The Influence of Ageing on Asphalt Mastic Properties Incorporating Calcium Carbonate

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ABSTRACT

The ageing of asphalt mastic is one of the key factors determining the lifetime of an asphalt pavement. The challenge created by proper selection of asphalt materials motivate researchers to investigate material properties that can further enhanced performance of asphalt pavement. The study investigated the ageing properties of asphalt mastics incorporating calcium carbonate ($CaCO_3$) combined with Ordinary Portland Cement (OPC). The empirical tests, which include penetration and softening points, were conducted to ascertain the asphalt mastics consistency. The rheological properties of mastics in terms rotational viscosity and Superpave rutting parameter using 60/70 asphalt binder blended with 5, 10, 15, 20 % of $CaCO_3$+OPC were calculated to evaluate asphalt mastics properties subjected to different aged conditions. Rotational viscometer (RV) was used to evaluate the properties of mastics. The dynamic shear rheometer (DSR) was used in temperature sweep test to measure the complex modulus (G*) and phase angle (δ). ANOVA statistical analysis was used to analyze the results .The test results showed that all asphalt mastics exhibited higher viscosity compared to the base binder. The addition of various content of $CaCO_3$+OPC increased the G* and decreased the δ significantly, indicating an increase in binder elasticity and stiffness, hence a better resistance to deformation.

Keywords: Asphalt mastic, Viscosity, Complex shear modulus, Phase angle, Ageing.

1 Introduction

The development of modern pavement technology is needed to accelerate significant improvement of pavement quality of highways. Pavement surface distress such as cracks is prevalent on pavements due to the action of repeated traffic loading and cyclic environmental conditions. Use of new materials may help to mitigate the problem by improving the properties of asphalt mixtures. This study focus on the effects of asphalt binder modified with $CaCO_3$+OPC as a modifier/filler on the rheological properties of asphalt mastics. Asphalt mastics is a combination of asphalt binder and filler that influence the overall mechanical performance of asphalt mixtures as well as placement workability [1].The properties of mineral filler have a significant effect on asphalt properties in terms of permanent deformation, fatigue cracking and moisture susceptibility [2]. Many different types of fillers obtained by processing natural or manufactures or recycled materials can be used for asphalt pavements such as Portland cement, hydrated lime, and ground slag [3]. Binder ageing is one of the principal factors causing the deterioration of asphalt mixtures [4]. There are two basic mechanisms involved in binder ageing, these include an irreversible process like chemical changes of the bitumen, consisting of oxidation of bitumen molecules, and loss of volatile components which subsequently has an impact on the rheological properties of the asphalt binders. Nowadays, most of ageing on the road is still regarded as thermally induced. The rate of thermal oxidation of asphalt binder in service depends to a large extent on pavement temperature [5]. It has been shown that different asphalt binders have very different increase of viscosity with ageing time, and the temperature-dependence of ageing is strongly dependent on the asphalt binders [6]. Rutting and fatigue are the most common surface distress on Malaysian roads [7, 8]. The main objective of this paper is evaluate the rheological properties of asphalt mastics subjected to the appropriate ageing conditions.

2 Materials and Methods

A conventional binder grade 60/70 supplied by SHELL Company was used and its properties are shown in Table 1.

Table 1: *Properties of base binder*

Ageing condition	Property	values
Unaged	Penetration [1/10 mm] Softening Point [ºC] Ductility @ 25 ºC [cm] Relative Density @ 25ºC G*/sinδ @ 64ºC [Pa]	63 48 115 1.03 1621.40
Short term aged	G*/sinδ @ 64ºC [Pa]	3584.20
Long term aged	G* sinδ @ 25ºC [MPa]	4.51

$CaCO_3$ plus OPC was used as filler to prepare the mastics. The 60/70 asphalt binder was separately blended with 5, 10, 15, and 20 % of $CaCO_3$ + OPC by mass of binder as shown in Table 2.

Table 2: *Asphalt mastic preparation*

Content	Description	Designation
0%	0% $CaCO_3$+0% OPC	Control
5%	3.75 % $CaCO_3$+1.25 % OPC	CO5
10%	7.50 % $CaCO_3$+2.50 % OPC	CO10
15%	11.25 % $CaCO_3$+3.75 % OPC	CO15
20%	15 % $CaCO_3$+5 % OPC	CO20

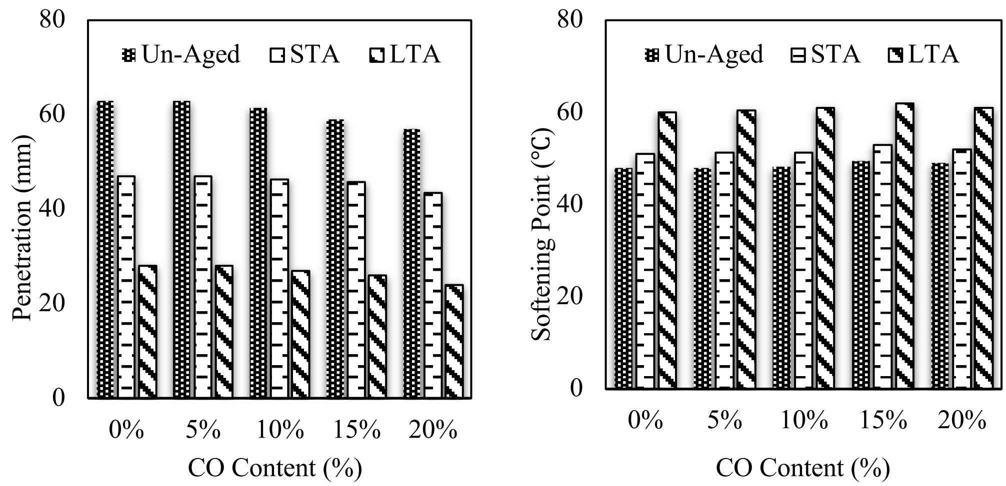
2.1 Sample Preparation and Test Methods

The preparing the modified binders, about 800 g of the binder was heated to liquefy in a 2 litter capacity metal container. Upon reaching 145±5°C, the proportion of fillers by 5%, 10%, 15% and 20% of mass of binder were added to the base binder in a high shear mixer for 30 min at 3000 rpm throughout the mixing process. These binder were then artificially short-term aged (STA) according to ASTM D2872 (ASTM, 2012) procedures via the Rolling Thin Film Oven (RTFO) at 163°C for 85 minutes [9]. Subsequently, the Pressure Ageing vessel (PAV) was used to subject the binder to long-term ageing (LTA) according to ASTM D6521 proceedings of the Eastern Asia Society for Transportation Studies, Vol.9, 2013(ASTM, 2013) procedures at 100°C for 20 hours [10].Conventional tests such as penetration, ring and ball were carried out according to (ASTM D5-97) [11] and (ASTM D36-95) [12] procedures respectively. The rotational viscosity using Brookfield viscometer (RV) was carried out over temperature ranging from 120 to 170ºC, spindle No.27, and rotating speed 20rpm. Rutting characterization was tested on parallel plates with 1 mm thickness, 25 mm diameter, loading condition on strain control mode at 1.59 Hz and at temperature ranging from 46°C to 82°C at 6°C increments using the Dynamic Shear Rheometer (DSR) subjected to different ageing conditions to determine the basic characteristics and rheological properties of the asphalt mastic.

3 Results and Discussion

3.1 Penetration and softening point

Figure 1 presents the test results of bitumen 60/70 blended with several CO contents. The results show that compared with control sample, all of asphalt mastics subjected to ageing exhibit lower penetration indicating stiffer asphalt mastics. The penetration changes due to ageing is greatly decreased 25% and 55% for STA and LTA samples, respectively. Incorporation of CO improves the resistance to flow deformation of the asphalt binder. On the other hand, the results show that compared with control sample, all of asphalt mastics exhibit higher softening point subjected to ageing, indicating that incorporation of fillers reduce the temperature susceptibility, increase the plasticity of the asphalt mastics. The softening point changes due to ageing indicates the thermal oxidative reaction of asphalt is reduced by the addition of CO. Sample 15% CO showed the highest softening point compared to other percentage of fillers in asphalt mastics. The reason for this improvement might be due to the bonding strength to restrict the flow of asphalt mastics and made it stiffer. Qin et al., (2014) indicated that the age hardening of asphalt binder is closely correlated and attributed to the compositional changes within the asphalt binder [13]. Stiffer asphalt mastics will be more resistant to rutting. The results show the potential of CO mastics to be an alternative material to be selected by engineers for improving asphalt mixtures properties.

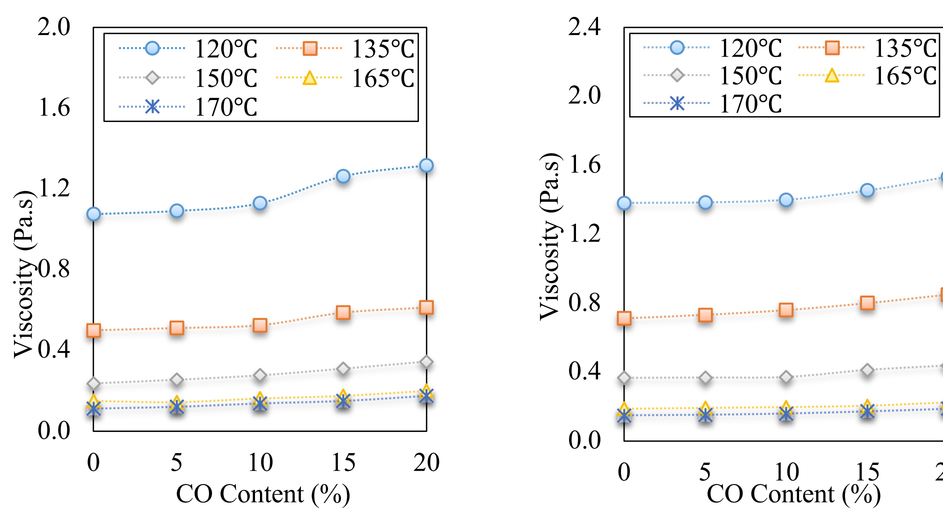


Penetration Softening Point

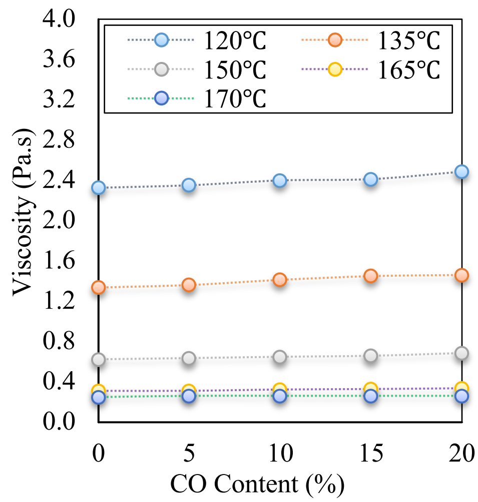
Figure 1: *Penetration and Softening Point of Asphalt Mastics Subjected to Ageing*

3.2 Viscosity

Binder viscosity is important during asphalt production and construction. The relationships between filler contents and viscosity subjected to different temperatures and ageing are shown in Figure 2. At lower temperatures, the viscosities of asphalt mastics containing various CO contents are high. As the temperature increases, the viscosity reduces. Similar trend is shown for asphalt mastics subjected to ageing but with a higher viscosity because ageing causes the binders to stiffen. The increase in filler contents also increases the viscosity compared to unaged base binder.



Un-aged STA



LTA

Figure 2: *Rotational viscosity values of CO subjected to different ageing condition*

Table 3 show the statistical analysis results using two-way analysis of variance (ANOVA) of the viscosity of CO at various ageing conditions at 95% confidence level. The ANOVA was carried out on the experimental data based on the un-aged and STA samples of asphalt mastics containing various filler contents at 120°C, 135°C and 165°C. The result indicates that temperature is the most significant factor that affects the viscosity followed by the effects of ageing and the type of additives. Moreover, the interaction effects between these parameters are found to be significant on the viscosity of asphalt mastics.

Table 3: *ANOVA Analysis of Viscosity CO*

Source	SS	Df	MS	F	P-Value	Significant
Corrected Model	89.5a	74	1.2	2044.9	<0.001	Yes
Intercept	107.8	1	107.9	182423.8	<0.001	Yes
TT b	69.7	4	17.4	29468.6	<0.001	Yes
AC c	11.8	2	5.9	9973.5	<0.001	Yes
CO d	0.276	4	0.069	116.7	<0.001	Yes
T T* AC	7.5	8	0.940	1589.2	<0.001	Yes
TT * CO	0.094	16	0.006	9.9	<0.001	Yes
AC * CO	0.045	8	0.006	9.5	<0.001	Yes
T * AC * CO	0.053	32	0.002	2.8	<0.001	Yes
Error	0.089	150				
Total	197.5	225				
Corrected Total	89.6	224				

a) R Squared = 0.99 (Adjusted R Squared = 0.99), b) Test Temperature, c) Aging Conditions and d) Asphalt Mastics Containing CO.

The change in viscosity is employed to evaluate the anti-ageing performance of asphalt mastics. The viscosity ageing increment (VAI) was calculated based on Equation (1) and the result is presented in Table 4.3.

$$VAI\,\% = \frac{\eta PAV - \eta RTFOT}{\eta RTFOT} * 100 \quad (1)$$

Where:

VAI	=	Viscosity ageing increment
η_{PAV}	=	Viscosity of asphalt mastics after LTA conditions.
η_{RTFOT}	=	Viscosity of asphalt mastics after STA conditions.

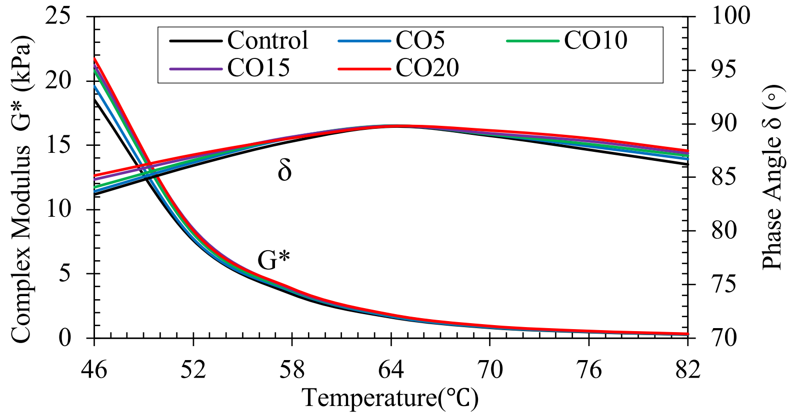
Table 4: *Viscosity Ageing Increment of CO*

Content (%)	Viscosity (MPa.s) at 135°C		
	STA	LTA	VAI
0	723	1349	86.58
5	733	1362	85.94
10	760	1413	85.92
15	800	1450	81.25
20	850	1462	72.00

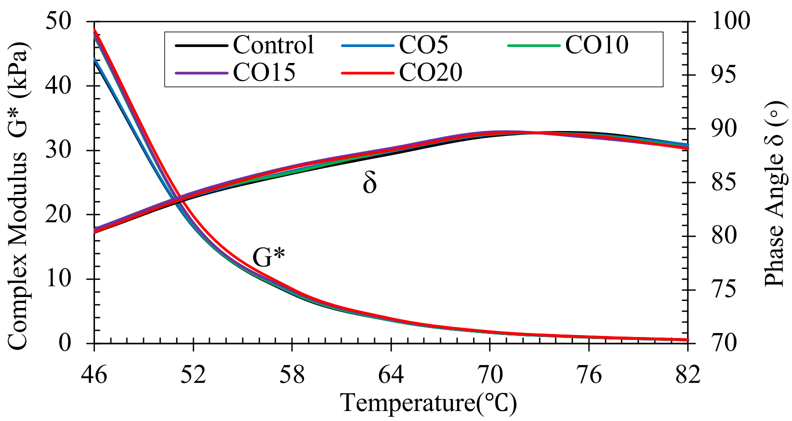
The analysed data show that the VAI of asphalt mastics decrease significantly as the filler content increases, which indicated better resistance to ageing, hence less susceptibility to LTA.

3.3 Superpave rutting parameters

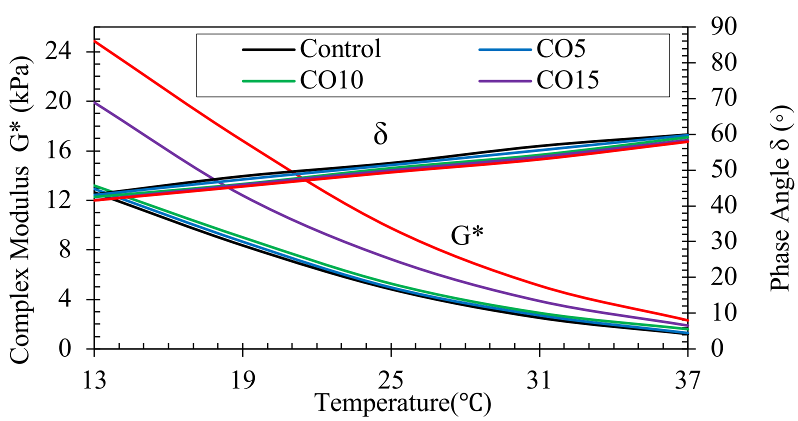
The effects of asphalt mastics containing various CO contents on G* and δ at various temperatures for unaged and aged conditions are illustrated in the master curves shown in Figures 3. This curve presents the variation of G* and δ versus temperature at 10 rad/sec frequency. To produce a mixture with a higher resistance to rutting, the asphalt mastic should have a higher G* and lower δ value. As the temperature increases, it has resulted in lower G* and continuously increased the δ. theoretically, a higher G* reflects a superior resistance to deformation. Meanwhile, the increase in δ reflects a reduction in elasticity. Higher CO contents increases G* and decreases δ at high temperatures. The result shows the effects of CO contents on the rheological properties of asphalt mastics samples. Similar trends were observed, the G*increases and proportionally decreases the δ of samples regardless of STA condition and CO asphalt mastics. It could be due to the structure formed in the asphalt mastics that reduce the temperature sensitivity and increases the elasticity of mastics based on the reduction of δ at elevated temperatures. A linear relationship between δ and temperature for LTA asphalt mastics. An exponential relationship for G*, with R^2 equal to 0.99 for LTA conditions are presented in the same figure. The addition of various CO contents combined with LTA ageing causes the asphalt mastics to be less susceptible to temperature.



Un-aged



STA



LTA

Figure 3: *G* and δ of Asphalt Mastics subjected to different ageing condition*

The two-way ANOVA was performed to analyse the effects of temperature on the increase of G* and reduction of δ. Tables 4 show the results of the statistical analysis. The results indicated that a higher test temperature has a significant effect on G* based on the *p*-value less than 0.05. The result for un-aged samples indicates that the interaction effects between these parameters are found the most significant effects on the complex modulus. The type of asphalt mastics has most significant effects followed by the test temperature for aged samples of asphalt mastics. The addition of various content in asphalt mastics increased the G* and decreased the δ significantly, indicating an increase in binder elasticity and stiffness, hence a better resistance to deformation.

Table 5: *ANOVA Analysis of the complex modulus (G*)*

Sample	Source	Mean Square	Df	F	*p*-value	Sig.
Un-Aged	TT[a]	6.60E+07	6	1503.26	<0.001	Yes
	CO[b]	5.08E+05	4	11.56	<0.001	Yes
	TT * CO	1.83E+08	24	4158.73	<0.001	Yes
	Error	4.4E+04	70			
	Total		105			
	Corrected Total		104			
		R Squared = 0.999 (Adjusted R Squared = 0.999)				
Sample	Source	Mean Square	Df	F	*p*-value	Sig.
STA	TT[a]	1.55E+09	6	166.51	<0.001	Yes
	CO[b]	3.52E+08	4	1167.77	<0.001	Yes
	TT * CO	2.7E+06	24	9.012	<0.001	Yes
	Error	9.54E+08	70	3166.49		
	Total		105			
	Corrected Total		104			
		R Squared = 0.999 (Adjusted R Squared = 0.999)				
Sample	Source	Mean Square	Df	F	*p*-value	Sig.
LTA	TT[a]	11.4E+13	6	99.94	<0.001	Yes
	CO[b]	5.20E+14	4	456.35	<0.001	Yes
	TT * CO	1.52E+13	24	13.37	<0.001	Yes
	Error	1.14E+12	70			
	Total		105			
	Corrected Total		104			
		R Squared = 0.980 (Adjusted R Squared = 0.970)				

(a) TT= Test Temperature, (b) Asphalt Mastics Containing CO

4 Conclusions

The study indicated physical hardness after simulating the base binder to ageing using RTFOT and PAV, reduces binder penetration and increases softening points. This indicates that ageing depends on various conditions relate to field ageing. The viscosity of asphalt mastic at 135°C was lower than 3 Pa.s which fulfils SHRP criteria for provide potential satisfactory result during industrial processing which involved handling, lay down and compaction. The adding 15% CO mastic increased the G* but reduced the phase angle which indicates improve stiffness of mastic asphalt. At high temperature, a good visco-elastic performance was observed for CO asphalt mastics. Hence, the asphalt mastics exhibit better resistance to rutting compared to base binder. This observation was also evident from the statistical analysis. Thus, it can be concluded that there are more advantages to use CO mastic in terms of rheological properties.

5 Acknowledgment

This study was carried out in the of Highway and Transportation laboratory, Faculty of Civil Engineering, Universiti Since Malaysia (USM), and all involved in the study are acknowledged.

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