero and Hainin 2012). One of the main properties of asphalt binder that affects the

constructed road's overall property is ageing. Ageing is physical, rheological, or chemical property change by which asphalt is exposed to high temperature at a specific period leading to loss of volatile material, evaporation, physical hardening and, oxidation of asphalt (Glaser and Glaser 2016; Tarsi et al. 2018). As a result, harder asphalt will be produced. Ageing increases asphalt binder viscosity and leads to an increase in the stiffness of asphalt binder due to this cracking and ravelling may happen (Dedene and Drive 2011; Kim and Lee 2000; Tarsi et al. 2018). In general bitumen, ageing takes place in two stages (Abdullah, Zamhari, and Buhari 2014) that are short term ageing during mixing, hauling, storage, and compaction and long term ageing during service time of the road (Abdullah, Zamhari, and Buhari 2014; Dedene and Drive 2011; Dondi et al. 2016, Lu, Talon, and Redelius 2008b).

This ageing process can be simulated in a laboratory; short term ageing is simulated by thin film oven test (TFO) or rolling thin film oven (RTFO) and long term ageing by pressure ageing vessel (PAV) (Colbert and You 2012; Lee et al. 2008; Shalaby 2002). In the rolling thin film oven test, 35 grams of asphalt binder is added into a glass container and put in the oven at a temperature of 163°C for 85 minutes (AASHTO T240 2013). After 85 minutes, the mass

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loss percentage is determined to get the percent of mass loss that simulates the ageing of asphalt binder during mixing, hauling, storage, and compaction (Lu et al. 2008a).

After the asphalt mix is produced in the mixing plant, it is hauled to the construction project site. Some times longer hauling distance may happen due to traffic jams, carelessness, and lack of knowledge. Longer hauling distance means a given asphalt binder exposed to a given specific temperature for a longer period, which causes further hardening and volatilisation (Sultana and Bhasin 2014). During hauling, temperature fluctuation will happen within the asphalt mix due to atmospheric temperature. Western countries designed a specific truck to prevent this temperature fluctuation, which is called a sealed truck. In developing countries such as Ethiopia, the truck is covered by plastic to prevent temperature fluctuation. In both conditions, the temperature is constant from mixing plants up to the site; this means asphalt binder is exposed to a specific temperature for a given period.

According to (Lu et al., 2008a), the time 85 minutes used for RTFO simulates the time needed for mixing up to compaction. In the real application in a congested city like Addis Ababa and the small number of mixing plants, this time is not attained. The ageing property of asphalt is variable depending on the time of exposure, i.e. when a given asphalt is exposed to a single temperature for a variable period, the parameters that define the ageing property like mass loss, retained penetration, retained softening point, rutting parameter such as modulus of elasticity and phase angle varies (Kifile and Jirga 2000). The concern with the elevated length of time is that the mixed asphalt will be aged more than the maximum required time that adversely affects the performance of asphalt pavement (ArafatYero and Hainin 2012; Lu et al. 2008a; Oliver 2013).

From the different studies, short term ageing is related to asphalt binder behaviour than the production and construction process (Lee et al. 2008), so studying the ageing property of asphalt binder can represent short term ageing of the whole hot mix asphalt. Thanks to technology and scholars, the aged behaviour asphalt binder can be controlled and limited. Different rejuvenators make the aged asphalt binder into its natural state. Rejuvenators are primarily used to restore aged bitumen's rheological properties into the non-aged state (Dondi et al. 2016; Mamun & Al-Abdul Wahhab, 2018; Syrmanova et al. 2017).

Rejuvenators are chemically or bio-derived additives that typically contain high maltiness, which can replace the maltiness content of aged bitumen lost during oxidation of asphalt (Sabahfar 2016). Some of those rejuvenating agents are industrial process oil, soft asphalt binder, asphalt flux oil, lube stock, and slurry oil (Dondi et al. 2016). Waste engine oil is one

of the rejuvenators for asphalt binders due to similar chemical composition (Brito et al. 2016). It has a softening property (Brito et al. 2016), increase rut depth and decrease complex modules (Fernandes et al. 2017; Lei, Bahia, and Yi-Qiu 2015; Qurashi and Swamy 2018). Waste material recycling into useful products has become the primary solution to waste disposal problems worldwide. So, research into new and innovative uses of waste materials is extensively encouraged (Kifile, Quezon, and Tesfaye 2020).

2. Materials and research methods

2.1. Study area

The study area was conducted in Addis Ababa City. It is the capital and the largest city in Ethiopia. Based on the 2019 census, the city has a total inhabitant of around 7.82 Million, and the city is divided into ten sub-cities. The federal transport statistics office reported more than 70% of the vehicles of the country are accumulated in Addis Ababa, in which, there was a sufficient amount of waste engine oil collected from vehicle repair shops. The city is mainly characterised by high traffic congestion, a high volume of vehicles, and a high rate of road construction and maintenance.

2.2. Materials and equipment

Asphalt binder and waste engine oil are the materials used for the study. The equipment used involves different convectional, rheological test equipment, and mechanical mixers for the production of the modified specimen. The asphalt binder with 80/100 penetration grade was selected for this study because a softer bitumen tends to adversely affect ageing than the harder one. Lubricating oil or engine oil is sometimes called lubricants, a class of oil used to reduce friction, heat, and wear between the mechanical components in contact (Appelddoorn, 1969). The waste engine oil (WEO) used for this experiment was collected from automobile repair shops, where a large quantity of engine oil is consumed. Using waste engine oil was added to a bitumen material for likely usage hot mix asphalt (HMA) production that can also solve the disposal issues of waste engine oil.

2.3. Research design

The ASTM and AASHTO procedures followed to meet the research's objective and answer the research questions relative to different convectional and rheological laboratory tests. The study used both descriptive and analytical methods. It used various laboratory tests considering 80/100 Penetration grade bitumen after reviewing and organising the previous literature and laboratory analyses conducted on the specimens.

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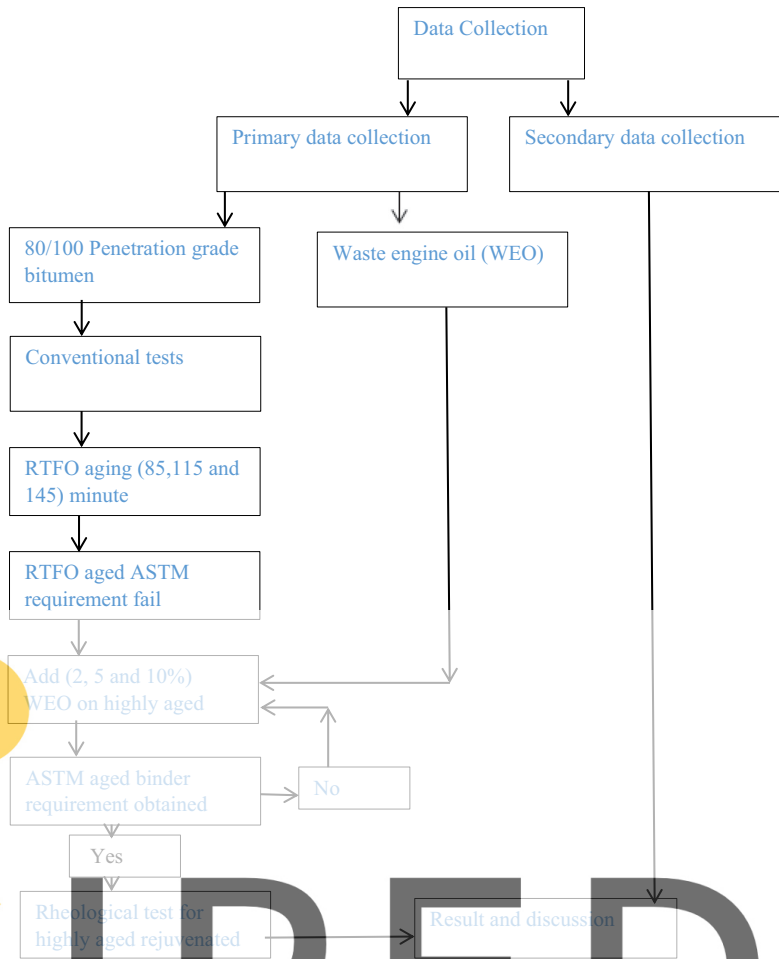


Figure 1. Flow chart of the research design.

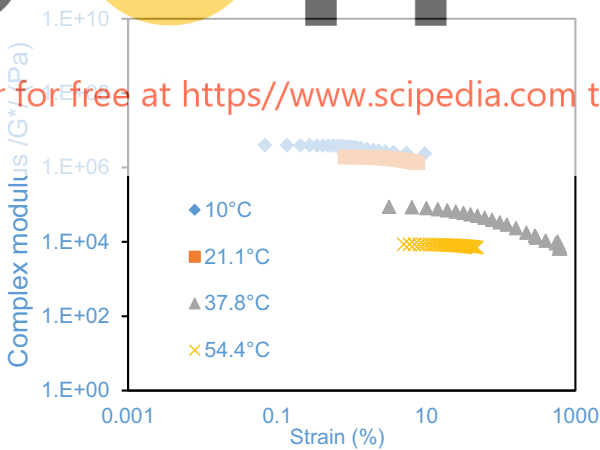


Figure 2. LVE graph for unaged neat asphalt binder.

The general process for the research is indicated in Figure 1.

As described in the above figure, 80/100 Penetration grade bitumen was aged using RTFO at the different ageing times of 85, 115, and 145 minutes, and the conventional properties were checked. After the test, conventional property outputs are evaluated according to the ASTM requirement, the regression model was developed, and a highly aged binder was selected. After this, the highly aged binder mixed with different contents of WEO at 2%, 5%, and 10% by

weight and checked whether the highly aged binder rejuvenated or not. Finally, the highly aged binder at 145 minutes mixed with 10% waste engine oil, was checked for its rheological property using the dynamic shear rheometer (Interactive and Pg 2011).

2.4. Conventional and rheological tests

The conventional asphalt binder tests like ductility (ASTM D113-99 1999), penetration (Astm 2008), softening point (D36-95 2008), flash and fire point (ASTM, D92 2007) were performed. The rheological property was evaluated using an amplitude sweep test, frequency sweep test, performance grade, and multiple stress creep recovery (Anderson 2014).

3. Results and discussion

3.1. The effect of ageing time on the conventional property of asphalt binder

The laboratory tests are conducted based on ASTM Manuals, and the results are tabulated below.

The above table shows that the binder's conventional property was not uniformed throughout the different ageing times. It means there was a strong

Table 1. Conventional property change due to ageing time.

Ageing time (minute)	Penetration (mm)	Softening point (°C)	Flash point (°C)	Fire point (°C)	Ductility (mm.)	Mass loss (%)
0	89.9	51.0	265	290	100	0
85	45.0	59.5	265	310	75	0.55
115	24.5	62.5	270	310	40	0.62
145	29.3	63.0	270	310	10	0.5

Table 2. Regression output for ageing time vs. conventional properties.

No.	Conventional parameters	Linear equation	Error square (R ²)
1	Mass loss (%)	$y = 0.0045x + 0.0572$	0.89
2	Penetration (mm)	$y = -0.4595x + 86.804$	0.93
3	Ductility (mm)	$y = -0.5957x + 107.63$	0.9
4	Softening point (°C)	$y = 11.081x - 567.53$	0.97
5	Flash Point (°C)	$y = 0.0373x + 264.28$	0.65
6	Fire point (°C)	$y = 0.1472x + 292.3$	0.85

Table 3. Conventional property change on highly aged binder due to rejuvenator.

Ageing time (minutes)	WEO (%)	Penetration (mm)	Softening point (°C)	Flash point (°C)	Fire point (°C)	Ductility (mm)
145	0	29.3	63.0	270	310	10.0
	2	37.9	60.5	260	285	11.0
	5	39.3	60.5	255	275	11.0
	10	52.9	60.0	240	270	11.0

Table 4. Regression data output for WEO content vs. conventional parameters.

Numbers	Conventional parameters	Linear equation	R ²
1	Penetration(mm)	$y = 2.1824x + 30.575$	0.95
2	Ductility (mm)	$y = 0.0749x + 10.432$	0.42
3	Softening point(°C)	$y = -0.3379x + 52.011$	0.58
4	Flash point (°C)	$y = -2.8114x + 288.35$	0.98
5	Fire point (°C)	$y = -3.5242x + 299.98$	0.74

Table 5. Summary of limiting strain value.

Binder type	sample	Temperature (°C)	G*(Pa)	0.95 G*	LVE range limiting strain Value (%)
Neat	S1	10	4.08E+06	3.88E+06	1.31E+00
	S2	21.1	2.25E+06	2.13E+06	1.42E+00
	S3	37.8	1.30E+05	1.24E+05	2.61E+01
	S4	54.4	3.03E+03	2.88E+03	8.96E+01
85 Minutes (Aged)	S1	10	2.73E+06	2.59E+06	7.63E-01
	S2	21.1	2.22E+06	2.11E+06	1.57E+00
	S3	37.8	2.05E+05	1.95E+05	7.77E+00
	S4	54.4	2.11E+04	2.00E+04	1.54E+01
145 Minutes (Neat)	S1	10	1.91E+07	1.82E+07	2.92E-01
	S2	21.1	4.98E+06	4.73E+06	1.10E+00
	S3	37.8	5.36E+05	5.09E+05	3.13E+00
	S4	54.4	4.31E+04	4.09E+04	4.98E+00
145 Minutes (Rejuvenated)	S1	10	5.12E+06	4.87E+06	1.55E+00
	S2	21.1	1.43E+06	1.36E+06	2.39E+00
	S3	37.8	2.42E+05	2.30E+05	1.08E+01
	S4	54.4	4.04E+04	3.84E+04	3.94E+00

Table 6. Shear modulus sigmoidal coefficient and temperature shift factors.

Ageing Time (Minutes)	Shear modulus sigmoid coefficients				Temperature shift factors			
	a	b	c	d	a ₁₀	a _{21.1}	a _{37.8}	a _{54.4}
0	22.79	-1.74	-13.51	0.248	1.41	0	-1.60	-2.60
85	22.90	-1.80	-13.26	0.233	1.34	0	-2.01	-3.25
145 neat	23.23	-2.87	-15.33	0.277	2.20	0	-2.52	-4.06
145 rejuvenated	22.81	-1.86	-13.57	0.185	0.40	0	-1.76	-2.97

indication of a decrease in bitumen penetration and ductility value when the ageing time reached 115 minutes. Further, at 145 minutes, the softening value increased when the penetration obtained 29.30 mm.

The above table shows the regression model developed, considering the conventional parameters. The study is mainly dependent on three ageing times that are described in Table 1. The developed regression equations are necessary to determine the conventional property change that will take place during a short term ageing process at a variable period of time.

Table 3 indicates the conventional property change due to the applied rejuvenator in the experiment. Provision of the rejuvenator by different content on highly aged asphalt binder at 145 minutes ageing time, the binder's property had changed significantly. This will show that the property change is dependent on the WEO percent dosage. As the content of WEO increases, the penetration, flash point, and fire point increase up to 5%. But there was an abrupt increase of 52.9 mm at 10% due to rejuvenator, while other values of the parameters are likely to show a slight decrease. Hence, the 10% Waste engine oil is the optimum content for rejuvenation of highly aged asphalt binder.

Table 2 below indicate the the linear regression equation for the change in the conventional property change due to aging time variation. Those equations are important to determine conventional property change different from the used time for the study.

After the process of rejuvenation, equations are developed to show the relationship between waste engine oil content and conventional property change, as indicated in Table 4. Similarly, these equations are used to determine the conventional property change

Table 7. Phase angle sigmoidal function constant and temperature shift factors.

Ageing time (Minute)	Phase angle sigmoid parameters and temperature shift factors						
	a	b	c	a ₁₀	a _{22.1}	a _{37.8}	a _{54.4}
0	73.18	2.67	0.16	1.57	0.00	-0.80	-40.07
85	29.40	1.93	0.17	1.61	0.00	-1.49	-1.02
145	87.27	3.29	0.18	1.13	0.00	-2.57	-36.39
145 (rejuvenated)	69.81	2.69	0.12	0.82	0.00	-1.34	-43.26

Table 8. Determination of high-temperature performance based on (AASHTO 1993).

Sample No.	Ageing time (Minute)	G*/sin δ (Kpa) \geq (1,unaged : 2.2,Aged)	Temperature (°C)	PG category
S-1	0	2.17	58.0	PG58-YY
S-2	85	4.46	64.0	PG64-YY
S-3	145	2.60	76.0	PG76-YY
S-4	145 (rejuvenated)	4.29	70.0	PG70-YY

Table 9. Summary of output data for 85 Minutes aged asphalt binder.

Ageing time	85 Minutes aged asphalt binder		
Description	Test temperature (°C)		
	58.0	64.0	70.0
Percent recovery at 0.1kPa	21.77	15.2	7.7
Percent recovery at 3.2kPa	13.09	5.02	1.57
Jnr at 0.1 kPa	0.48	1.23	3.31
Jnr at 3.2 kPa	0.52	1.40	3.82
Jnr difference (%)	7.09	14.07	15.47
Penetration grade (PG)	64.0		

Table 10. Summary of output data for 145 Minutes aged neat bitumen.

Ageing time	145 Minutes aged neat bitumen			
Description	Test temperature (°C)			
	58.0	70.0	76.0	82.0
Percent recovery at 0.1kPa	23.67	15.65	11.66	7.17
Percent recovery at 3.2kPa	14.80	5.36	1.90	0.25
Jnr at 0.1 kPa	0.46	1.21	2.94	7.40
Jnr at 3.2 kPa	0.50	1.39	3.74	10.00
Jnr Difference (%)	7.33	14.71	27.10	35.18
Penetration grade (PG)	76.0			

Table 11. Summary of output data for 145 minutes aged rejuvenated.

Ageing time	145 Minutes aged rejuvenated			
Description	Test temperature (°C)			
	64.0	70.0	76.0	82.0
Percent recovery at 0.1kPa	62.07	27.02	18.04	8.92
Percent recovery at 3.2kPa	16.91	4.52	1.03	-0.55
Jnr at 0.1 kPa	0.35	1.41	3.90	10.45
Jnr at 3.2 kPa	0.58	2.26	7.05	18.53
Jnr difference (%)	67.1	60.40	80.83	76.52

Table 12. Binder specification requirements based on the MSCR test (AASHTO 2013).

Traffic design	Traffic level (ESALs), Millions	Load rate (Km/h)	Jnr 3.2, Max (Kpa ⁻¹)
Standard traffic 'S'	<10	>70	4.5
Heavy traffic 'H'	10 to 30	20-70	2.0
Very heavy traffic 'V'	>30	<20	1.0
Extremely very heavy traffic 'E'	>30	<20	0.5

for different waste engine oil content that will take place during a short term ageing process at a variable period of time. Table 5 indicate the limiting strain value for aged and unaged sample. From the table it can be concluded that as the aging time increase there is increase in the limiting strain value and as temperature increase there is decrease in the limiting strain value.

3.2. Rheological properties of rejuvenated asphalt binder

3.2.1. Amplitude sweep test (AST)

Amplitude sweep test performed for each specimen at a temperature at 10°C, 21.1°C, 37.8°C, and 54.4°C, respectively, with similar loading conditions ranging from 100 Pa to 90,000 Pa in stress-controlled mode at a constant frequency of 10 rad/sec, indicating 80-100 Kph of traffic speed (Admas 2017). The AST test results represented graphically with a log-log scale of complex shear modulus (G*) at the y-axis and strain in percent along the x-axis.

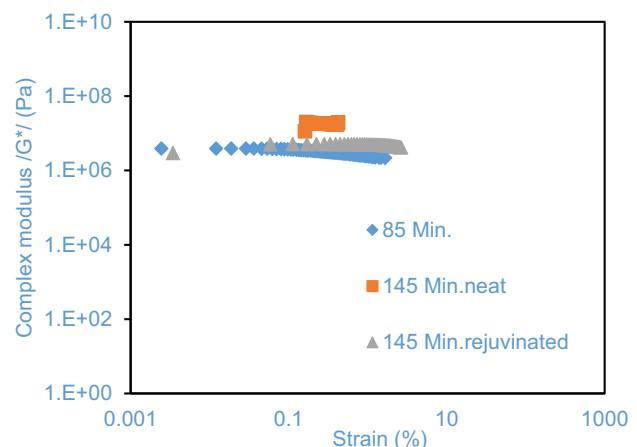
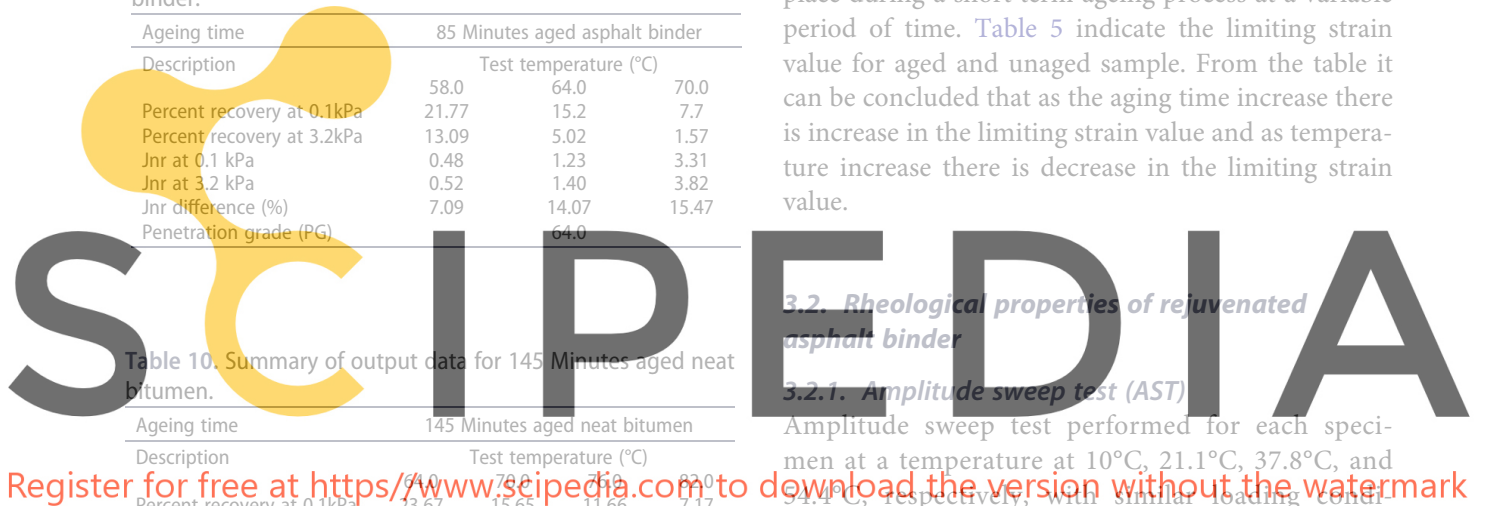


Figure 3. LVE graph for different ageing at 10°C.



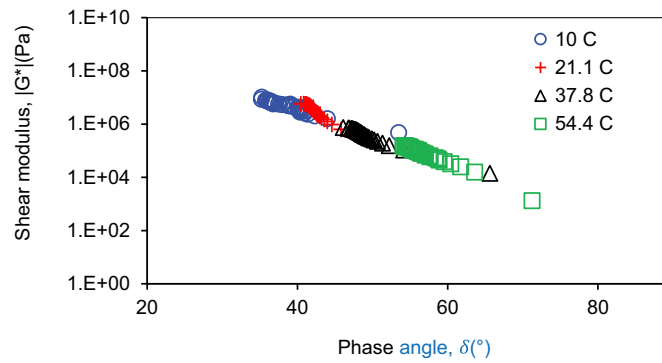


Figure 4. Black space diagram for highly aged bitumen rejuvenated with 10% WEO.

Figure 3 indicates that the rheological property changed due to ageing time and the effectiveness of the rejuvenator. At 145 minutes, the aged binder has lost its viscoelastic property. The graph shows almost similar strain levels at constant complex modulus. However, it could be observed that the rejuvenation performed with the same binder content was almost the same property results at 85 minutes aged binder. The purpose of AST is to determine the limiting strain value of the binder, indicate the linear visco elastic range of neat binder. From the figure it can be concluded that as aging rate increase there is a decrease in modulus of elasticity. Figure 2

The table below shows the limiting strain value for each condition of the AST test.

3.2.2. Frequency sweep test (FST)

The purpose of this test is to construct a master curve using a time-temperature superposition principle. The output of the FST is composed of a complex modulus and phase angle. These outputs are used to express the tested binder's behaviour in terms of the black space diagram and master curve.

The above figure 4 shows the graph was not dispersed, indicating that the obtained data is a good quality of samples. The analysis is in the LVE range and time-temperature equivalence.

As the test temperature increases, the black space diagram is shifted into a higher phase angle and lower stiffness and vice versa.

3.2.3. Shear modulus and phase angle master curve

The rheological characteristics of asphalt binders are mainly presented as interims of phase angle δ ($^{\circ}$) and complex modulus master curve, which require shifting of dynamic shear rheometer (DSR) output into a single reference temperature. As shown in the graph, the binder master curve is used to extrapolate the test results up to high

frequency (10^{15} Hz) and very low frequency (10^{-6} Hz), which indicates the transition of asphalt binder from high glassy material to the viscous fluid. In this test, data obtained from four different tests shifted to a reference temperature of 21 $^{\circ}$ C to determine a single smooth curve. The modulus and phase angle master curve was constructed using an excel solver to fit the sigmoidal function for the asphalt binder test. The sigmoidal function to best fit the obtained the shear modulus (G^*) and phase angle data obtained from the dynamic shear rheometer (DSR). It was carried out with trial and error by changing sigmoidal constant and shift factors. The sigmoidal function to calculate complex shear modulus is represented as:

$$\log|G^*| = a + \left(\frac{b}{1 + e^{c \log fr + d}} \right) \quad (1)$$

a, b, c, and d represent Sigmoidal constant.

Fr: reduced frequency

The formula obtains reduced frequency $\log Fr = \log f + aT$

Where:

Fr: Reduced frequency

F: Frequency

aT: Temperature shift factor

G^* : complex shear modulus

The sigmoidal coefficients used for the optimisation process in the analysis were obtained from the excel solver by minimising the error between the predicted value and observed value of complex shear modulus at a temperature of 21.1 $^{\circ}$ C.

Several temperatures shifting factor techniques used to construct a modulus master curve by using of time-temperature superposition. They are a numerical method, log-linear method,

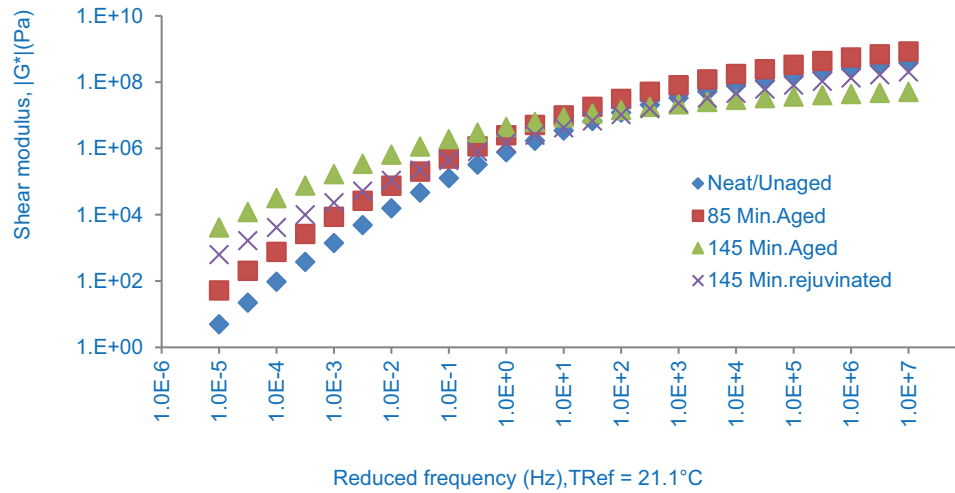


Figure 5. Phase angle master curve.



Figure 6. Phase angle master curve.

Williams-Landel-Ferry (WLF), Modified Kaleb, and Arrhenius. The most commonly used for the construction of a modulus master curve is the WLF equation (Forough, Nejad, and Khodaii 2014).

$$\log aT = \frac{-C1(T - Tref)}{C2 + (T - Tref)} \quad (2)$$

Where:

T: Temperature

Tref: is reference temperature C1 and C2 are constants.

The phase angle master curve is constructed with a different form of generalised logistic function with the binder phase angle by the same procedure. The generalised logistic function is:

$$\begin{aligned} \delta &= 90 * b d \frac{e^{((c+d(\log fr))}}{(1 + e^{(c+d(\log fr))})^2} \quad 4.3\delta \\ &= 90 * b d \frac{e^{((c+d(\log fr))}}{(1 + e^{(c+d(\log fr))})^2} \quad (3) \end{aligned}$$

Where: b, c, and d represent sigmoidal function constants

fr: reduced frequency,

δ: phase angle

In Figure 5, the ageing time and provision of WEO had a different effect on the shear modulus of asphalt binder. In all cases, as frequency increases, shear modulus also increases; this indicated that the binder is in the plastic region (viscous) at low frequency. As the ageing increases, the modulus of elasticity increases at low frequency and decreases as the frequency is approaching a high rate.

From Figure 6 following points had observed during the experiment:

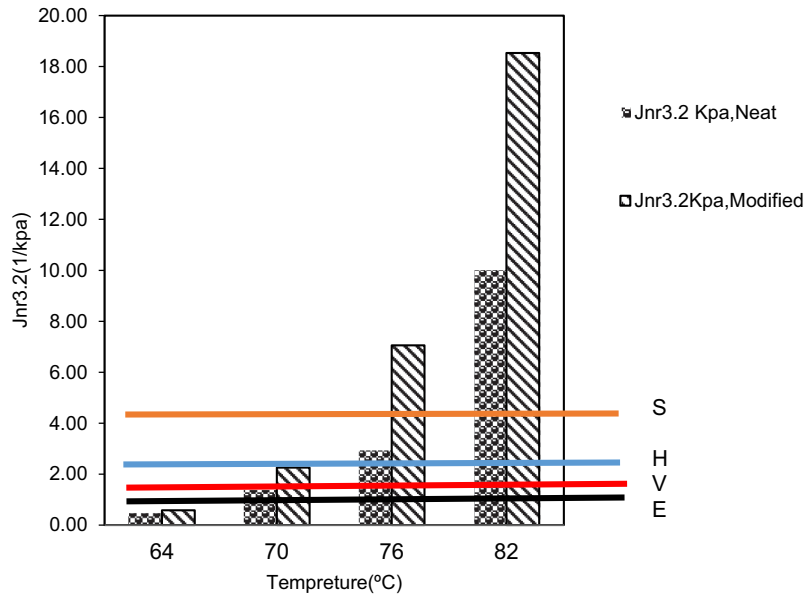


Figure 7. Jnr 3.2Kpa⁻¹.

- The rejuvenated binder had an almost similar pattern with 85 minutes aged binder, indicating that rejuvenation is effective.
- At low frequency (high-temperature), the phase angle decreased due to the provision of WEO.
- At high frequency (low-temperature), the phase angle increased due to the provision of WEO.
- The rejuvenation effect of WEO provision on highly aged asphalt binder is the frequency (temperature) dependent.

temperature. The analysis was performed with a 6°C increment or decrement from the higher PG value. The percent recovery value to be obtained will indicate an elastic response and stress dependency of modified and non-modified asphalt binder. It measured how much sample returns to its original shape after a given load was removed.

$$R_{0.1} = \frac{\sum(\epsilon_{r0.1}, N)}{10} \quad (4)$$

$$R_{3.2} = \frac{\sum(\epsilon_{r0.3}, N)}{10} \quad (5)$$

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3.2.4. Performance grade (PG)

The performance grade test is essential to determine the grade of a given asphalt binder. It was performed at high temperature oscillatory loading using DSR with a 6°C temperature increment at a high temperature starting from 46°C. If a given asphalt binder passes the first selected temperature, it moves to the next 6°C incremental temperature. The study used the rutting parameter expressed in G*/sinφ to determine the maximum temperature that the asphalt binder could meet the minimum criteria of AASHTO M-320.

From the above table, it can be explained that rejuvenation makes the binder decrease the Performance Grade (PG), resulting in the likely increase in complex shear modulus value from 2.60 to 4, indicating that the rejuvenated binder has high rutting resistance.

3.2.5. Multiple stress creep recovery (MSCR)

This method is one of the test methods conducted by using DSR. MSCR test performed after the Penetration grade (PG) test has been obtained. The PG at high temperature is essential to decide which temperature to be applied for the MSCR test. Accordingly, the temperature for the MSCR test is at PG high

Non-recoverable creep compliance (Jnr) is a residual strain in the specimen after creep and recovery divided by applied strain. It measures the stress sensitivity of a given aged binder.

$$Jnr(Kpa@0.1 \text{ or } 3.2^{-1}) = \frac{\epsilon_{10}}{0.1 \text{ or } 3.2} \quad (6)$$

Percent elastic recovery difference (%) is the variation of elastic difference in percent between elastic recovery @ 0.1kpa and 3.2kpa applied strain.

$$\text{Percent elastic recovery} = \frac{(\text{strain@1sec} - \text{strain@10}) * 100}{\text{strain@1sec}} \quad (7)$$

$$\begin{aligned} &\text{Percent difference in non} \\ &\text{recoverable creep compliance } (Jnr_{diff}) \\ &= \frac{(jnr_{3.2} - jnr_{0.1}) * 100}{jnr_{0.1} * 100} \quad (8) \end{aligned}$$

The main output of MSCR tests was used to determine the asphalt binder's behaviour for the percent recovery, non-recoverable creep compliance, percent elastic recovery difference, and percent difference in non-

recovery creep compliance that depends upon test temperature, loading rate, and time of ageing.

AASHTO MP-19 has briefly described the specification for performance grade asphalt binder using the MSCR test.

Based on AASHTO MP-19 described, the table and the horizontal value in the above graph (Figure 7) represented the standard J_{nr} value for a given representative traffic volume and design speed.

The result indicated that the rejuvenated binders, when mixed with the other asphalt components, can sustain and carry heavy axle loads based on the test result of $J_{nr}3.2$ value equivalent to 0.58. It means the rejuvenation is effective for environmental temperature below 70°C. The Standard specification clearly emphasised that below this temperature will outperform above 70°C with increasing $J_{nr}3.2$ value.

4. Discussions

Different literature explains the performance of constructed asphalt pavement, which depends on the binder's property to be used. According to (Lee et al. 2008), one of those properties is ageing; a short term ageing of the mix is mainly reliant on the property of asphalt than the production.

This study tried to explore and investigate the effect of ageing time on the conventional rheological property and the possibility of using waste engine oil (WEO) as a rejuvenator for highly aged asphalt binder. The study focused on 80/100 Penetration grade bitumen with a corresponding lower viscosity. It is believed that soft asphalt binder is more prone to ageing than the bitumen with higher viscosity.

Laboratory test results indicated a significant change in the binder's original property due to ageing time taking place with a varying dosage of waste engine oil (WEO). There was a decrease in penetration, ductility, and mass loss from the conventional test data output and an increase in softening point, flash point, and fire point. During the process, the changes occurred due to the asphalt binder exposed to a temperature for a longer time.

Hence, the temperature is the main factor causing the binder to become stiffer. When a given material is stiff, its tensile property will increase, and the bond between particles increases. At this point, it requires high thermal energy to break the bond between the particles of the asphalt concrete material. On the other hand, the laboratory test was not limited to conventional. It was extended the analysis for the rheological property using the DSR test to evaluate the ageing process of bitumen. The findings showed that as the ageing age increased, there was also an increase in complex shear modulus, with a corresponding decrease in phase angle. It indicates that the rate of ageing has

a stiffening effect on the binder, and this stiffening property is so-called temperature-dependent. Likewise, the FST test analysis demonstrated that the rejuvenation effect was caused by temperature and frequency-dependent.

So, at low frequency (i.e. high temperature) with waste engine oil (WEO) is related directly to the highly aged binder that was become less stiff. The provision of WEO as a rejuvenator indicated an increase in $G^*/\sin \delta$ value, ranging from 2.60 to 4.29, but a decrease in Penetration grade (PG) requirements from PG76 to PG70 (i.e. becoming highly viscous bitumen).

5. Conclusion

In developing countries like Ethiopia, there are several factors affecting road project implementation. To name a few, lack of budget, improper mix design proportion, carelessness of temperature during the asphalt concrete mix production at the batch plant, hauling issues, and the temperature at which rolling operation or compaction commence. The finding of the study, optimum amount of waste engine oil that rejuvenates the aged binder is 10% by weight of the bitumen, and the rejuvenation is effective for environmental temperature below 70°C.

The results of multiple stress creep recovery (MSCR) test indicated a highly aged rejuvenated asphalt binder, which means the sample is prone to pavement rutting at a temperature above 70°C, and cannot be recommended the Hot Mix Asphalt (HMA) for use in the project. It was because the computed $J_{nr}3.2$ value is beyond the standard. Besides, the viscoelastic property is essential to make the asphalt binder to resist fatigue and rutting (i.e. deformation) of the asphalt pavement under successive axle loadings within the service life. Therefore, during the production process of Hot Mix Asphalt (HMA) at the batch plant, transporting to the project site, and compaction, care should be exercised considering the asphalt temperature so that the pavement will not show premature deterioration such as fatigue cracking and rutting after opening to traffic.

Acknowledgments

The authors would like to express their profound gratitude to the Civil Engineering Laboratory of AASTU for allowing the researchers to conduct experiments at a minimal cost, and the assistance extended by the laboratory technician.

Disclosure statement

The authors declare that there is no conflict of interest regarding the publication of this article.

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